WATER CONSERVATION:

IMPLICATIONS OF USING RECYCLED GREYWATER AND STORED RAINWATER IN THE UK

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No. of pages:	(i) - (iv) of preamble 84 of text
Appendices	A1-A4

EXECUTIVE SUMMARY

This report details the results of research into the implications of using recycled greywater and stored rainwater in the UK. A number of proprietary systems are available on the market worldwide and several are produced by UK manufacturers. Not all those produced overseas are appropriate for use in the UK. Many of the greywater recycling systems sold in the USA, for example, are designed for direct sub-surface landscape irrigation, an application currently of limited applicability in the UK. Some of the systems currently produced or under development by UK manufacturers have significant potential to achieve substantial market penetration in the UK and overseas.

An important constraint on the uptake and use of greywater reuse and stored rainwater systems in the UK is their perceived risk to public health. This is particularly so for greywater recycling systems, as there is a possibility that greywater, having been in primary or secondary contact with humans, at least once before reuse, may contain low levels of faecal contaminants. Health considerations have led a number of authorities outside the UK to severely restrict the types of greywater recycling system that are permitted. However, due to recent advances in wastewater treatment technology, experience gained elsewhere, and because public health risks are very application-specific, similarly restrictive regulations on the end-use of recycled water may not be required in the UK. Instead it is suggested that individual systems should be tested to a previously determined standard by an accredited test-house before they can be sold or installed, and that water quality criteria should be application specific.

Suitable water quality standards for the UK are proposed in this report, based on relevant standards from the UK and overseas. Additionally, general UK requirements are included for the design, construction, operation and maintenance of systems necessary to protect public health and minimise deleterious effects to plumbing systems and the environment.

User/social acceptability is unlikely to discourage the uptake and use of systems in the UK. Published reports from overseas and reported experiences concerning the limited number of systems already installed in the UK, suggest that user/social acceptability will not be a problem if systems are appropriately designed and operated.

The report includes a comprehensive economic analysis of the application of recycled greywater and stored rainwater systems in five building types, using six generalised system types, two toilet cistern sizes and both new-build and retrofit situations. Of the building types considered, hotel installations appear to yield the shortest pay-back periods. An important conclusion is that for systems to be economically viable, it is not necessary that they should be designed to utilise a large percentage of the rainwater or greywater available, as this increases the cost of storage provision.

It is difficult to predict the degree to which greywater and stored rainwater technologies will be utilised in the UK. However, the use of such systems would undoubtedly become increasingly attractive if water charges were raised or if a recognised system of accreditation were introduced, to verify the safety and performance of such systems.

CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 BACKGROUND

Rising demand for water, particularly for domestic uses, has led to an increasing strain on water supplies in some areas of the UK. Although rainfall levels are relatively high over much of the UK, and the construction of new reservoirs might therefore be seen as a solution, recent increases in environmental concerns have led to this becoming a more controversial option. Instead, critics point out that the use of existing resources has yet to be optimised, through reduced leakage and effective demand management. Such an approach has recently received backing from the House of Commons Environment Committee [1].

This report presents the results of an investigation into the implications for the UK of using recycled greywater and stored rainwater as alternatives or supplements to mains water supplies. The potential water savings could be significant; recycled greywater or rainwater could supply the total demand for toilet flushing, which would reduce mains water consumption in dwellings by up to one third. The report is also timely in the light of the recent introduction to the UK market of several systems for greywater reuse and stored rainwater supply.

In a number of other countries, greywater and/or rainwater is already reused on a much wider scale than in the UK. In the drought-prone western states of the USA, for example, landscape irrigation using greywater is a common practice; in Germany a significant number of rainwater supply systems have been installed in buildings; and in Japan greywater reuse is practised on a scale that ranges from the use of simple 'hand basin toilets' to complex recycling systems in office blocks. Part of the remit of the current project has been to summarise the knowledge and experience gained in other countries and to relate this to the UK situation.

1.2 SOURCES OF INFORMATION

The information on which this report is based was obtained from a variety of sources, including:

- Published material, identified in an extensive literature search using BSRIA's database IBSEDEX, as well as BRIX and AQUALINE available on-line through the European Space Agency (ESA).
- Selected contacts including product and system manufacturers and developers, those responsible for installing and operating systems already in use and other experts knowledgeable in the field (See Appendix A1).
- Information obtained from the INTERNET.
- Information already in BSRIA's possession, following previous work in this field, which has included the production of a major report on the recycling of domestic greywater [2].

1.3 SCOPE

The scope of the study has been broad, in order that the full range of implications for the UK of using recycled greywater and stored rainwater could be considered. A wide range of systems have been examined. These range from 'DIY' systems to complete proprietary systems and in complexity from simple garden water butts to advanced greywater recycling systems. In size they range from systems designed for single family dwellings to systems for use in large office blocks or groups of buildings. The only significant restriction on the scope of the study has been that schemes involving public supplies of rainwater or reused water, including treated sewage effluent, have been excluded.

Details have been obtained of systems currently marketed or under advanced development in the UK and overseas. The systems have been categorised, based on such factors as water treatment method and recycled water source, and a detailed description of each key type is given in the report. Assessments have been made of the likely user/social acceptability of systems if used in the UK. Information has been obtained on the guidelines and standards for systems that apply in the UK and in selected countries overseas, as well as those produced by the World Health Organisation. The report also includes details of possible deleterious effects that may result when recycled greywater or stored rainwater are used, and the restrictions of use that may need to be imposed. Also, an assessment of the current and potential economics of systems is presented, using an analysis that considers separate installations in houses, flats, offices, hotels and prisons. Throughout the report, the potential implications for the UK of using such systems are considered, and application-specific water quality guidelines and generalised conditions of use are proposed for the UK.

1.4 DEFINITIONS

"Greywater" is defined in this report as all wastewater from domestic (non-process) appliances and fittings with the exception of that from WCs and bidets. It thus includes the discharges of wastewater from kitchen sinks, washroom basins, baths, showers, washing machines and dishwashers. It should be noted that other authors have used the words "Graywater", "Grey Water", "Gray Water" and "Sullage" as alternative terms. Also, in a number of cases greywater has additionally been defined as not including wastewater from sources such as kitchen sinks.

- "Stored rainwater supply systems" are broadly defined in this report as systems which collect and store rainwater from hard surfaces on and around buildings, and distribute it, with or without treatment, to the point(s) of use.
- "Greywater reuse systems" are broadly defined as systems which transfer greywater, with or without storage and/or treatment, from the point(s) of production to the point(s) of reuse.
- "Combined systems" possess a combination of the above features, being designed to collect both greywater and rainwater for reuse.

1.5 AUTHORS

This study was carried out by S.E. Mustow, R.W. Grey, T.K. Smerdon, C.M. Pinney and R. Waggett of BSRIA, during the period October 1996 to February 1997, for the Drinking Water Inspectorate of the Department of the Environment.

2. SYSTEMS CURRENTLY MARKETED OR UNDER ADVANCED DEVELOPMENT

2.1 INTRODUCTION

This section of the report examines the use of both separate and combined rainwater and greywater systems. Systems from around the world which are currently available or in an advanced stage of development have been considered in terms of their potential for use in the UK. The social and user acceptability of such systems is a key factor influencing the extent of their use and so these aspects make up a significant part of the discussion.

2.2 RAINWATER SUPPLY SYSTEMS

The main incentive for the on-site use of rainwater is the reduction in the amount of water required from the mains supply, reducing the overall costs of water services if the building has a metered water supply.

The collection and on-site use of rainwater also contributes to a slight reduction in the amount of water treated at water treatment works. Also, the stormwater loading of combined sewers and wastewater treatment plants could be reduced, leading to less wastewater being treated overall and potentially lower sewage treatment costs.

Sales of rainwater reuse systems in the UK are increasing. One manufacturer of rainwater systems remarked that his business, started six years previously, had shown a marked increase from January 1996 [3]. A number of proprietary systems are now available on the UK market, with several having been installed in new houses with water meters.

Bermuda is a good example of a country heavily dependent on rainwater collection. The country depended entirely on this source of water until the 1930s, and now rainwater provides most of its domestic requirements and about 50% of its total water demand [4]. Roofs are constructed of limestone and sealed with non-toxic latex paint, and rainwater run-off is collected and stored.

One million people in Australia also rely on rainwater as one source of their water supply [4]. The government of South Australia has recently encouraged rainwater collection and use by providing information on cistern sizing, materials and maintenance to the general public and interested parties [4].

2.2.1 Untreated Rainwater Use

The simplest rainwater collection system available on the market is the domestic water butt, which can be connected to the downpipe of rainwater gutters from roofs to collect water. Water collected in butts is usually used for irrigation. The collected water can be utilised by simply paling it out manually with a bucket, or through a tap at the base for a watering can or hose. Contamination of the water by debris or insects can be minimised by the use of tight-fitting lids.

Large plastic storage tanks installed underground or fitted into basements are also used, although often the storage of rainwater for use in dwellings is not the main purpose for which such tanks were originally designed. The possible contamination of rainwater by tank materials must be considered, but this is unlikely to be a problem if the water is only used in gardens or if tanks are made of materials approved by the UK Water Byelaws Scheme. Larger tanks are used in commercial buildings to store rainwater from roofs and hard surfaces for landscape irrigation and for vehicle or facade washing. If the water is piped to a storage lake or pond, it can also provide an attractive landscape feature, although some water will be lost through evaporation and additional pumping may be required.

2.2.1.1 Initial Runoff

The quality of rainwater in the UK is generally such that most physical and chemical characteristics comply with minimum WHO standards for drinking water [5].

However, roofs are contaminated during periods of drought by the settlement of atmospheric particulates. This build-up of particles can be washed into a rainwater collection system by the first rains after a drought [5] and debris such as leaves, bird droppings and vegetation can contaminate the water. As a result, it is recognised that the first rain collected after dry spells will be more heavily polluted than subsequent runoff [6].

For irrigation, the rainwater collected does not need to be treated to any great extent as a small amount of contamination should have little effect on plants. In general, however, products that use rainwater for irrigation have basic coarse filtration by a mesh screen to exclude leaves and other debris from the storage vessels. The incorporation of a diverting valve into these systems to remove the first runoff of rain is also possible. However, this increases costs and can complicate the system without significant benefit.

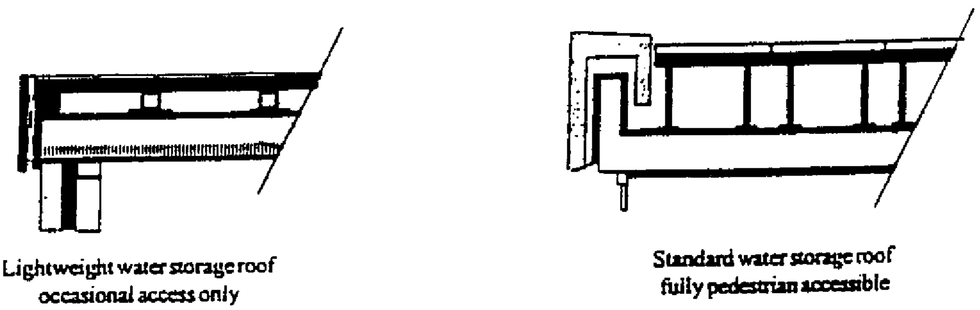
2.2.1.2 Water Storage Roofs

A water storage roof is a “flat” roof designed specifically to collect rainwater for reuse either in the building or the surrounding area. A waterproof membrane is used which prevents penetration of rainwater through the roof and acts as a water retaining membrane. Even in a relatively dry area with only 600mm of rain per year, a house with a water storage roof could collect 75,000 litres of rain per annum which would provide 30% of the water consumption for a four person dwelling [7] (the average UK rainfall is 1089 mm per year [8]).

Uncovered roofs will increase the degree of water evaporation and the likelihood of freezing and algal growth. The collected rainwater is therefore protected by expanded polystyrene insulation supported above the water level, covered in turn by paving slabs [9]. The draw off level of the water stored on the roof should be raised slightly above the base of the store, by around 10mm, to allow for the settlement of any debris, which should be regularly removed.

If water usage is greater than the amount of rainfall collected, then a top-up supply from the mains would be required. However, the need for a rainwater disposal system from the roof itself could be eliminated, therefore saving money on the cost of outlets, downpipes and soakaways. The distributed load of a water storage roof can frequently be carried by standard structures, although the structural strength of any existing roof must be checked carefully before converting it to store water. The problems associated with wind forces damaging flat roofs due to their light-weight construction, may be reduced due to the extra weight of the water. Also, a water storage roof could be added as a thermal upgrading measure for a building as the water acts as an insulation layer. These benefits, however, would obviously not apply in dry periods if the water store on the roof was empty.

Figure 1: Diagrams of Water Storage Roofs [9]

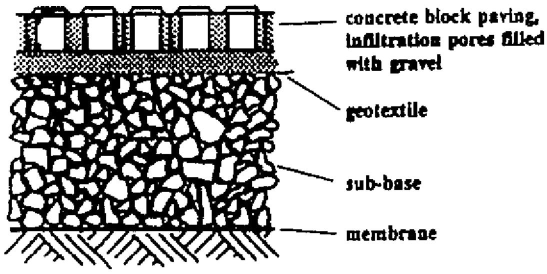


2.2.1.3 *Permeable Paving*

Permeable paving collects rainwater and incorporates water storage within its own structure. Storage may involve the use of an underground tank, but often the sub-base of a permeable pavement contains an impermeable membrane with suitable material laid over the top. This rainwater collection and storage system is relatively easy to construct, because only shallow excavation is required.

A permeably-paved area must be able to provide adequate support for the loads applied to it. Tank sub-structures can provide suitable load-bearing urban surfaces, although these require deeper excavation. Otherwise, fills such as crushed stone can accommodate loads and provide significant voids for water to be stored. Some new plastic honeycomb materials also offer appropriate water storage and load-bearing characteristics.

Figure 2: Diagram of a Typical Permeable Paving Water Storage System [10]



Precautions must be taken against contamination by oil spills and dirt on collector and storage pavements. Because of the risk of contamination any rainwater collected should not be used for drinking or culinary purposes without appropriate treatment. Some treatment may be necessary for stored rainwater used for WC flushing.

Systems can be designed for individual dwellings or more effectively for groups of buildings, with the main area of permeable paving usually used for car parking. A survey has been carried out in the UK which found that the site areas within which houses are constructed are typically 5-8 times greater than the roof areas [10]. Thus the potential for rainwater collection from permeable paving could possibly be greater than that from roofs.

Rainwater collected via permeable paving is particularly suited to irrigation. The quality of water required for irrigation is relatively low and the location of the paving and therefore the water store is likely to be near the area to be irrigated. A suitably paved area could be designed into a garden or landscape to collect the water required for irrigation.

This form of rainwater collection and storage has a number of advantages and disadvantages [10].

Advantages include:
- inconspicuous;
- no loss of land if using footpaths and vehicle standing areas;
- shallow construction, hence reasonably cheap and convenient access to sub-surface pumping equipment;
- no danger of drowning to children and animals as storage is entirely enclosed;
- few problems in the UK climate from freezing below ground.

Disadvantages could include:
- lack of durability of sub-surface impermeable membrane;
- difficulties in cleaning if contamination of the stored supply occurs;
- need for back-up mains supply for dry periods.

2.2.1.4 *Toilet Flushing*

Toilet flushing is the most likely use for rainwater within premises. In one experimental system in the UK it was found that the turbidity of the collected roof water was satisfactory for WC flushing and that treatment of the water was unnecessary [11]. It was found that the first flush of rainwater was of slightly poorer quality but despite this a diverting valve was not required. It was suggested, however, that the intake to the WC cistern should be fitted with a coarse mesh filter to remove larger items of debris washed off the roof.

Other domestic rainwater collection systems which only supply water to flush toilets are discussed in more detail in Section 2.2.3. Toilet flushing does not have such important water quality considerations as other uses, such as bathing or washing, because the water is less likely to come into contact with humans.

2.2.2 Treated Rainwater Use

For certain applications it is often considered necessary or prudent to treat rainwater before use to a higher standard than can be achieved using basic filtration. These applications mainly include those in which there is either an intention or a risk of the collected rainwater being consumed. This would be the case for water used in bathing, washing or drinking.

2.2.2.1 *Rainwater Treatment*

Rainwater treatment frequently consists of filtration as a first stage, usually between 20µm and 1µm. Filtration is followed by disinfection generally using chlorine, ozone or ultra-violet light. These treatments are capable of limiting, if not eliminating, microbial contaminants in the water, and can be used where there is a possibility that the water will come into contact with humans. However, regular maintenance, renewal and checking of the treatment system is required and there is also a need to install a warning system in case of failure.

2.2.2.2 *Potable Use of Rainwater*

The manufacturers and suppliers of the majority of rainwater collection systems currently available in the UK do not suggest that rainwater is used for drinking and cooking. A supply of wholesome water is legally required for drinking, cooking and food preparation purposes, requiring a continual, fail-safe system. However, a relatively small proportion of properties have no mains water supply. The main barriers to the widespread uptake of rainwater systems for total supply are the concerns about water quality, associated water treatment costs and storage requirements.

2.2.3 Rainwater Supply Systems

There are now three proprietary systems available on the UK market which provide a complete rainwater reuse system, including treatment, storage and pumping to appliances. These are produced by WISY, Wilo Salmson and Kiskic Enterprises Ltd (see Appendix A1). The manufacturers generally suggest that the water is used only for flushing toilets and possibly for washing machines.

A number of different stormwater collection systems are available overseas. These include systems which utilise roofs or driveways to collect rainwater and store it in either one or two tanks. Some systems are connected directly to the cold water header tank, so that the header tank will only fill from the mains supply if there is no water in the rainwater reservoir. It is generally considered good practice to locate the main collection tank in the ground or basement to maintain cool conditions and minimise the possibility of odours or microbial growth [11].

The proprietary systems currently available in the UK are designed for the residential market, in order that metered customers may reduce their water bills. Storage is generally in roof tanks, but some feature underground tanks. Several commercial buildings in the UK now have systems in operation which use custom designed rainwater systems to flush toilets [3]. These are similar to, but larger than, the proprietary systems intended for the domestic market, and can yield considerable savings in certain building types.

2.2.3.1 Common Features of Rainwater Collection and Treatment Systems

- A mains back-up supply in case of increased demand for water which cannot be met by the stored rainwater.
- A safety mechanism so that rainwater is not stored for more than one or two days before use.
- A treatment system incorporating filtration or other means of exclusion of particulates.
- Biocidal treatment, often chlorine or hypochlorite.
- An unrestricted overflow to prevent mains water contamination, incorporating a 'type A air gap' between the level of the lowest part of the inlet pipe and the spillover level of the receiving vessel (specified in the 1986 Model Water Byelaws to prevent contamination of mains water by backsiphonage, backflow or cross-contamination, see Section 3.2.1).
- Water coloration to indicate the fact that the water is not potable.
- An attachment so that the stored water can be used outside for garden watering or car washing.

2.2.3.2 Tank Sizing

There is currently a debate concerning the optimum size for rainwater collection tanks. One prototype system, being tested at Coventry University [12], uses large rainwater collection tanks of between 2,000 - 4,000 litres, placed at ground level, to accommodate the storage required for total annual toilet flushing demands in a typical dwelling. The system is designed to include a safety margin to prevent overflows, in order to remove the need for a connection to the stormwater sewer. The storage tank is at ground level as few houses could support the load of full tanks of this size in the roof space. However, this means that pumping is required to raise the rainwater to a separate roof tank, to provide gravity flow to the internal supply system.

A similar system is being tested at Nottingham Trent University [5]. The tests indicate that the use of a much smaller collection tank has economic and design advantages. Such a tank would cost significantly less and could be located in the roof space. It would be designed to supply only about half of the water required for annual total toilet flushing demands, the rest being supplied from the mains. Once tank size is increased beyond this optimum level, benefits progressively diminish.

When calculating tank size it is common to use rainfall loss models [13], which can include:

- Critical period methods
- Moran related methods (mathematical models)
- Behavioural models

The behavioural model is used most, although monthly behavioural models have been found to give inappropriately large tank sizes. For example, the monthly behavioural model used to size the tank for the collection system of Robert and Brenda Vales' house in Nottingham, indicated a need for three times the actual storage required [14]. In contrast, recent research has indicated that daily behavioural models are more accurate, leading to the recommendation of smaller tank sizes [13]. These tanks cope adequately with day to day water demands, but are not designed to meet high demand peaks such as for gardening watering in summer. They therefore require stormwater overflow connections.

An indirect benefit of storing collected rainwater in the roof is that transfer to solar heat collectors is easy and these can be used to heat the stored water if required [15]. This may be a particularly useful feature in autonomous houses, which are separate from mains supplies of both water and power.

2.2.3.3 *'DIY' Systems*

The potential for the uptake of simple 'DIY' rainwater collection systems is great, particularly in the light of recent hosepipe bans imposed by water companies. Also, keen gardeners who use hoses or sprinklers are obliged by some water companies to have a metered water supply, and they would thus benefit from obtaining irrigation water from another source.

The average 'DIY' enthusiast could build an appropriate rainwater collection system from items sold in outlets such as garden centres or builders' merchants. Systems comprise of a guttering network leading from the roof, via downpipes, into storage tanks which usually take the form of water butts.

Tanks

As the pH of rainwater can vary with location and roof material and may be aggressive towards concrete, plastic storage tanks are usually recommended [11]. Inlets to tanks should be designed so as not to agitate the stored water, nor any sediment that has settled out. Outlets should be slightly raised above the base of storage tanks to prevent the discharge of any sediment and sludge. Maintenance for tanks is usually required annually, but filters need more frequent cleaning.

An unrestricted overflow must be included in any system with a mains back-up supply to prevent mains water contamination by backflow. This must incorporate a 'type A air gap' as specified in the 1986 Model Water Byelaws (see Section 3.2.1).

Pipes and Guttering

It may be advisable to use plastic pipes in systems to minimise possible corrosion. Care should be taken to ensure that rainwater is not accidentally used for drinking or culinary purposes through accidental cross-connections, possibly by employing different coloured or sized pipes and careful labelling. The rainwater could also be coloured with a vegetable dye to show that it is not from the mains and is therefore not safe to drink. The latter measure may be unsuitable if the water is to be used in washing machines.

Treatment Systems

If collected rainwater is to be used for irrigation, treatment is not usually necessary, apart from basic filtration to remove leaves and other debris which could block the system. However, if the water is to be used internally, for toilet flushing or supplying washing machines, treatment is generally recommended. There are various suitable water treatment systems available on the market, although most were not originally designed to be incorporated into rainwater collection systems.

Systems are available which use disinfection treatments such as chlorination, ozonation and UV (ultra-violet light) to treat water within storage tanks. Several were designed for use in emergency relief and development projects around the world, and so are small and portable. Certain point-of-use treatment systems may also be appropriate.

Pumps

If rainwater is to be used internally for WC flushing, it must in most cases be pumped from its collection point up to a roof tank to allow gravity flow to fill toilet cisterns inside the building. There are several suitable pumps available, with submersible pumps being used most frequently in proprietary systems. These can often be the most expensive part of any system.

There are several examples of 'DIY' systems which are currently being promoted:

- The Casa Del Aqua project in Tuscon, USA channels rainfall for direct use and also stores water for irrigation [16]. Part of the system collects rainwater from the roof and stores it in a cistern connected to a pump that can supply water to drip irrigation lines and an evaporative cooler. The collector system has gutters 5 inches (22.5 cm) wide installed on a slight gradient. Downspouts have a collective area of 1 square inch (6.5cm^2) of downspout for every 100 square feet (9.3 m^2) of roof area. Casa has one rainwater collection tank with a total volume of 7,000 gallons (26,500 litres), although it has been suggested that the installation of several smaller tanks might have been more appropriate, because they are easier to install near points of use.

- The Greenhouse Trust Environmental Centre in Norwich recently acquired new premises in which a rainwater supply system is being installed [17]. Rainwater will be filtered, collected in a sump, and then pumped into the main roof space for storage in two 1,200 litre tanks. The system is due to be up and running by the end of March 1997, with the collected rainwater used for low flush toilets on both floors of the building. In addition, the Trust have installed low water using appliances and are planning to run a parallel, but separate, greywater recycling system at a later date.

- Robert and Brenda Vale designed and built a well known autonomous house in Nottingham. Here, rainwater is collected from the roof using copper gutters and down pipes. It is stored in the cellar in twenty reused Israeli bulk orange juice containers [18]. The containers are interconnected so that they fill and empty together to avoid stagnation of the water. From these, the water passes through a sand filter into a primary treatment tank, and then up to a header tank in the roof. Water used for drinking and cooking purposes is treated to a higher quality at the point-of-use using carbon filters. This water is supplied to separate taps in the kitchen and children's bathroom.

2.2.3.4 Manufactured Systems

A number of groups in Germany are encouraging rainwater collection, particularly in multi-storey flats. Manufacturers have produced 'unit' kits which include a tank, pump, controls and a pressurisation system, which although relatively expensive, can attract grants for up to 50% of the cost [19].

Two of the systems currently commercially available in the UK originate from Germany:

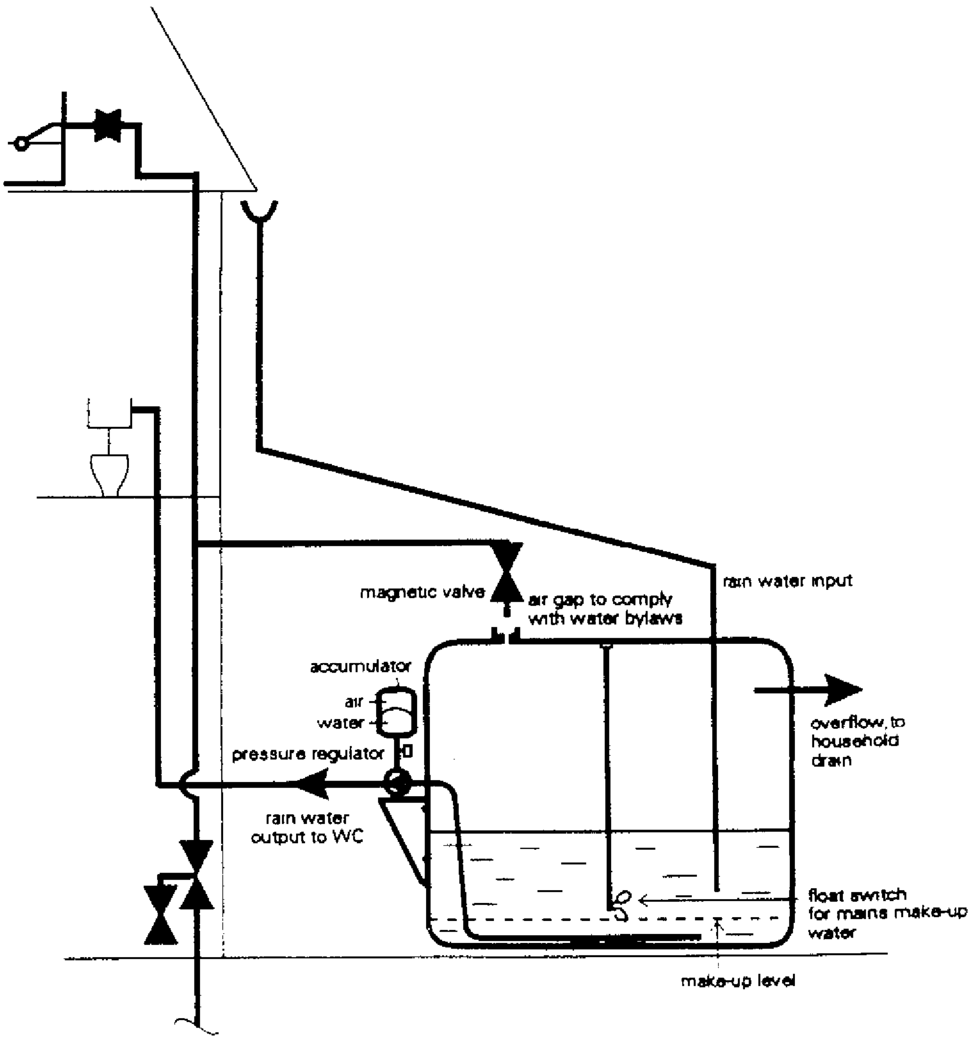
Wilo Salmson System

The Wilo Salmson system uses a single tank, a pump and an accumulator to distribute water to WCs within the building. The system is currently being tested by researchers at Nottingham Trent University [5].

Rainwater is collected from the roof by gravity feed, via a downpipe, and stored in a polyethylene tank with a capacity of 2,032 litres. A coarse filter is fitted to the downpipe to remove any large debris. An overflow is fitted to the storage tank which discharges to sewer if necessary. The whole system is pressurised by a pump, which pumps water into the accumulator, until a pressure switch deactivates the pump at a pressure of approximately 4 Bar.

If insufficient rainwater is available, a float switch near the bottom of the tank activates a magnetic valve, which allows mains water to flow into the tank. In order to comply with the Water Byelaws, the mains water is not fed directly to the tank, but is channelled instead via a funnel connected to the top of the tank, which incorporates a 'type A air gap' (see Section 3.2.1).

Figure 3: Diagram of the Wilo Salmson Rainwater Collector [5]



WISY System
The WISY system also originates from Germany and is distributed in the UK by The Green Shop, Stroud. One system arrangement has been installed in a garage workshop adjacent to the shop, which utilises WISY filters and pipes but has a 5000 litre over-ground tank [20]. The system is gravity fed and the use of WISY pumps has not been necessary.

In the workshop, rainwater is used for everything except drinking and culinary use. Data from sub-meters installed in October 1996 have shown that the systems are supplying 90% of the total water requirements of the premises. The main tank is automatically topped-up from the mains when the level falls below 10% of the full volume but this has not been required since August 1995 (at the time of writing this report).

A complete WISY system is due to be installed in the actual shop in early 1997, at a cost of £1,000. The system is self-regulating and is claimed to be mainly self-cleaning, using a 'three stage' cleaning process, involving a rainwater collector filter, an overflow process to remove floating debris and the biological breakdown of sediment at the base of the storage tank. It is claimed that any competent plumber can fit the system easily.

Kiskic Enterprises System
Only one proprietary rainwater collection system is currently designed and built in the UK. The Kiskic rainwater system collects, stores, treats, filters and then pumps rainwater back into the house for non-potable uses. It uses a 'bidding tank' (gravity feed tank) in the loft to provide low cost water for toilet flushing. Slowly dissolving chlorine tablets are used for disinfection, and are available from chemists and swimming pool suppliers.

The system is provided in 'kit' form at a price lower than other comparable systems available in the UK, although this does not include installation. Installation might prove difficult for a person inexperienced in 'DIY'. Kiskic also produce a greywater system for garden irrigation purposes.

2.2.3.5 Customised Design Systems

Customised rainwater collection systems, designed and built on an individual basis, or available in 'kit' form, can be retrofitted into existing buildings. Several installers offer 'made-to-measure' systems and prices vary according to the needs and demands of customers [3]. Design flexibility is one advantage of these systems. Tanks, for example, can either be at ground level, thus requiring a pump to distribute the water throughout the property, or at a high level within the roof structure, thus allowing gravity flow through the system, once water has been pumped to the storage tank from source.

Customised designed systems are particularly suitable for older buildings which have more varied structures and perhaps inadequate structural strength to support large tanks at roof level. However, older properties are less likely to be metered, so the incentive to save money on water bills may not exist.

One company offering customised systems in the UK reported that a feasibility study is part of their overall installation package. This involves an examination of a year's water consumption data relating to the building in question. A system is then designed according to the particular requirements allowing, where appropriate, flexibility for growth or fluctuation in demand.

Other parameters that should be considered in the design of customised rainwater collection system are [21]:

- collection area, i.e. roof area
- demand pattern
- rainfall pattern
- necessary storage volume (see Section 2.2.3.2)
- reliability

Several computer and mathematical models have been designed which aim to determine optimum roof collection areas and optimum locations for buildings to be sited if they are to be reliant on rainwater collection [20, 22]. It has been suggested that multi-storey office blocks are ideal for rainwater recovery [19]. A single rainwater storage tank could be located high up, collecting water from the roof. This would then allow all WCs on the floors below to be gravity fed.

Examples of customised rainwater collection systems include:

- A system installed at the Highfield Junior School, Plymouth. The school reports that the social acceptability of the system has not been a problem [23]. Maintenance requirements are acceptable and the school is very satisfied with the system. The only problem to date has been a system management fault, where the system was not switched back on after a routine maintenance check.

- A customised internal rainwater collection system is being designed by Caradon Bathrooms in conjunction with the University of Coventry [12]. This system, which is intended to be finished later this year, is to be installed in Housing Association properties in Nottingham, London and Birmingham, and is to be run as a trial for 2-3 years. One of the main purposes of the trial is to monitor and report user acceptability of the systems installed.

2.2.4 The Social Acceptability of Rainwater Use

2.2.4.1 Benefits of Rainwater Collection Systems

There are considerable conservation and potential cost saving benefits from the use of stored rainwater supply systems in the UK.

Water Savings

The most important of these benefits is the potential for water savings of at least 30% which can be expected for a typical dwelling in the UK, even if the rainwater is used only for flushing toilets. As most water companies are looking for new sources of water to cope with increasing demand, the need to save water wherever possible is becoming increasingly important. Water saving devices may feature more heavily in the demand management strategies of water companies in the near future[24].

Reduced Water Charges

Installation of rainwater utilisation systems in low income, high occupancy homes may also reduce problems associated with the payment of water bills. Several Housing Associations in the UK are recognising the potential for the use of rainwater to reduce water charges. Housing Associations now supply the majority of rented accommodation in the UK. Their concerns usually relate to the maintenance of systems rather than to the initial outlay. In order to minimise costs to residents they are more supportive than most of 'radical' design solutions, such as rainwater use. As nearly 50% of new-build housing in the UK in the next few years will be by Housing Associations [25], this could be an important market for rainwater supply systems for use in dwellings.

New-Build Houses

As water meters are now being installed in more new houses, the fitting of rainwater supply systems in such houses has become more economically attractive. Some areas of the country require housebuilders to include external stormwater detention features, such as holding ponds, for their new-build housing developments. These limit off-site stormwater discharge rates, at an additional cost of £600-800 per dwelling. It has been suggested that rainwater collection systems could be installed instead, for approximately the same price [12]. This would obviate the need for stormwater detention and allow the collection of usable water. However, housebuilders now give guarantees for new-build houses of between 3-10 years and therefore require reliability in rainwater systems. The few systems available are not yet 'tried and tested' sufficiently to give this confidence. Also, estimated costs produced by some housebuilders for installing rainwater systems are in the region of £1,500 - £2,000 per dwelling and house purchasers may be unwilling to pay additional premiums of this size.

Softer Water

Other benefits would result in some areas of the UK, where rainwater is softer than the mains supplied water. Consequently, equipment using water such as heating and cooling equipment, if using rainwater, may require less anti-scaling treatment. Washing and bathing would require less detergent and soap.

2.2.4.2 Barriers to the Implementation of Rainwater Collection Systems

Cost of Systems
The cost of rainwater systems ranges from £20 for water butts up to £2000 for customised systems and beyond. An enthusiastic gardener would benefit by irrigating with rainwater, due to the short payback time. However, installation of a complete system is too expensive for many. Longer payback times will not prove attractive if a house is to be lived in for a relatively short time. There may also be problems when trying to sell on the property if potential buyers do not consider the system to be beneficial.

Health Concerns
The second barrier to the acceptance of rainwater systems arises from concerns about the health of occupants, particularly children, resulting from the possibility of accidental ingestion of rainwater. This might be caused by cross-contamination within the plumbing system, or by water mistakenly being drawn from the rainwater system for drinking or bathing. However, provided that care is taken with pipework to ensure that rainwater supplies and potable supplies are kept entirely separate and are clearly labelled, such risks would be minimal.

Storage Tank Size
Adequate storage facilities for rainwater can occupy a great deal of space. The tanks ideally need to be in a safe and cool area and be designed to avoid contamination of the stored water. The need for storage arises because of the uncertainty of the quantity of rainwater supply. Whilst winter monthly rainfall may be high, summer months may contain long periods without rain. The rainwater supply must then either be supplemented by an alternative supply, such as the mains or a greywater system (see Section 2.3), or else sufficient storage must be available to cope with demand through periods of drought. Tank sizing is considered in more detail in Section 2.2.3.2.

Water Companies' Response
Recent interviews of representatives of water companies, conducted by researchers from Coventry University, have indicated that water companies apparently have four main areas of concern regarding the principles of rainwater supply systems [12]:

- compliance with the Water Byelaws;
- water quality;
- lack of tried and tested systems; and
- loss of revenue.

Despite these concerns, some water companies were found to have a positive attitude towards the potential use of rainwater collection systems [12]. This was because, with the increase in stormwater loadings on wastewater treatment works due to runoff from ever increasing residential and urban development, sewage is becoming more dilute and treatment costs are rising. Also, it is now the duty of all water companies to "promote the efficient and economic use of water supplied to their customers". Additional benefits could include reduced operating and water resource infrastructure costs.

2.3 GREYWATER REUSE SYSTEMS

Greywater, by definition because it excludes black water (i.e. foul water from WCs), has relatively low levels of microbiological contamination. This has led to greywater being reused as a source of non-potable water, with the most common applications being the use of greywater to flush toilets or to water gardens.

For practical purposes, however, it is best to avoid the use of wastewater from kitchen sinks and dishwashers in greywater recycling systems, as the food particles, grease and oils contained within it are difficult to filter and can clog pumps and membranes[26].

There is currently no legislation in the UK specifically to regulate the use of greywater. There is also no guidance as to the quality requirements for toilet flushing water. It is often assumed, in the absence of separate guidance, that the water should be potable due to concerns about the possibility of children and pets drinking from the toilet and because of possible bodily contact brought about through splashing and the creation of aerosols during flushing. However, experience from outside the UK suggests that recycled water can be safely used for toilet flushing, using water quality standards that are less stringent than those for potable water (see Chapter 3). This has implications for the uptake of systems, as an insistence on potable quality water would add considerably to the cost of systems. The current lack of specific standards has led to the marketing and installation of several types of greywater recycling systems, in which differing levels of water treatment are employed.

Greywater recycling systems have relatively high capital costs and significant installation, operation and maintenance requirements so, in the past, they have only been used in relatively large industrial premises [27]. However, the majority of proprietary systems now available in the UK are designed to be installed or retrofitted into dwellings.

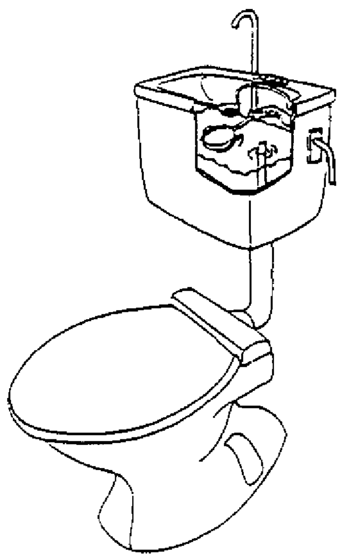
2.3.1 Direct Use of Greywater

Greywater is often defined as all wastewater from domestic appliances and fittings with the exception of WCs and bidets. It thus includes the discharges of wastewater from kitchen sinks, washroom basins, baths, showers, washing machines and dishwashers [30]. Most uses of greywater require some form of treatment, although untreated greywater can be used where there is a very low risk of human contact, such as occurs with sub-surface irrigation. This direct application of greywater requires only simple storage, with a coarse filter to remove any large debris, hair and other particles. Most such systems are simple, incorporating storage and pumped or gravity fed hoses or drip feeds for irrigation systems. Irrigation using greywater is very popular in the USA, where a greater percentage of water is used for irrigation and other outdoor purposes than is the case in the UK.

The Agwa greywater system is an example of a complete system approved by the California Plumbing Code [28], which only allows greywater use for sub-surface irrigation (see Appendix A3). This system is made up of three major components: a 55-gallon collection tank, a 1/2 hp pool pump and a sand filter. A float switch turns on the pump which forces the greywater through the auto-backwashing sand filter and out to the irrigation system. All the major components are conventional swimming pool technology and the manufacturer states that service requirements are minimal and initial costs are moderate. Maintenance is a simple five minute procedure once a month. The system comes complete with colour coded hardware and it is claimed that assembly takes less than one hour.

Another very simple idea for the direct use of greywater within a building is a basin which fits directly over a low-level toilet cistern. When water is used in the basin for hand washing, it drains directly into the cistern and can then be used to flush the toilet. There is thus no need for complicated pipe networks or additional storage. Water treatment is unnecessary as the greywater is generally used very quickly and originates only from hand washing. Hand-basins can be retrofitted on to existing cisterns using cheap, easy to install kits as lid replacements. However, care must be taken that designs conform to the Water Byelaws, particularly concerning the location of waste/warning pipes.

Figure 4: 'Hand-Basin Toilet' Fitted onto Low-Level Cistern [29]



2.3.2 Treated Greywater Reuse

Greywater from hand basins, baths and showers makes up 26% of the wastewater produced in an average UK dwelling [30]. With the inclusion of effluent from washing machines this increases to 47%. As the water required for toilet flushing is around 33% of the total water used, there is sufficient greywater produced in the majority of UK households for toilets to be flushed using solely recycled greywater.

There are now several systems on the market worldwide which reuse greywater produced during bathing and recycle it to flush toilets. These systems are generally less suitable for use in office and commercial buildings due to these buildings' low production of greywater and high use of WCs. Commercial buildings which incorporate showers or other bathing facilities, such as leisure centres, may be able to use such systems more economically. The majority of proprietary systems now available in the UK are designed to be installed or retrofitted into dwellings.

2.3.2.1 *Methods of Greywater Treatment*

There are currently two schools of thought regarding the treatment of greywater: one insists that greywater should always be treated to potable standard; the other that the degree of treatment should depend on the end-use. If the water is likely to come into contact with humans or is intended to be stored for any length of time then undoubtedly a relatively high degree of treatment should be included. However, if the water is just intended for immediate external sub-surface irrigation, then simple filtration with a mesh will in all general cases be adequate.

More advanced treatment usually involves several stages: filtration; a secondary treatment usually either flocculation, a biological treatment or a combination of both; and disinfection after treatment. Table 1 below, lists several types of greywater treatment systems and describes their principal advantages and disadvantages (information from Glucklich [31] and Kilford *et al.* [32]). The final stage of treatment often consists of chlorine, ozone or UV disinfection. Chlorination has the advantage of leaving a significant residual cleansing effect in the system, which is not the case for either ozone or UV treatment

The costs of treatment systems varies and details can be obtained by contacting manufacturers (see Appendix A1). Many proprietary greywater recycling systems include a water treatment system as part of the package.

Table 1: Some Greywater Treatment Options

Treatment	System	Advantages	Disadvantages
Physical	Settlement Tank	Inexpensive	Not very effective
	Gravel Box	Inexpensive	Not very effective; problems with removal of sludge
Biological	Rotating biological disc	Compact - can be installed inside buildings	Problems with sludge disposal; no physical filtration occurs; requires an additional tank.
Physical and Biological	Rapid sand filter	Compact - can be installed inside buildings	Problems with removal of sludge; filter easily obstructed.
	Slow sand filter	No sludge removal problems	Large, so usually requires area outside building
Disinfection	Chlorine	Very powerful and fast acting; leaves residual in treated water	Can react with some organic materials in water to form acids
	UV	Achieves very high microbiological kill rate	No residual effect; may not work effectively in water with low UV transmission
	Ozone	Achieves rapid kill; effective against many micro-organisms; reduces to oxygen; can be produced in situ	Lack of residual; not very effective in an open system; turbid water may diminish effectiveness

Recent innovations in greywater treatment include products based on membrane technology. For example, field trials of a prototype membrane treatment system designed by Anglian Water are now underway in a domestic property [33, 34]. However, Anglian Water consider that the system is more cost effective in larger, high occupancy buildings and so a larger sized commercial system is currently being developed [33], intended for hotels and similar.

Point-of-use (POU) treatment devices are one option to treat greywater on a smaller scale. POU devices are commonly used to treat water at the tap for drinking, which is an unlikely application for recycled greywater. Their effectiveness in treating greywater is currently untested [27]. However, it is considered that greywater could be treated by POU devices, possibly using larger capacity 'point-of-entry' systems.

Many types of POU treatment systems are available, including filtration and disinfection systems. Filtration can be by the use of particulate filters, activated carbon filters or osmosis. UV is generally the chosen method of disinfection, although ozone can also be used. Chlorination is more appropriate for point-of-entry treatment.

Maintenance requirements of POU systems treating greywater may be high due to the presence of contaminants in the greywater, which may also affect the performance of the systems. Some manufacturers whose products incorporate activated carbon state that their devices should not be used on waters that are 'microbiologically unsafe or of an unknown quality', which includes greywater. This does not, however, rule out POU devices for greywater recycling, as pre-treatment can be used to remove contaminants to required levels and water of potable standard is not required for certain end-uses.

2.3.3 Greywater Reuse Systems

At their most basic, proprietary greywater recycling systems consist of a simple network of pipes designed to channel greywater from sources such as baths and washbasins to the point of use. However, most systems possess some or all of the more advanced features described below.

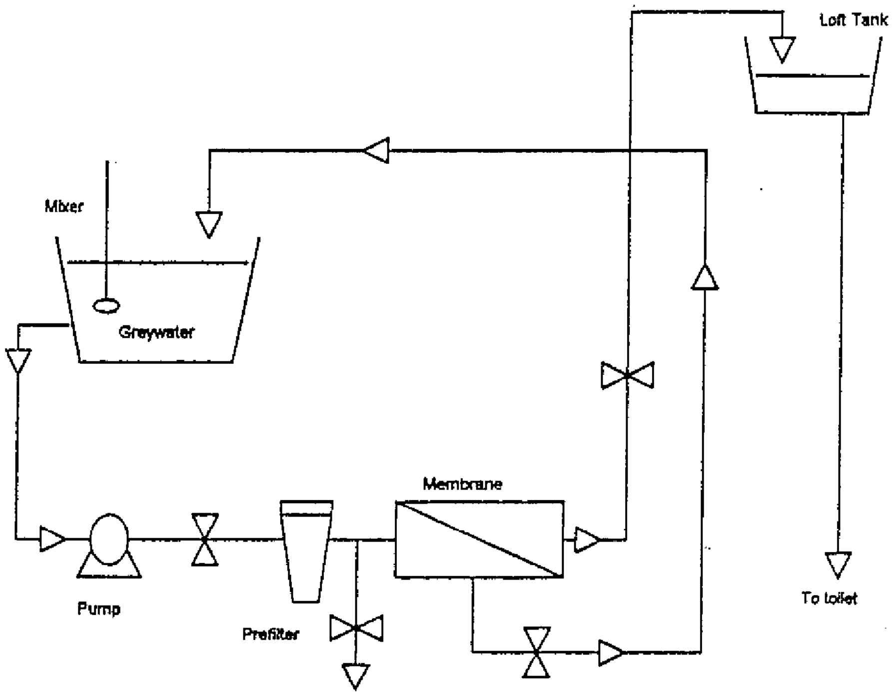
2.3.3.1 Features of Greywater Recycling Systems

- A mains back-up supply in case of increased demand which cannot be met by the stored greywater.
- A mechanism which allows the user to bypass the greywater supply and restore the full mains supply, if desired.
- A safety mechanism so that greywater is not stored for more than a day or two before use.
- A one or two-stage treatment system.
- A disinfection process, often using chlorine or hypochlorite.
- An unrestricted overflow to prevent mains water contamination by backflow, incorporating a 'type A air gap' between the level of the lowest part of the inlet pipe and the spillover level of the receiving vessel, as specified in the 1986 Model Water Byelaws (see Section 3.2.1).
- Water colouration to indicate that the water is not potable.
- An attachment so that the stored water can be used for garden watering or car washing.
- One or more storage tanks.
- Clear labelling of system parts to avoid confusion with potable supply pipes and components.

The last point may be achieved using different coloured pipes or warning signs. One American greywater company, Agwa, supplies labels to be fitted on 'DIY' systems to show which pipes contain greywater and which mains water [35].

The most sophisticated and large-scale greywater recycling systems (excluding municipal schemes) generally have their own treatment plants which include surge tanks, filters, purification equipment and storage tanks. The storage tanks are generally very large (typically more than 2000 litres) to ensure that supply meets demand. The output quality of the water is generally very high, sometimes to drinking water standard, and as a result relatively sophisticated engineering is required. Figures 5 and 6 below show schematic layouts of two systems, one from the UK and one from Germany.

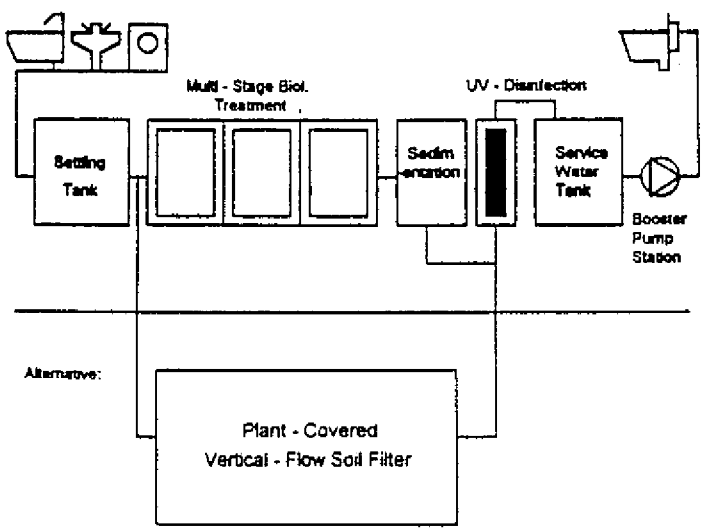
Figure 5: UK Greywater Recycling Pilot Plant [33]



The system shown above operates so that the treated water storage tank is full and the collection tank is empty each morning, with the process operating on cheap rate electricity, as follows [33]:

07:00 to Midnight	All the greywater produced is collected in the storage tank, if too much is produced the tank overflows to the sewer.
Midnight to 07:00	The treatment unit operates to fill the loft tank with recycled greywater, when the tank is full the system stops. If insufficient recycled water is available the tank is topped up with mains water via a low level ball valve.

Figure 6: Greywater Treatment Concept for Reuse for Toilet Flushing (Germany) [32]



Similar types of system have been installed elsewhere, for example in communal systems in Berlin and Hanover, Germany.

A desk study of greywater reuse carried out by BSRIA in 1992 used a modelling technique to design and 'run' a greywater system [36]. The system involved 200 litres of storage, filtration and disinfection and was deemed unlikely to be economic for dwellings, due to installation costs of £1000 - £2000 per dwelling and predicted gross savings per annum of only £50 - £100. Running costs due to pumping, treatment and maintenance were likely to outweigh the savings made on water bills.

One conclusion was that single tank systems are preferable for use in dwellings due to their simplicity, low cost and small size. The study also suggested that further work was needed on larger systems for use in buildings such as hotels or halls of residence, where the economics are likely to be more favourable. One such greywater system has been tested at a hall of residence in Texas, USA [37]. Another greywater recycling research project has been recently proposed to develop a system for a hall of residence at the University of Loughborough [38].

Large, complicated systems are generally too costly and require too much storage space to make installation in dwellings a viable option. For this reason, systems designed to be sold for this market tend to have much lower tank sizes and employ lower levels of water treatment. Such a system is the SMR system produced by Water Dynamics, a UK manufacturer, and discussed below.

2.3.3.2 SMR System

The patented SMR (Supply Management Recycling) technology reuses greywater from handbasins, baths and showers to flush WCs or water the garden.

The greywater is filtered, disinfected and coloured before storage. Continuity of supply is guaranteed by the system automatically receiving mains water if insufficient greywater is produced. The main tank in the system is called the 'break tank', which is effectively a small header tank to which both mains and greywater are supplied. Incorporation of an overflow and 'type A air gap' prevents contamination of the mains supply.

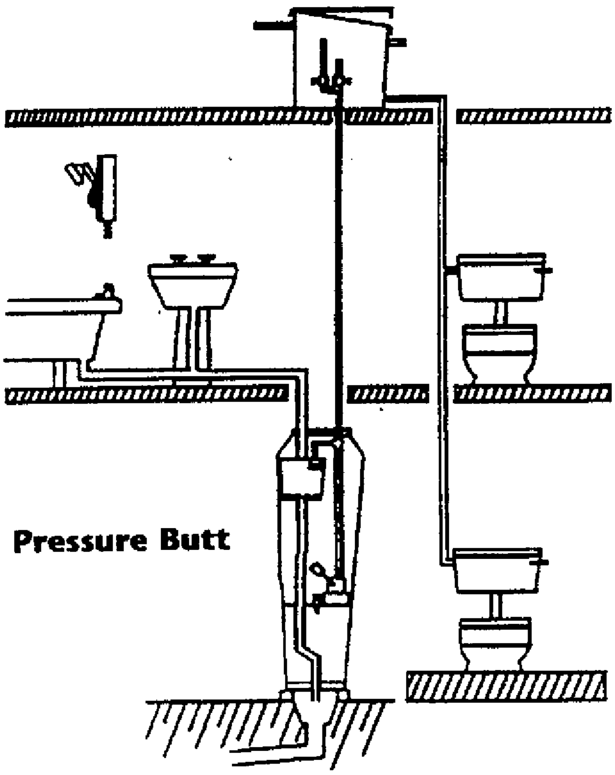
The water storage capacity of these systems is calculated as the amount needed for normal toilet operation; 180 litres per typical day for a family of four. By only storing the amount of water needed for a short period, the manufacturer claims that the engineering, health and economic drawbacks of other greywater systems have been largely eliminated.

The system does not receive water from kitchen sinks or dishwashers, as the level of organic material in these water types is high. All received water is from showers, baths and hand basins. Coarse filtration is still necessary, however, to remove hair and soap particles. The filters are made of a resilient foam that can be washed and reused many times. Any excess greywater entering the system is first used to backflush and clean the filtering system before being automatically discharged to sewer.

Disinfection is carried out using hypochlorite-based tablets which provide a small controlled dosage. The manufacturer claims that they do not add any more chemicals to the environment than would otherwise be released due to toilet bowl cleaning. However, other disinfection methods are being considered for possible use in later models.

The SMR system is available in three types, designed to suit new-build or retrofit in domestic single or two storey homes. The system complies to the 1986 Water Byelaws [39]. The company reports that, subject to survey, purchase and installation costs £1,000 in a new building, while retrofit costs £1,500 including VAT [40].

Figure 7: Diagram of Pressure Butt Layout



2.3.4 The Social Acceptability of Greywater Reuse

2.3.4.1 Benefits of Greywater Recycling Systems

Although there are some concerns regarding greywater reuse, several countries outside the UK have already realised the benefits of recycling greywater. For example, in Tokyo, such recycling is mandatory for buildings over 30,000m^2 or with a potential water reuse of more than 100m^3 per day [41]. Other Japanese cities also require smaller buildings to recycle greywater.

Water Savings

Again, like rainwater systems, even if the recycled greywater is used only for toilet flushing, water savings of at least 30% can be expected for a typical UK dwelling after installation of a greywater recycling system.

Reduced Water Charges

In addition to using less mains water, greywater systems recycle what would normally run to sewer. As a result, both water and sewage charges could be reduced, as less wastewater would run to sewer overall. The discount would be given at the discretion of the relevant water company, and may involve the use of meters to measure flows.

Storage Tank Size

Compared to rainwater systems, the storage required for greywater reuse is small, as there is a regular, dependable supply of bathing and washing waste water ensuring continuity of greywater supply. As a result, the smaller storage tanks can be easily fitted into a loft or cupboard. The maintenance of most greywater systems is limited to the occasional cleaning of filters or disposal of collected solids in tanks and should therefore not pose a major barrier to uptake.

Multi-Occupancy Buildings

Systems available in the UK have to date most frequently been installed in dwellings, where the achievement of appropriate greywater quality is more straightforward than in higher occupancy buildings. The main uptake of these systems is likely to be for new-build or renovation because installation is easier. However, multi-occupancy buildings, such as halls of residence and hotels, could benefit greatly from using greywater recycling systems due to the large volumes of greywater produced. Even in buildings such as offices where the ratio of greywater produced to toilet flushing water used may be low, economies of scale may allow the installation of greywater systems to be an economically viable option.

2.3.4.2 *Barriers to the Implementation of Greywater Recycling Systems*

Cost of Systems

The main barrier to the wide uptake of these systems is the high initial financial outlay. With the smallest systems for individual dwellings starting from around £1000, few private owner/occupiers are likely to be inclined to install these. Also, as with rainwater collection systems, retrofitting a greywater collection system is not particularly easy. Care has to be taken to ensure pipework is kept separate from potable supplies and a tank must be installed for greywater storage. However, several Housing Associations are now showing considerable interest in such systems and the cost is minimised if the system is installed during construction of the property.

Health Concerns

Probably the main concern with such systems results from the possible health implications of using greywater. This issue is considered in detail in Chapter 3 of this report.

Greywater Content

The fact that care has to be taken concerning what goes into greywater at source may act as a barrier to implementation. If water from washing machines is collected, for example, then the types of cleaning agents used may affect the quality of the greywater. Some American manufacturers of greywater systems recommend specific washing powders or suggest that water is only reused from rinsing cycles.

Treatment Requirements

Depending on the end-use of the recycled greywater, relatively high levels of treatment may be required, and so both the resulting cost and higher maintenance requirements could restrict the use of systems. Manufacturers are therefore trying to reduce treatment costs and maintenance requirements in new products.

Water Companies' Response

A possible barrier to the use of greywater systems may be the resulting changes in the volume and concentration of sewage effluent discharged to sewer. If such systems were used on a very wide scale, the sewage entering wastewater treatment works would be expected to be slightly lower in volume but slightly higher in BOD (Biological Oxygen Demand), which could have either positive or negative implications for existing wastewater treatment plants, depending on specific local conditions [42].

2.4 COMBINED RAINWATER AND GREYWATER SYSTEMS

Currently there are few systems available that integrate the reuse of greywater and rainwater. There is obvious potential for a system which utilises a single set of plumbing and tanks, while obtaining water from both sources.

Rainwater only systems frequently have large collection tanks and treatment is not always necessary. Greywater systems on the other hand tend to have smaller tanks, to minimise storage time, and treatment is usually required. An optimally designed combined system might involve a compromise between these differing requirements.

In order to be installed in a domestic property, storage tanks should ideally be small, operation and maintenance must be easy and the system must be adaptable to allow for variable supply and demand patterns.

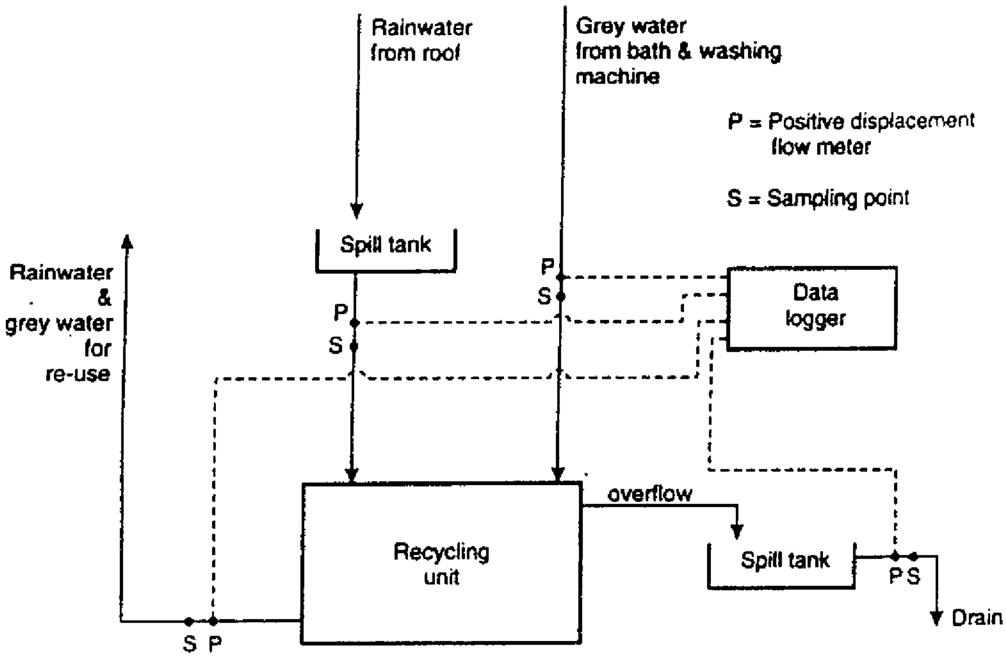
A current research project [43], funded by the Engineering and Physical Sciences Research Council (EPSRC) and now halfway through the three-year research period, is investigating the possibility of a system to collect rainwater and greywater in combination for domestic reuse. Greywater and rainwater have first been characterised in order to evaluate the treatment necessary. A computer model is being written to design and optimise the system in terms of storage volumes required. Finally a combined reuse system will be installed in a domestic dwelling in Nottingham for a trial period of 4-6 months in order to assess the economic and social issues in-situ. Samples of the greywater and rainwater inflow and outflow will be collected and analysed on a regular basis. Treatment options will also be assessed by considering filtration, aeration and disinfection, with tests of all three carried out in-situ. Results should be available in 1999.

The main design problem to be overcome is likely to concern the achievement of appropriate water quality. As storage of the water is inevitable, a study will be carried out to examine deterioration in the quality of greywater diluted with various proportions of rainwater. The impact of environmental conditions such as light levels and temperature on the water mixture will be assessed. The aim is to establish the optimal proportion of greywater to rainwater, in order to minimise the degree of treatment required.

The simplest final system design would be the collection of greywater and rainwater in a common storage vessel. However, in order to produce optimal dilution levels between the two types of water, a more efficient system might employ either a split tank or two separate tanks, one for rainwater and one for greywater, between which water could be transferred.

An initial schematic of a theoretical combined system, from this research project, is shown below:

Figure 8: Schematic of Combined Greywater/Rainwater System [43]



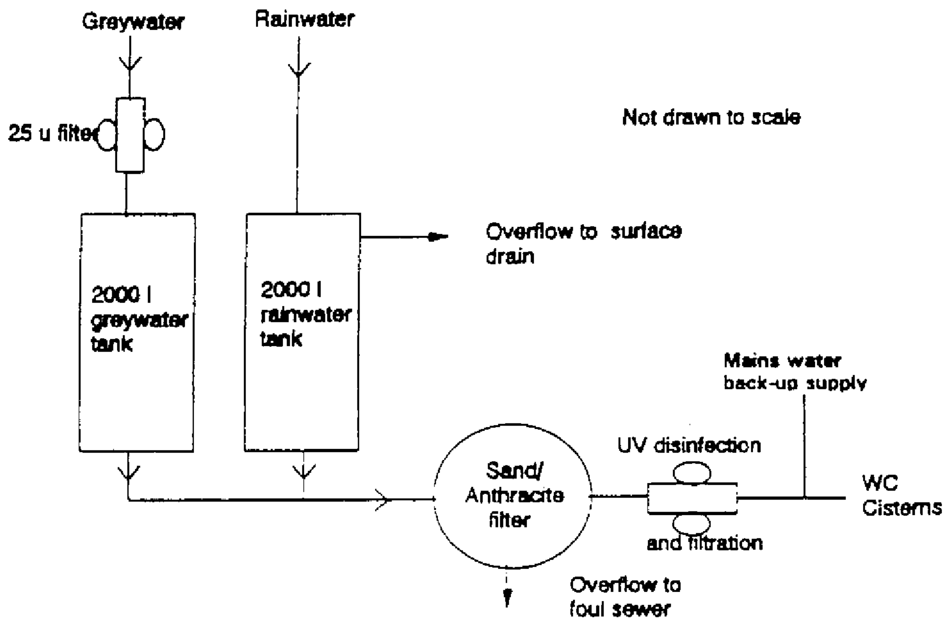
2.4.1 Examples of Combined Systems

Devon and Cornwall Housing Association, following advice from BSRIA, is currently in the process of installing various combined water recycling systems on a new housing development of seventeen homes [44]. A proprietary greywater recycling system will be used to flush toilets and a rainwater utilisation system will provide water for bathing and washing. Mains water provides a potable supply and general back-up. BSRIA are closely following the progress of this project, and are particularly interested in the acceptability of the systems to residents.

A combined system has been installed in a university hall of residence at Linacre College, Oxford. This system initially collected the different waters in two separate underground sumps which kept the rainwater and greywater separate. The greywater was passed through a 25 micron filter to remove larger particulates such as hair or dirt. It was then mixed with rainwater and passed through a sand/anthracite filter to extract finer particulates.

There were no chemical treatments in the system and the disinfection was by UV. Unfortunately, however, severe water quality problems were experienced, due to the fact that greywater was stored in an untreated state for extended periods of time. The system is currently being redesigned to avoid this problem.

Figure 9: Diagram of Original Linacre College Combined System [45]



3. WATER QUALITY AND CONDITIONS OF USE FOR SYSTEMS

3.1 INTRODUCTION

The primary concern when considering the widescale use of recycled greywater and stored rainwater is the potential risk to human health resulting from the presence of pathogenic micro-organisms in such waters.

Such risks are generally somewhat lower when rainwater, rather than greywater, is reused. Rainwater reuse systems collect water from roofs and other hard surfaces, and as the rainwater does not generally come into contact with humans prior to its use, there is less chance that it will contain human pathogens. However, some degree of contamination can occur, with research showing, for example, that coliform bacteria may be present, probably due to the presence of bird faeces on roofs [5]. For some applications, treatment before use may therefore be necessary.

Although by definition greywater does not contain gross faecal contamination, tests have shown that there are sometimes faecal contaminants present. For example, analysis of greywater from the washers, showers and bathroom sinks of different families in the USA, revealed the presence of micro-organisms of faecal origin. Total and faecal coliforms were found to be more abundant in shower and bath water than in laundry water [46].

Storage of rainwater and greywater, particularly if untreated, can allow microbial growth to take place and hence short storage times are recommended. A potential threat might be posed by the proliferation of legionella bacteria in untreated water. However, water quality is only one of the factors which influences the growth of legionella [47] and the overall risk to health would additionally depend on, for example, the type of water treatment, if any, before reuse, and on the degree of human inhalation of and susceptibility to airborne droplets containing legionella. Threats to human health may also arise from the presence of non-biological contaminants in rainwater and greywater. Rainwater collected from roofs sited near roads, for example, may contain contaminants from exhaust fumes. However, unless such water is to be used for drinking, it might be expected that such contaminants would have little direct effect on human health.

As a result of the potential health risks referred to above, many systems incorporate a water treatment process. Different types of rainwater and greywater treatment systems have been described in Chapter 2 of this report. The actual epidemiological risk to health posed by the use of recycled greywater and stored rainwater depends not just on the degree to which the water is contaminated, but also on the degree to which humans are exposed to the water. In certain applications, therefore, such as sub-surface landscape irrigation, in which there is little or no human contact with the water, it can be safe to omit treatment. Concerns about human health have resulted in a number of overseas authorities setting water quality limits specifically for reused water. These are frequently application-specific, and in most cases they have been set based on the reuse of municipal wastewater. Additionally, relevant guidelines and standards on the safe use of systems and on plumbing requirements, have been produced by a number of authorities. In this chapter some of the most important standards and guidelines are described and modified versions are suggested for use in the UK. Information on standards and guidelines from a number of additional countries, including Japan, is contained in the US Environment Protection Agency (EPA)'s manual on guidelines for water reuse [53].

3.2 SELECTED NATIONAL AND INTERNATIONAL GUIDELINES AND STANDARDS

3.2.1 United Kingdom

At present there is no published standard in the UK designed to relate directly to greywater reuse and rainwater supply systems. However, depending on the particular circumstances under which the systems are to operate, a number of Regulations and Acts of Parliament may apply. These are outlined below[1].

3.2.1.1 Water Industry Act 1991

Section 52 of the Water Industry Act 1991 defines the domestic supply duty of water undertakers. In subsection (1) paragraph (a) it is stated that, in relation to any premises, the duty of a water undertaker is:

"(a) to provide to those premises such a supply of water as (so far as those premises are concerned) is sufficient for domestic purposes."

Section 68 defines the duties of water undertakers with respect to water quality and states in subsection (1) paragraph (a) that:

"(1) It shall be the duty of a water undertaker- (a) when supplying water to any premises for domestic or food production purposes to supply only water which is wholesome at the time of supply."

"Wholesome" is defined in the Water Supply (Water Quality) Regulations 1989 (SI 1989/1147), later amended by the Water Supply (Water Quality) (Amendments) Regulations 1989 (SI 1989/11471/1384) and 1991 (SI 1991/1837). As long as there is a constant supply of water which is within the quality requirements set out in these Regulations (limits for selected parameters are shown in Table 2) then the Water Industry Act will not be infringed.

The Water Industry Act 1991 also contains a number of specific restrictions as to what may be discharged to a public sewer, particularly in separated sewage systems where there are dedicated foul and surface water sewers. Surface water is defined by Section 219(1) of the Water Industry Act 1991 as including 'water from roofs'.

Section 106 (2) b of the Water Industry Act 1991 disallows the discharge of rainwater directly into a foul sewer. However, this should not restrict the use of stored rainwater

[1] Regulations and Acts of Parliament relating specifically to Scotland and Northern Ireland are not included.

in buildings, as once the rainwater has been used for a purpose such as toilet flushing, it is no longer classified as 'surface water' [48].

Table 2: Selected Prescribed Concentrations or Values for Drinking Water Quality contained in the Water Supply (Water Quality) Regulations 1989

Parameters	Units of Measurement	Concentration or Value (maximum unless otherwise stated)
Colour	mg/l Pt/Co scale	20
Turbidity (including suspended solids)	Formazin turbidity units	4
Odour (including hydrogen sulphide)	Dilution number	3 at 25°C
Taste	Dilution number	3 at 25°C
Hydrogen ion	pH value	9.5 5.5 (minimum)
Dry residues	mg/l	1500 (after drying at 180 °C)
Total coliforms	number / 100 ml	0*
Faecal coliforms	number / 100 ml	0
Faecal streptococci	number / 100 ml	0
Sulphite-reducing clostridia	number / 20 ml	≤ 1**
Colony counts	number / 1ml at 22 °C or 37 °C	No significant increase over that normally observed

Note: *See regulation 3(6); **Analysis by multiple tube method

3.2.1.2 The Private Water Supplies Regulations 1991

The Private Water Supplies Regulations 1991 (SI 1991/2790) relate to the quality of water from private supplies for drinking, cooking, washing or food production. The 1991 Regulations were made under the Water Industry Act 1991.

The Regulations set out quality standards that water from private supplies must meet if it is to be used for the purposes listed above. These standards may be relaxed by written authorisation from the local authority under certain circumstances.

3.2.1.3 Bathing Waters (Classification) Regulations 1991

Although there are published water quality standards for drinking water (see Table 2) there is no guidance in the UK on the water quality required for domestic purposes (for example WC flushing) other than those which are directly potable.

One suggestion has been that until specific water quality standards for greywater re-use and stored rainwater supply systems are established in the UK, it is appropriate to use the UK's bathing water quality standards as guidelines (Bathing Waters (Classification) Regulations 1991 (SI 1991/1597); see Table 3). These are less stringent than the standards required for potable use and are designed for a situation in which there is physical contact with water and in which there may be occasional accidental ingestion.

Table 3: Selected Quality and Sampling Requirements contained in the Bathing Waters (Classification) Regulations 1991 (SI 1991/1597)

Parameter	Parametric value	Minimum sampling frequency
Micro-biological:		
Total coliforms	10,000 / 100ml	Fortnightly *(see Note 1)*
Faecal coliforms	2,000 / 100ml	Fortnightly *(see Note 1)*
Salmonella	Absent in 1 litre	*(see Note 2)*
Entero viruses	No plaque forming units in 10 litres	*(see Note 2)*
Physico-chemical:		
pH	6 to 9	*(see Note 2)*

Notes

1. Samples may be taken at intervals of four weeks where samples taken in previous years show that the waters are of an appreciably higher standard than that required for the classification in question and the quality of the waters has not subsequently deteriorated and is unlikely to do so.

2. Samples must be taken in relation to this parameter when there are grounds for suspecting that there has been a deterioration in the quality of the waters or the substance is likely to be present in the waters.

3. For details of methods of analysis and inspection, and for sampling requirements and classification criteria, see the Bathing Waters (Classification) Regulations 1991 in full.

3.2.1.4 Water Byelaws

Any connection of a mains water supply to a storage tank which may contain greywater or rainwater must comply with the Water Byelaws of the water supplier, in order to prevent contamination of the mains water supply. The Water Byelaws of the water undertakers in England and Wales derive from and are identical to the 1986 Model Water Byelaws published by DoE [39]. The Water Byelaws apply where a private water supply is used as an alternative to a mains water supply. The Water Companies have a statutory duty to enforce their byelaws. Several byelaws affect the use of greywater recycling and rainwater collection.

1. In order to protect the water supply system from backflow of potentially contaminated water, byelaw 12 requires that:

   "(1) No supply or distributing pipe which conveys, or cistern which receives, water supplied for domestic purposes shall be connected so that it can convey or receive water supplied for non-domestic purposes.

   (2) Paragraph (1) shall not apply to a cistern, or to any pipe conveying water from such a cistern to a point of use if water is discharged into that cistern through a Type A air gap."

   In addition, byelaw 25 contains general requirements for protection against back-flow risk at every point of use or draw-off which is supplied with water for domestic purposes.

2. In order to prevent the contamination of stored water, byelaw 30 requires that:

"(1) Every storage cistern for water supplied for domestic purposes, shall:

(a) be installed in a place or position which will prevent the entry into that cistern of surface or ground water, foul water, or water which is otherwise unfit for human consumption; and

(b) comply with paragraph (2).

(2) Every cistern of a kind mentioned in paragraph (1) shall-

(a) be insulated against heat and frost; and

(b) when it is made of a material which will, or is likely to, contaminate stored water, be lined or coated with an impermeable material designed to prevent such contamination; and

(c) have a rigid, close fitting and securely fixed cover which-
(i) is not airtight,
(ii) excludes light and insects from the cistern,
(iii) is made of a material or materials which do not shatter or fragment when broken and which will not contaminate any water which condenses on its underside,
(iv) in the case of a cistern storing more than 1000 litres of water, is constructed so that the cistern may be inspected and cleansed without having to be wholly uncovered, and
(v) is made to fit closely around any vent or expansion pipe installed to convey water into the cistern."

and byelaw 31 requires that:

"Every storage cistern shall be installed in a place or position such that -
(a) the inside may be readily inspected and cleansed; and
(b) any float-operated valve or other device used for controlling the inflow of water may be readily installed, repaired, renewed or adjusted" [2]

3. Byelaw 38 requires that to minimise contamination of the stored water :

"(1)Every storage cistern which has a capacity exceeding 1000 litres shall, subject to paragraph (2), be fitted with an overflow pipe and a warning pipe, and every other storage cistern shall be fitted with a warning pipe only.

(2) Paragraph (1) shall not apply to require the fitting of both an overflow pipe and warning pipe where -

[2] This is accepted as being satisfied where a storage cistern has an unobstructed space above it of not less than 350mm

(a) *in the case of a storage cistern with the capacity exceeding 5000 litres but not exceeding 10,000 litres, that cistern is fitted with an instrument which indicates when the water level is not less than 25mm below the overflowing level of the lowest pipe; or*

(b) *in the case of a storage cistern with a capacity exceeding 10,000 litres, that cistern is fitted with an audible or visual alarm operating independently of the valve or device which controls the inflow of water and indicates when the cistern is about to overflow."*

Byelaw 7 regulates the types of material that may be used in the construction or installation of pipes or water fittings which convey or receive water supplied for domestic purposes, in order to minimise contamination of the water. Compliance with BS 6920 [49] is deemed to satisfy byelaw 7. BS 6920 specifies the detailed requirements for the suitability of non-metallic products, with regard to their effect on the quality of the water. Included amongst these is the requirement that the material should be deemed not to support appreciable microbial growth, a factor which is of particular importance in the design of greywater reuse and rainwater supply systems.

3.2.2 World Health Organisation

In 1989 the World Health Organisation (WHO) published "Health guidelines for the use of wastewater in agriculture and aquaculture" [50].

The water quality guidelines for wastewater use in agriculture, contained in the WHO (1989) guidelines, are reproduced below as Table 4. Due to the lack of experimental and field data on the health effects of sewage-fertilised aquaculture, only a tentative bacterial guideline of a geometric mean number of faecal coliforms of $\leq 10^3$ per 100ml was recommended for fish-pond water.

In formulating the 1989 guidelines, WHO moved away from what it described as a "zero risk" concept, which had been adopted in earlier standards such as the extremely strict Californian standards for effluent reuse [54]. This was because WHO believed that a number of new epidemiological studies showed that the actual risk associated with irrigation with treated wastewater was actually much lower than previously estimated.

If the WHO's 1989 guidelines were to be applied to greywater re-use and stored rainwater supply systems, the following points must be considered :

1. The guidelines are particularly demanding on permitted concentrations of helminth eggs, as it was realised that these were the main actual public health risk associated with wastewater irrigation in those areas of the world, particularly tropical developing countries, where helminthic diseases are endemic [51]. However, such a consideration is likely to be unimportant in the UK, where the prevalence of helminthic diseases in the human population is extremely low.

2. When formulating the guidelines, account was taken of the fact that when wastewater is used for irrigation, the natural rate at which pathogens die-off in the field constitutes a valuable additional safety factor in reducing potential health risks. Pathogen inactivation takes place by ultraviolet irradiation, by desiccation and by natural biological predators. In most cases, such processes would not take place in greywater re-use and stored rainwater supply systems and indeed there is the potential for the "re-growth" of certain pathogens within these systems.

3. For many greywater re-use and stored rainwater supply systems the criteria shown for Category A reuse conditions (Table 4) would be of most relevance, as these were formulated to take into account contact by the public with areas to which wastewater has been applied.

Table 4: Microbiological Quality Guidelines for Wastewater Use in Agriculture Recommended by WHO (1989)[a, 50]

Category	Reuse conditions	Exposed group	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100 ml[c])	Wastewater treatment expected to achieve required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	≤ 1	≤ 1000[d]	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤ 1	No standard recommended	Retention in stabilisation ponds for 8 - 10 days or equivalent helminth and faecal coliform removal
C	Localised irrigation of crops in category B if exposure of workers & the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

Notes

[a]In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and the guidelines modified accordingly.

[b]*Ascaris* and *Trichuris* species and hookworms.

[c]During the irrigation period.

[d]A more stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

[e]In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

3.2.3 USA

An overview of water reclamation and reuse criteria in the US has been given by Crook and Surampalli (1996) [52] and details of the guidelines and standards adopted by the different States have been published by the US Environmental Protection Agency (1992) [53].

In the US, regulations concerning water reuse are made by individual states, as there are no relevant federal regulations. This has resulted in differing standards among the states that have developed criteria. Additionally, although uniform codes exist, individual US states have separate plumbing laws that the County and City regulatory authorities administer. In 1989, the Santa Barbara County Board in California became the first US authority to make residential greywater reuse legal [59] and a permitted option under the State Uniform Building Code. Subsequently, greywater guidelines have been included in the Uniform Plumbing Code (UPC), to which the 22 western states of the USA administer their plumbing (they were included as Appendix W and later as Appendix G).

In 1968 California was the first state to introduce standards for water reclamation and reuse [54]. These were designed to control the use of reclaimed water in agriculture. They have been updated and extended several times. Subsequently, other states have introduced regulations or guidelines, although not all have done so and no state has regulations which cover all potential uses of reclaimed water. In California and Florida, the legislative scope has been expanded to mandating water reuse under certain conditions, in which the use of potable water is unnecessary. These states also have active reuse programmes and comprehensive regulations that prescribe requirements according to the end use of water.

In 1992 the US Environmental Protection Agency [53] published guidelines to assist states that have not yet developed their own criteria or guidelines. Also, although not yet accepted throughout the USA, a standard has been produced by NSF International (formerly the National Sanitation Foundation), last revised in 1983 and currently being revised again, regulating the minimum water quality for recycled wastewater [55].

Details of the most important regulations and guidelines from the USA follow in subsequent pages.

3.2.3.1 EPA Guidelines

The guidelines suggested by the EPA (Environmental Protection Agency) [53] are based on eleven categories of reuse:

1. Urban Reuse

2. Restricted Access Area Irrigation

3. Agricultural Reuse - Food Crops
   - Food crops not commercially processed
   - Commercially processed food crops and surface irrigation of orchards and vineyards

4. Agricultural Reuse - Non Food Crops
   - Pasture for milking animals and fodder, fiber, and seed crops

5. Recreational Impoundments

6. Landscape Impoundments

7. Construction Uses

8. Industrial Reuse

9. Environmental Reuse

10. Groundwater Recharge
    - Spreading or injection into non-potable aquifer

11. Indirect Potable Reuse
    - Spreading into potable aquifer
    - Injection into potable aquifer
    - Augmentation of surface supplies

Of these, category 1 is of greatest relevance to greywater re-use and rainwater supply systems, and in certain cases categories 3 (food crops not commercially processed only), 5 and 6 may also be applicable. The suggested guidelines for these categories are reproduced in Table 5 below.

Table 5: Guidelines Suggested by the US EPA for Water Reuse [a]

Types of Reuse	Treatment	Reclaimed Water Quality[1]	Reclaimed Water Monitoring	Setback Distances	Comments
1. Urban Reuse All types of landscape irrigation. (e.g., golf courses, parks, cemeteries) - also vehicle washing, toilet flushing, use in fire protection systems and commercial airconditioners, and other uses with similar access or exposure to the water	• Secondary • Filtration • Disinfection	• pH = 6 - 9 • ≤ 10 mg/l BOD[2] • ≤ 2 NTU • No detectable faecal coli/100ml[3,4] • 1 mg/l Cl_2 residual (min.)[5]	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• See full EPA manual for other recommended limits. • At controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water, a lower level of treatment, e.g., secondary treatment and disinfection to achieve ≤ 14 faecal coli/100 ml, may be appropriate. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. • Reclaimed water should be clear, odourless, and contain no substances that are toxic upon ingestion. • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • A chlorine residual of 0.5 mg/l or greater in the distribution system is recommended to reduce odours, slime and bacterial regrowth. • See full EPA manual for recommended treatment reliability.
3 Agricultural Reuse - Food Crops Not Commercially Processed[4] Surface or spray irrigation of any food crop, including crops eaten raw.	• Secondary • Filtration • Disinfection	• pH = 6-9 • ≤ 10 mg/l BOD[2] • ≤ 2 NTU • No detectable faecal coli/100 ml[3,4] • 1 mg/l Cl_2 residual (min.)[5]	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• See full EPA manual for other recommended limits. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • High nutrient levels may adversely affect some crops during certain growth stages. • See full EPA manual for recommended treatment reliability.
5 Recreational Impoundments Incidental contact (e.g., fishing and boating) and full body contact with reclaimed water allowed	• Secondary • Filtration • Disinfection	• pH = 6-9 • ≤ 10 mg/l BOD[2] • ≤ 2 NTU • No detectable faecal coli/100ml[3,4] • 1 mg/l Cl_2 residual (min.)[5]	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	• Dechlorination may be necesaary to protect aquatic species of flora and fauna. • Reclaimed water should be non-irritating to skin and eyes • Reclaimed water should be clear, odourless, and contain no substances that are toxic upon ingestion. • Nutrient removal may be necessary to avoid algae growth in impoundments. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • Fish caught in impoundments can be consumed. • See full EPA manual for recommended treatment reliability.
6 Landscape Impoundments Aesthetic impoundment where public contact with reclaimed water is not allowed	• Secondary • Disinfection	• ≤ 30 mg/l BOD[2] • ≤ 30 mg/l SS • ≤ 200 faecal coli/100 ml[3,6] • 1 mg/l Cl_2 residual (min.)[5]	• pH - weekly • SS - daily • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	• Nutrient removal processes may be necessary to avoid algae growth in impoundments. • Dechlorination may be necessary to protect aquatic species of flora and fauna. • See full EPA manual for recommended treatment reliability.

Notes to Table 5

[a] Unless otherwise noted, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility.

[b] As determined from the 5-day BOD test.

[c] Unless otherwise noted, recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. Either the membrane filter or fermentation tube technique may be used.

[d] The number of faecal coliform organisms should not exceed 14/100 ml in any sample.

[e] Total chlorine residual after a minimum contact time of 30 minutes

[f] The number of faecal coliform organisms should not exceed 800/100 ml in any sample.

Some of the notes given in the original table from which this has been reproduced have been omitted for reasons of brevity.

3.2.3.2 National Sanitation Foundation International, Standard 41

NSF International, Standard 41[55] covers wastewater recycle/reuse and water conservation devices, intended for processing blackwater and greywater wastes from plumbing fixtures and appliances in places of human occupancy, for uses such as toilet flushing. The standard is currently under revision, with expected completion near the end of 1997. The revision process will result in the division of the two primary technologies currently covered by the standard. As a result, water conservation devices will continue to be covered in the revised Standard 41 while recycle/reuse devices will be covered in a separate publication, Standard 45.

The current Standard 41 lays out minimum requirements for :

- materials
- design and construction
- performance
- operation and maintenance

Section 6.5 of the standard states that recycled fluid from wastewater recycle/reuse devices under test should comply with the following:

"6.5.1 START UP: Data shall be recorded in report, but not used to determine compliance.

6.5.2 STRESSING: The device shall recover to levels in Item 6.4.3 [this is apparently a misprint and should read 6.5.3] *for total coliforms and odour in 48 hours, and turbidity and BOD_5 (if applicable) in seven days.*

6.5.3 PRELIMINARY ROUTINE OPERATION: The device shall meet the following requirements: total coliforms $\leq 240/100$ mL; turbidity ≤ 90 TU; BOD_5 ≤ 45 mg/L as 7-day running average, and ≤ 30 mg/L as 30-day running average; odour non-offensive; oily film not visible; and foam not in contact with user of recycled fluid.

NOTES:

- *The specified value for any parameter shall not be exceeded in more than 10 percent of samples.*

- *Running averages shall be determined by sampling days.*

6.5.4 COLOUR: Any discernible changes in colour shall be reported, but shall not be used to determine compliance.

6.5.5 FLASH POINT: Non-aqueous recycle fluid shall have a minimum flash point of 200 ^{o}F (93.3 ^{o}C) as determined by the Cleveland Open Cup Method, and shall not be readily ignitable by objects typically thrown into it.*

6.5.6 TOXICITY SPECIFICATIONS: Compliance with Toxicity Category IV shall be required for all tests:

Oral LD_{50}	*> 5,000 mg/kg*
Eye Effects	*No Irritation*
Skin Effects	*Mild or Slight Irritation at 72 hours*
Dermal LD_{50}	*> 20,000 mg/kg*
Inhalation LC_{50}	*> 20 mg/L"*

(* this paragraph is therefore not relevant to systems considered in this report)

3.2.3.3 Californian and Florida Legislation

Summarised versions of the treatment and quality criteria for water reclamation and reuse which apply in California and Florida, are given in Appendix A2 of this report. The criteria are in general similar to those published by the US EPA (see Table 5). Thus both the EPA and Florida criteria state that for end-uses such as toilet and urinal flushing there should be no detectable faecal coliforms/100 mL, with the Californian criteria allowing a total coliform limit of 2.2/100 mL.

In addition to legislation covering treatment and quality aspects, California was the first State to develop plumbing code standards to permit installation of residential greywater systems, modelled on Appendix G of the Uniform Plumbing Code (UPC). This standard is known as Appendix J of the California Plumbing Code (CPC) [28] and is included as Appendix A3 of this report. Both Appendix G of the UPC and Appendix J of the CPC restrict greywater reuse to single family residential occupancies in which untreated greywater is used for subsurface irrigation.

3.2.4 Australia

The full range of issues surrounding wastewater reuse and stormwater management are currently under review in Australia[56, 57]. The first steps towards residential water recycling were taken with the publication of the non-statutory New South Wales Guidelines for Urban and Residential Use of Reclaimed Water in 1993. These Guidelines cover use of reclaimed water for non-potable uses including toilet flushing, garden watering and car washing[58]. In March 1996, general guidelines for domestic greywater reuse for Australia were published by the Urban Water Research Association of Australia (UWRAA) [29]. This followed on from publication of a report by UWRAA in 1994, which examined the applicability of domestic greywater reuse to Australia and took into account overseas practices [59]. However, for the application of on-site domestic greywater re-use for lawn and garden watering to be permitted in areas with municipal sewers, Australian state legislation will first have to be amended, as this practice is currently illegal [29].

The 1996 guidelines set out the requirements for the design and installation of domestic greywater re-use systems for premises connected to municipal sewers and apply to new installations as well as alterations, additions and repairs to existing installations. Only three types of system are covered by the guidelines, all others being considered inappropriate for use, primarily due to the perceived health risks with which they are associated. The three approved types are defined as follows:

"*a. Hand Basin Toilets - these incorporate a hand basin in the top of the cistern with a spout for hand washing which operates automatically when the toilet flushes, simultaneously refilling the cistern while allowing for hand washing.*

b. Primary Greywater Systems (PGS) - these directly re-use untreated domestic greywater from a single family home for sub-surface lawn and ornamental garden watering. These systems do not allow storage or treatment, apart from a coarse screen filter which removes lint, hair and coarse particles. To prevent human contact with untreated greywater, the following sub-surface watering techniques are specified as the only recommended method of re-use:

- *sub-surface drip irrigation*
- *sub-surface trickle irrigation.*

c. Secondary Greywater Systems (SGS) - these are any systems that re-use domestic greywater that can not be categorised as either Hand Basin Toilets or Primary Greywater Systems (PGS). Secondary greywater systems may be used for multiple occupancy dwellings. Short term storage to facilitate filtration prior to drip irrigation is acceptable where the stored greywater does not present a health risk or cause nuisance. The method of re-use is for the purposes of lawn and ornamental garden watering using sub-surface watering techniques as specified for primary greywater re-use systems."

Systems, other than hand basin toilets, that employ greywater for toilet flushing, and which use only coarse screening and disinfection, were not included in the guidelines, because toilet and urinal flushing water cannot be totally separated from human contact. It was perceived that health risks do exist with the potential for splashing of flush water onto the genitals and from aerosols formed during flushing. Hand basin toilets, however, were not thought to pose the same microbial health concerns, as it was assumed that pollutants transferred to a cistern after hand washing would be minimal, and any health risks would be of no greater level than those associated with ordinary toilet use. Such hand basin toilets are widely used in Japan.

3.2.5 Germany

The use of rainwater supply systems in Germany is becoming increasingly widespread[60], with several firms now offering compact off-the-shelf rainwater use systems [61]. There has also been uptake, to a lesser extent, of greywater reuse technology, usually involving the installation of 'DIY' and customised design systems. As in the UK, there has to date been no specific rulings nor specific standards relating to rainwater and greywater reuse facilities[60]. Therefore, equivalent German technical regulations, such as DIN 1988, DIN 1986 and the ATV (General Technical Regulations) sheets are applied [60]. The relevant requirements of DIN 1988 in respect to rainwater utilisation facilities have been summarised in a recent journal article[61], the relevant sections of which have been translated into English and included in Appendix A4 of this report. In general, the German requirements are very similar to those that apply in the UK (see Section 3.2.1), including, for example, a requirement for the inclusion of air gaps to prevent cross-contamination of potable supplies. There appears to be increasing support in Germany, however, for an independent ruling to be devised for such installations[60].

In Bavaria, a set of technical guidelines for rainwater utilisation were developed in 1992[62], intended to supplement the technical regulations. These included the following recommendations:

- the use of greywater must be rejected due to risks to hygiene and poorly developed technology;
- using rainwater outside buildings for garden watering is to be recommended;
- internal uses of rainwater must only include toilet flushing;
- rainwater must not be used in old people's homes, hospitals and establishments with children;
- existing regulations are sufficient for technical purposes (i.e. DIN 1988);
- separate drains must be used in case a blockage leads to rainwater backing up into the drinking water supply;
- involvement of health authorities is not necessary;
- risks of subsequent installations causing cross-connections must be avoided;

- other methods of water conservation must also be considered;
- it must be possible to access equipment and check it after installation;
- extreme care must be taken to avoid confusion between the water systems, in particular to protect children. Suggestions include meticulous labelling and warning signs such as "Not Drinking Water" and a general sign in the dwelling "Attention ! This house also has a rainwater system". A special key to turn on the water, or taps well above the reach of children are other options.

Opinion in Germany appears to be divided concerning the potential risks to public health associated with the use of recycled greywater and stored rainwater. Use of the former seems to be most controversial, with a number of authors recommending that it should not take place [62, 63]. Use of rainwater has gained much greater acceptance, particularly amongst certain State authorities [60], although there are still those that argue against its use on public health grounds [64]. The arguments in Germany for and against rainwater utilisation, from the standpoint of hygiene, have been summarised in a recent article by Hollander [65], which is too extensive to reproduce here.

3.3 WATER QUALITY CRITERIA MOST APPROPRIATE FOR PRINCIPAL UK APPLICATIONS

Water quality is an important factor to consider when assessing the possible implications for public health of using recycled greywater and stored rainwater. Rainwater and greywater may also adversely affect plumbing systems and the wider environment, as discussed in Chapter 4.

As described in Section 3.2, there are as yet no published water quality criteria in the UK that apply specifically to rainwater and greywater systems. In their absence, it has often been assumed that recycled water should be treated to either potable or bathing water standards. This ambiguity is a matter of concern both to the developers and manufacturers of systems and to those with responsibility for safeguarding public health.

Where specific criteria relating to wastewater reuse have been developed in other countries, and by WHO, these have frequently been application specific and based on the level to which the human population is likely to be exposed to the recycled wastewater. It would seem logical, when proposing criteria for the UK, for these to be similarly based. With reference to the reuse categories used by WHO and by authorities in the USA (see Section 3.2 above), and taking into account the particular circumstances existing in the UK and the differences between greywater and rainwater reuse, it is suggested that UK applications are categorised as shown in Table 6.

Of the existing water quality criteria that have been considered in Section 3.2, those listed below are of relevance to the applications listed in Table 6.

Category of Use 1
Water should be of potable quality, hence the water quality criteria defining wholesome water in the UK's Water Supply (Water Quality) Regulations 1989 (SI 1989/1147) (reproduced in part in Table 2), and as amended in 1991, are relevant.

Category of Use 2
Water quality criteria produced by the US EPA for "Urban Reuse" (Table 5), by WHO for "Category A" agricultural reuse (Table 4), by the States of California and Florida for uses including toilet flushing (Appendix A2), by NSF International for recycle/reuse devices for toilet flushing (see Section 3.2) and by the UK Government for bathing water (reproduced in part in Table 3) are relevant.

Category of Use 3
No water quality criteria required, as there is a very low likelihood of human contact with the water and/or negligible epidemiological risks.

It is proposed that the application-specific water quality criteria shown in Table 6 would be appropriate for use in the UK, based on an assessment of the published guidelines and standards listed above. As is the case with the WHO guidelines for wastewater use in agriculture (Table 4), the proposed water quality criteria have been formulated from the standpoint of protecting public health and so provide limits for faecal coliform concentrations in reused water. Limits for Categories of Use 1 and 2 have been set at the lowest (i.e. safest) level used in overseas standards (i.e. no faecal coliforms detectable). Additionally for Category of Use 1, as there is either the intention, or risk, that the reused water will be consumed, it must fully conform, in terms of quality, to the UK Water Supply (Water Quality) Regulations 1989 (and as amended in 1991). No water quality requirements are given for Category of Use 3, however, as the degree of human exposure to the reused water is very low and/or the epidemiological risks are negligible.

Due to the high diversity of greywater reuse and stored rainwater supply systems available, and the range of different situations in which these may be employed, parameters such as turbidity, BOD and pH have not been included in the proposed water quality criteria. This is because it is considered that elevated levels of these parameters cause adverse effects only under certain circumstances. For example, in systems which ensure that greywater is reused within a few hours for toilet flushing, a high level of BOD in the reused water will probably be inconsequential, as there is insufficient time for significant organic decomposition to occur that would lead to problems with odour. Also, if disinfection systems are appropriately designed, effective disinfection of water with a relatively high level of turbidity is possible. In place of standards for these parameters, relevant means to protect plumbing systems and the environment and additional mechanisms to ensure health and safety are incorporated into the design and use requirements detailed in Section 3.4 and Section 4.5 of this report.

It is suggested that the minimal risks involved do not warrant water quality monitoring on every individual greywater reuse or rainwater supply system installed in the UK. Instead, a scheme should be devised by which different system types are comprehensively tested by a recognised test-house before use is permitted. Tests should be devised, similar to those produced by NSF International for wastewater recycle/reuse and water conservation devices [55], that are application specific (i.e. accreditation would be for Category of Use 1, 2 or 3). Once a manufactured system received such accreditation, it could be sold, and installed on premises by a qualified and specially trained plumber, without further testing or water quality monitoring. Certain 'DIY' designs could also receive such accreditation. Such an approach to water quality control is based on the recommendations of WHO [50]. This approach can also be justified in view of the fact that blackwater (i.e. that containing gross faecal contamination) is not being treated by such systems, and thus the potential dangers associated with system malfunction are reduced. The fact that greywater is of domestic (non-process) origin also means that, for Categories of Use 2 and 3, it is unnecessary to set water quality standards for toxic substances such as heavy metals and pesticides. However, instructions should be supplied with greywater recycling systems to ensure that users know that such substances, should they be used in the home, must be disposed of correctly and must not, for example, be discharged into kitchen sinks.

Table 6: Proposed Water Quality Criteria for Recycled Greywater and Stored Rainwater in the UK[a]

Category of Use	Type of Use: Greywater and Combined Greywater / Rainwater Reuse Systems	Type of Use: Stored Rainwater Supply Systems	Magnitude of human exposure and/or potential epidemiological risk if water was reused without treatment	Faecal coliform limits (count / 100ml)[b]	Other water quality criteria that apply
1[c]	Drinking, cooking, bathing, irrigation of crops to be eaten uncooked	Drinking, cooking, bathing	High	None detectable	Standards contained in the UK Water Supply (Water Quality) Regulations 1989, as amended in 1991
2[d]	Toilet flushing (hand-basin toilets excepted), vehicle washing, clothes washing, surface landscape irrigation, irrigation of crops to be eaten cooked, impoundments, use in fire protection systems and commercial air conditioners	Toilet flushing, clothes washing, use in commercial air conditioners	Medium	None detectable	None
3[e]	Sub-surface landscape irrigation, hand-basin toilets[f]	Vehicle washing, surface and sub-surface landscape irrigation, irrigation of crops to be eaten cooked and uncooked, impoundments, use in fire protection systems	Low	Not applicable	None

Notes

[a]Criteria proposed by BSRIA

[b]Recommended quality limits apply to the reclaimed water at the point of discharge from the system, prior to reuse, under routine operation of the system. Stored rainwater supply systems are to be tested using rainwater collected at the test site. Greywater and combined greywater/rainwater reuse systems are to be tested using simulated greywater including a known content of an identifiable faecal coliform organism. It is equally acceptable for faecal coliform removal efficiency to be assessed using artificial greywater including a known concentration of an identifiable general coliform organism.

[c]The limit for Category of Use 1 is taken from the UK Water Supply (Water Quality) Regulations 1989 (and as amended in 1991). Sampling requirements and methods of analysis should be based on those already in use for testing drinking water.
[d]For Category of Use 2, the test procedure must involve the daily collection of a test sample, from Monday to Friday, for a period of eight weeks. Faecal coliforms must not be detected in more than 10% of samples and in no sample should the number of faecal coliforms exceed 14/100ml. Analysis should be conducted using methods and procedures recommended and described in the Standing Committee of Analysts' series of monographs on *Methods for the Examination of Waters and Associated Materials*[66] published by HMSO, in particular in the monograph *The Microbiology of Water 1994 Part 1 - Drinking Water*[67].
[e]Water quality testing is not required for Category of Use 3.
[f]Hand-basin toilets are placed under Category of Use 3 because although the level of human exposure to reused water may be similar to that which occurs with other recycled water flushing systems, the source of the water is from hand washing alone and this type of toilet has been used in Japan on a wide scale, with no known detrimental effect on public health [59].

3.4 RECOMMENDED HEALTH AND SAFETY REQUIREMENTS FOR THE UK

Listed below are generalised health and safety requirements that it is suggested should apply to all greywater reuse and rainwater supply systems used in the UK. Except as otherwise provided for in these requirements, the legal provisions already in place in the UK will apply and suffice (see Section 3.2.1). Although the majority of requirements apply primarily to designers, manufacturers, suppliers and installers of systems, a number are inevitably the responsibility of system users.

The recent Australian guidelines for domestic greywater reuse [29] contain similar requirements. However, not all of the Australian requirements have been incorporated as it is considered that they may be more restrictive than is necessary for UK conditions. Instead, the approach has been taken that different systems and end-uses of greywater and rainwater should each be considered on their merits, following rigorous testing and appraisal. This means, however, that a wide range of applications are possible, thus making the production of detailed, application-specific conditions of use for systems, inappropriate at this point.

Health and Safety Requirements for Greywater Reuse and Stored Rainwater Supply

To minimise health risks from pathogenic micro-organisms, the following requirements are considered necessary:

- All gross faecally contaminated waste, such as that from WCs and bidets, must pass directly to the sanitary sewer system.
- Greywater or rainwater must not contaminate any domestic potable water supply or be discharged directly into or reach any stormwater drainage system or waterway.
- Regulatory anti backflow devices (as required by the UK Water Byelaws) must be installed on the potable water service to the property and at other critical points on the premises.

- Where potable water is used for back-up supplies to greywater or rainwater storage vessels, a type A air gap must be provided for backflow protection. An overflow to sewer must be incorporated into these vessels to ensure the integrity of the air gap.

- Colour coding and labelling must be used to identify the contents of pipe work, valves and fittings.

- At any point where human contact with reused greywater or rainwater may occur, such as at a tap from which it is supplied, a clear warning sign must be in place. Under circumstances in which this measure may be inadequate to prevent inappropriate use, additional precautions should be taken, such as the application of a coloured dye to the reused water, to avoid confusion with potable supplies, or the placement of locks on supply points, to prevent use by unauthorised individuals.

- Greywater reuse systems must not include laundry water that is likely to contain gross faecal contamination (e.g. from soiled nappies) or any wastewater resulting from the bathing of animals (e.g. family pets).

- Greywater reuse systems should in general not include water from kitchen sinks, dishwashers and waste disposal units.

- Systems must be designed to minimise the potential for the growth of micro-organisms in stored greywater or rainwater. Cool conditions should be maintained, where possible below 20 °C, and the period of storage should be minimised. Untreated greywater should not be stored for longer than 48 hours.

- Systems must be designed in such a manner that inadequately serviced systems will not compromise public health and so that systems have user friendly operation and simple routine service requirements.

- Systems must be supplied with a full and clearly worded set of safety instructions.

- Systems must only be used in applications for which they have been specifically designed and tested.

4. ASSESSMENT OF POSSIBLE DELETERIOUS EFFECTS AND RESTRICTIONS OF USE

4.1 INTRODUCTION

The possible deleterious effects of using recycled greywater and stored rainwater can be characterised in three ways; those which impact on human health; those which impact on plumbing systems; and those which impact on the external environment as a whole. The first of these categories has been dealt with in Chapter 3. The latter two are considered below.

4.2 SYSTEMS

The reuse of rainwater and greywater can have adverse effects on existing plumbing systems and on reuse systems themselves. There are four main areas of concern; growth of micro-organisms (closely linked to health and hygiene concerns - see Chapter 3); corrosion of metals; scaling; and fouling or sedimentation.

4.2.1 Growth of Micro-Organisms

Micro-organisms such as bacteria, algae, fungi and protozoa can colonise and proliferate in water systems. Their presence can cause blockage of pipes and a reduction in efficiency, as well as problems associated with corrosion and health and safety. Of these micro-organisms, bacteria are probably of most concern in greywater and rainwater systems, as they present the greatest health risk.

Although bacteria can proliferate in all water systems, particular features of recycling systems may exacerbate the problem. Bacteria flourish at temperatures between 20-45°C, with optimum growth at 37°C [68]. In some water systems it is possible to minimise microbial growth by maintaining water temperatures above 60°C, which kills the majority of species. However, maintaining temperatures at this level may not be easy to achieve or desirable in recycling systems, as the water that they contain is frequently only intended for purposes, such as irrigation or toilet flushing, that do not require the water ever to be at such elevated temperatures.

Rainwater should be stored in cool conditions, such as occur in basements, in order to reduce the temperature of the water [5]. At temperatures below 20°C the number of microbial species that can survive is reduced. In greywater systems, however, water temperatures may be relatively high, due to influxes of warm wastewater, such as that from baths and showers. Storage in cool conditions may therefore not be sufficient to maintain a sufficiently low temperature.

Also, the growth of suspended organisms will be exacerbated in systems where water is stored for significant periods of time. Therefore, it is advisable to restrict the period of storage, and eliminate or reduce to a minimum 'deadlegs' in the system. Most bacteria grow best in water of pH 6.5 - 8.5; the pH range common in most domestic water supply systems [68]. Greywater is generally alkaline due to the soaps and detergents present in the water, and so may be outside this range, although this will be affected to a great extent by the composition of the detergents used. Rainwater may be acidic, and may thus lower the pH to a level unsuitable for bacteria.

Due to these factors, for many applications it is important that recycled water, particularly greywater, is treated to eliminate or reduce the levels of micro-organisms, especially if it is to be stored for any length of time. Possible treatments are described in Chapter 2.

4.2.2 Corrosion of Metals.

Corrosion can be a serious problem in water systems, potentially leading to increased maintenance costs, reductions in efficiency, increased power consumption and increased growth of micro-organisms.

Limitation of corrosion should be considered when designing, installing and maintaining all water systems, not only those for rainwater supply and greywater reuse. The most important consideration in the prevention of corrosion is the use of appropriate materials. Metals should be galvanically compatible or insulated, as should welded seams [68].

The types and combinations of metallic components suitable for inclusion within systems are directly related to the corrosive nature of the water [11]. Factors influencing the corrosive capability of water include the following:

pH	More acidic conditions increase the likelihood of corrosion. This can be of particular importance in rainwater supply systems as, depending on atmospheric conditions, rainwater is often acidic.
Oxygen	In neutral solutions, the rate of corrosion is directly proportional to the oxygen concentration. This may be of importance if aeration of greywater is used to assist aerobic breakdown of organic material, a process which has been recommended by some researchers[69].
Total dissolved solids (TDS)	High levels increase conductivity and therefore promote corrosion [68]. Recycled water frequently contains high levels of TDS.
Chlorides	Can encourage corrosion by breaking down passive oxide films which develop naturally on some metals. Use in systems of chlorides or use of products which break down to form chlorides could be a problem.
Surface condition	Dirty or contaminated surfaces are more susceptible to localised corrosion. The water passing through rainwater and greywater systems is in general more likely to contaminate surfaces than is mains water.
Temperature	Frequent variations in temperature increase the rate of corrosion. In addition, certain metals will corrode preferentially at high temperatures.

It is possible to introduce inhibitors and other chemicals into a system to reduce corrosion. However, in once-through systems such as greywater reuse and rainwater supply systems, this would require continuous and costly dosing with possibly hazardous chemicals. It is therefore best to design systems to limit the occurrence of corrosion. Designs should minimise the use of metal parts liable to corrode and these should be easily accessible for regular checking and replacement. Where metals are used, the characteristics of the water should be considered during material selection. The Institute of Plumbing Services in the UK publish a Design Guide including detailed information on metals and other common system materials, including their corrosion properties [70].

4.2.3 Scaling of the System

Scaling, commonly known as limescale, is caused by the precipitation of calcium salts, often calcium carbonate. Scale can cause problems such as a reduction in efficiency and heat transfer and blockage of pipes leading to reduced water flow. The concentration of scale-forming minerals in greywater is unlikely to be significantly different to that of mains water. Therefore the use of greywater to flush toilets or in other devices prone to damage by scaling should not lead to increased problems. In addition, scale mainly precipitates on heating surfaces, which are not generally present in recycling systems.

In many areas of the UK, rainwater has a lower concentration of scale-forming minerals than mains water; it is 'soft' water. In these areas, it may make economic sense to source water systems prone to scaling (such as evaporative coolers and spray or steam humidifiers) with rainwater. In domestic situations, equipment such as boiler feed water and washing machine feed water could benefit from the use of soft water. This would reduce costs of descaling systems and other costs such as those associated with heating. It is important to note, however, that the precipitation of a small amount of scale is often beneficial, as it can form a protective layer against corrosion.

4.2.4 Fouling or Sedimentation

There are two main types of fouling associated with water systems. Environmental fouling involves materials present as a result of external factors (i.e. substances introduced into the system). Mechanical fouling is caused by system characteristics such as corrosion products, scale and microbiological growths [68]. Deposits can block pipes and mechanisms, reduce efficiency and prevent certain treatment methods from working efficiently.

Although a peripheral problem in conventional water systems, fouling is a major area of concern in the systems considered in this report, in particular those in which greywater is reused. The presence in greywater of soaps, hair, grease and particulate matter increases the likelihood of deposition considerably. They can also cause recycled water to appear turbid and lead to a reduction in aesthetic acceptability.

To reduce these problems it is necessary to filter the water in order to exclude as much as possible of the particulate debris. Rainwater does not normally contain a great deal of particulate matter, although research has shown that the first rain after a prolonged drought may be more contaminated due to dry deposition on the roof. If particulate content is of particular concern it may be beneficial to discard the first rain after a drought for this reason. Under general circumstances however, it is only necessary to filter out leaves and other large debris.

Greywater requires more robust filtration, with some proprietary systems including a two-stage (or more) filtration process. Reduction of the suspended solid load by filtration reduces detrimental effects such as blockages, colonisation by micro-organisms and abrasion. The latter tends to decrease the durability of parts and mechanisms such as pumps.

Removal of suspended solids by filtration also has an effect upon the perceived cleanliness of the system, and thus it's aesthetic acceptability. Yellowish colour toilets have been used in apartment buildings in Japan, in order to mask potential colouring of the bowl by suspended solids and dissolved substances in reclaimed water. A survey of acceptability to people using such systems in Japan was carried out in 1978; 84.5% of people claimed not to have noticed any difference from tap water. With respect to aesthetic qualities such as odour, foam and colour, the overwhelming majority felt that reclaimed water was no different to mains water [71].

It is important, however, to make greywater easily distinguishable from drinking water and this is normally accomplished by the use of a coloured dye (often blue). This may also improve the aesthetic appearance of greywater [72].

4.3 OTHER EQUIPMENT

The use of recycled water can have effects on equipment other than existing plumbing systems and recycling systems themselves. For example, if untreated greywater is used to irrigate land, high levels of particulates could block water outlets, such as those in drip irrigation systems. This may also be a problem if spray irrigation or sprinkler systems are used, although use of this equipment may not be recommended for health reasons to eliminate aerosols.

One potential use of greywater and/or rainwater is the washing of cars and other vehicles. No evidence has been found in the present study to suggest that use of such water would have an adverse effect upon the bodywork of vehicles. However, it must be taken into account that the washing of vehicles with recycled water may necessitate either direct contact with humans (during washing by hand), or the creation of aerosols (during automated washing). Associated risks to health will depend on a number of factors, in particular the degree to which the water is contaminated. If water is reused from previous vehicular washings, such as reuse of rinse water, then health risks are likely to be low. In domestic situations, where greywater has previously been in contact with humans, the risk would be greater.

4.4 ENVIRONMENT

The environmental effects of using greywater re-use and stored rainwater supply systems can be broadly categorised into two groups :

i. 'direct effects' resulting from the particular characteristics of the water within systems;
ii. 'indirect effects' resulting from changes to previous patterns of water usage.

4.4.1 Direct Effects on the Environment

The majority of these effects are most closely associated with greywater rather than rainwater systems, as the water produced by the latter is in general of higher quality, as it is not contaminated with soaps, hair, grease and high levels of particulate matter.

Greywater and rainwater can be used to irrigate land, preferably through sub-surface irrigation systems, which are frequently recommended because they reduce or eliminate human contact with the water and because they reduce water wastage by delivering water directly to the root zone and by reducing evaporation losses [73]. There are a number of potential environmental problems associated with the use of greywater for irrigation. Of foremost concern is the potential for greywater to cause negative health effects due to microbial contamination. Also, if greywater or rainwater is allowed to pool on the surface, it may provide a breeding ground for disease vectors or "nuisance species" with an aquatic stage, such as mosquitoes. If greywater has received little or no treatment and is allowed to pond, there will also be odour problems. Landscape irrigation should be discontinued in heavy rain as the ground will be saturated and greywater may then run along the surface, rather than being absorbed by the ground [26].

Greywater may contain chemicals, for example salts, which although non toxic at the concentrations at which they generally occur, can build up in plants to levels toxic to plants and/or humans if consumed [50]. Salts usually do not present a problem, however, as they are leached away by heavy rain. Care thus needs to be taken concerning the chemicals which enter the greywater system. Also, the irrigation of edible crops with greywater should be controlled. Harmful chemicals present in greywater may enter at source or be added within the re-use system as part of the water treatment process (e.g. hypochlorite used for disinfection).

Irrigation with greywater can have advantages and disadvantages for vegetation. The soaps and detergents present in greywater make it unsuitable for the irrigation of certain plants (those which require acidic conditions), and as previously mentioned, some chemicals can have cumulative toxic effects. Excessive irrigation can lead to soil problems, although this is dependant on the characteristics of the soil. For example, sodium (used in large amounts in water softeners and present in detergents) when applied excessively to clay soils can damage the soil structure and reduce drainage capability. Conversely, phosphates and other nutrients such as potassium, calcium, magnesium and sulphur, present in greywater, act as fertilisers. However, care should be taken not to over water, as some of these nutrients, such as magnesium, can cause soil and/or plant damage if applied excessively [29].

Where greywater is used for irrigation, there is a potential risk of groundwater contamination resulting from the transport of biological and chemical contaminants through the soil. In consequence a precautionary approach has been taken in Appendix J of the California Plumbing Code [28], which relates to the use of greywater for irrigation (see Appendix A3), and states:

'No irrigation point shall be within five vertical feet of the highest known seasonal groundwater, nor where greywater may contaminate the groundwater or ocean water...'

However, existing research suggests that risks, of microbial contamination at least, may be negligible. For example, the results of studies into ground contamination caused by pit latrines [74], which dispose of material containing a far greater percentage of faecal matter than is present in greywater, have shown that even in porous soils exposed to heavy rain, the downward travel of bacteria is usually less than 3 m. A study by the Office of Water Reclamation of the City of Los Angeles [75], has investigated the presence of indicator bacteria in the soil of domestic gardens before and after irrigation by untreated greywater. It was found that levels of bacteria fluctuated widely, but were not correlated to the use of greywater. It was therefore concluded that background variation of these bacteria in the soil environment, from domestic and wild animals, overwhelms any contributions from human sources through the greywater distribution system.

4.4.2 Indirect Effects on the Environment

Although the overall amount of organic waste discharged to the sewer is not reduced through greywater recycling, the total volume of water discharged is reduced, thus leading to an increase in the BOD levels of the sewage discharge. If greywater recycling were carried out on a wide scale, problems could possibly arise due to the blocking of pipes through a reduction in flow. Also, because the sewage transferred to municipal wastewater treatment works would be more concentrated, there may be, subject to specific local conditions, positive or negative implications for the operation of the treatment works. Widescale use of stored rainwater supply systems could potentially lead to a reduction in the amount of water reaching stormwater sewers and combined sewers, the implications of which could again be either positive or negative.

There is a slight possibility that treatment chemicals used in certain proprietary systems could affect the operation of treatment works, if such systems were used very widely. Many systems use chemicals such as chlorine or chlorine derivatives to treat the recycled water before use, and it is possible that some of these would reach municipal wastewater treatment works in the sewage. However, the use of chlorine as a treatment for recycled water for flushing toilets might mean that WC cleansing products, such as bleaches, would be unnecessary. This would conceivably counterbalance any potential negative effects.

The use of rainwater may also affect the environment by reducing the volumes of rainwater available to replenish local aquifers and rivers, although this will be counterbalanced by reduced pressure on the aquatic systems which supply mains water. The interception of rainwater can also have a positive effect on the freshwater environment by reducing storm loadings on stormwater and combined sewers and on wastewater treatment plants. As storm events are often associated with pollution peaks due to the flushing out of drains and sewers, this would result in better quality discharges to controlled waters.

4.5 ADDITIONAL REQUIREMENTS CONSIDERED NECESSARY FOR THE PROTECTION OF PLUMBING SYSTEMS AND THE ENVIRONMENT IN THE UK

Taking into account possible deleterious effects to general and reuse plumbing systems, to other equipment and to the environment, it is suggested that the requirements and restrictions of use listed below are appropriate for the UK, to be used in conjunction with the health and safety requirements (see Section 3.3). The recommendations have been adapted from those published overseas, including recent Australian guidelines for domestic greywater reuse [29].

To Protect Systems

- Plastic or other corrosion-resistant materials are required in construction. Any metal parts which may be prone to corrosion must be easily accessible in order to allow regular checking, maintenance and replacement.

- All water collected for reuse must be coarsely filtered to remove large debris. Greywater must be filtered more finely to remove hair, large soap particles and other such matter.

- Systems must be constructed, operated and maintained to:

    - prevent the likelihood of blockage, leakage, or overflow;

    - be provided with access points for maintenance and clearing of any blockages;

    - be ventilated to prevent the likelihood of foul air accumulating in the installation and drainage system.

To Protect the Environment

- Where recycled greywater is used for irrigation, adequate care must be taken to avoid the contamination of underlying aquifers and neighbouring watercourses.

- Systems must be designed in such a manner that inadequately serviced systems will not harm the environment.

- It must be ensured that by-products of systems, including chemicals used for water treatment, are disposed of in a manner which is not detrimental to the environment or the sewer system.

- Systems must be constructed, operated and maintained to:

    - prevent the likelihood of air and gases entering buildings or causing nuisance;

    - prevent the likelihood of discharged water causing offensive odours and nuisance.

- Recycled greywater should only be used to irrigate tolerant plant species.

5. ASSESSMENT OF THE CURRENT AND POTENTIAL ECONOMICS OF SYSTEMS

5.1 INTRODUCTION

This Chapter details the financial aspects of using greywater and rainwater systems for WC flushing and/or external uses. A number of building types are considered, as listed below:

- Houses
- Blocks of flats
- Offices
- Hotels
- Prisons

Assessments have been made for new and existing buildings with the following WC flush volumes:

- Existing buildings: 9 litres
- New buildings: 7.5 litres
6 litres

5.2 ASSUMPTIONS

Any assessment of financial or water savings which may result from the use of a particular system must depend on a number of assumptions. These relate, for example, to the consumption of water in the building, the amount used for WC flushing, external uses, and the amount of greywater produced. For dwellings it has been assumed that the consumption patterns are broken down according to Anglian Water's Survey of Domestic Consumption [30], as reproduced in Table 7. The average daily consumption of water is assumed to be 147 l/person/day [76] for existing housing and 100 l/person/day [44] for new buildings.

Table 7: Breakdown Of Water Consumption

Demand type	%	New buildings litres /person/ day	Existing Buildings litres /person/ day
Total	100	100	147
Toilets	33	33	48.5
Dishwashers	1	1	1.5
Washing machines	21	21	31
Wash hand basins	9	9	13
Outside taps	3	3	4.5
Kitchen sinks	16	16	23.5
Baths	13	13	19
Showers	4	4	6

For the other building types figures for water consumption have been derived from a number of sources. These are summarised in Table 8. In addition, a number of other assumptions have been necessary and these are listed below.

- For hotels, the analysis has been undertaken on the basis of water use in hotel rooms only (i.e. not including water use in kitchens, laundries etc.). Assumed use per room per night is:
  - 5x WC flushes (30, 37.5, 45 litres depending on flush volume)
  - 1x bath (80 litres)
  - 1x shower (20 litres)
  - miscellaneous uses (5 litres total)

- Rainfall is 2.3 mm/day [77].

- The cost of water services is £1.28/m^3 [78].

- 50% of the total rainwater and greywater which is available is used to offset mains water. The storage volumes required to enable use of a greater proportion of grey or rainwater are significant, and the most cost effective solution is to rely on a mix of grey/rain water and mains water. The effect of increasing this amount to 80% is discussed in Section 5.5.

- Life expectancy of all systems is 25 years.

- Exchange rates used against Sterling, taken from the Financial Times in December 1996 [79], are:
  - $US 1.6564
  - $AUS 2.1129
  - DM 2.5152
  - $CAN 2.2109

Table 8: Assumptions Used In Calculations

	House	Flats**	Office	Hotel	Prison
Water consumption (m^3/a)	88/129*	1056/1548*	370***	9250/ 10250*	800
WC water use (%)****	20/26/33	20/26/33	43[80]	22/26/30	20/26/33
External water use (%)	3	0	3	3	3
Greywater production (%)****	31/28.7/26	31/28.7/36	32.2/29.8/27 [80]	78/74/70	31/28.7/26
Footprint (m^2)	50	200	2000	3500	5000

* New/existing respectively
** Assumes a block of 12 flats
*** Derived from a BSRIA survey into utility costs [81]
**** The actual percentage depends on the flush volume of the WC (6, 7.5, 9 litre flushes respectively).

It is important to point out that it is extremely difficult to make a robust calculation of the savings from a rainwater collection system without detailed knowledge of the form of the building in question. The amount of rainwater which would be available for a building depends heavily on the roof area of the building in relation to its water consumption. It is assumed that rain is collected only from the roof of buildings, although for high rise buildings it would in theory be possible to collect rain from the walls. It is also possible to collect rain from hard surfaces such as car parks. As flats, offices and hotels in particular may be low, medium or high rise, with little difference in roof area but significant difference in occupancy and water consumption, the economic analysis is extremely difficult. For these building types, the following built form has been assumed:

Flats: Three storey square plan building with four flats per storey. Total net floor area of $200m^2$.

Offices: Medium rise office block (2 - 3 storeys) with a total net floor area of 2000 m^2.

Hotels: Medium rise (4 storey) hotel with 250 rooms and total net floor area of 3,500 m^2.

5.3 SYSTEM TYPES CONSIDERED

A number of generic system types have been assessed, within which specific products or systems can be categorised. These are listed below:

Type A	Rainwater collection for external use only
Type B	Rainwater collection for external and internal* use
Type C	Greywater collection for external use only
Type D	Greywater collection for external and internal* use
Type E	Rainwater and greywater collection for external use only
Type F	Rainwater and greywater collection for external and internal* use

* Internal use is restricted to WC flushing.

Each system Type has been assessed for application on each building type, for the WC flush volumes given above.

5.4 CAPITAL AND RUNNING COSTS OF SYSTEMS

The following sections summarise the cost data which are available on rainwater/greywater reuse systems and products. The range of costs for each system is large, due to the varying levels of sophistication of the products. However, a more expensive product would not necessarily be capable of reusing more water than a cheaper version within the same system group, and so in all cases a 50% use rate has been assumed unless indicated otherwise.

Most of the costs available are for products designed for use in residential applications. There is thus very little information available on the cost of the various systems in different building types, and indeed how these costs vary between new build and retrofit applications. In addition, data on the running costs of products is often difficult to obtain. In order to undertake an analysis of the potential economics of these systems it is necessary to identify all of these elements, and so an attempt has been made to estimate the likely capital and running cost of the systems for use in the different building types, from the information available in the literature.

5.4.1 System A - Rainwater Collection for External Uses

- £27 - Blackwall 45 gal rainwater butt fitted with Rainsaver collection system .[82]
- \$84 - \$189 (£51 - £114) - Stormwater Catch Basin - rainwater collection and filtration system [83].
- \$134 (£61) - Vancouver Rain Barrel [84].
- £712 - KISKIC rainwater collection and irrigation system [85].

System costs assumed are:

		Capital Cost (£)	Running Cost (£/a)
HOUSE	New	30 (- 712)	0
	Existing	30 (- 712)	0
FLATS	New	-	-
	Existing	-	-
OFFICE	New	200	0
	Existing	200	0
HOTEL	New	200	0
	Existing	200	0
PRISON	New	200	0
	Existing	200	0

For all building types the running cost of this system is assumed to be zero, as there is no treatment or pumping required. An economic assessment has not been made for the use of this system in flats, as the external use of water per flat would be negligible. For the larger building types the cost of the system has been assumed to increase to £200, approximately the cost of ten water butts (with bulk discount).

5.4.2 System B - Rainwater Collection for External and Internal Uses

- No specific system or product cost data available.

System costs assumed are:

		Capital Cost (£)	Running Cost (£/a)
HOUSE	New	625	5
	Existing	750	5
FLATS	New	2000	20
	Existing	3000	20
OFFICE	New	5000	40
	Existing	7000	40
HOTEL	New	5000	40
	Existing	7000	40
PRISON	New	5000	40
	Existing	7000	40

BSRIA work suggests that the cost of installing this system in a new dwelling would be around £625 [44]. The capital cost of retrofitting this system would be greater than that for installing it in a building under construction due to the internal works required. The capital and running costs of this system for the other building types are estimated on the basis of other systems, in particular system Type D. The principal additional cost is due to the extra internal pipework required with this system. Running costs are due principally to pumping requirements, but also to treatment and maintenance.

5.4.3 System C - Greywater Collection for External Uses

- $400 - $800 (£241 - £483) - Domestic low tech using water from washing machines.
- $1,000 - $1,500 (£604 - £906) - Domestic low tech, using all greywater.
- $2,500 - $5,000 (£1509 - £3019) - Domestic automatic, using all greywater with mains backup [75].
- $AUS 500 (£237) - Domestic DIY system, $AUS 5 (£2.4) per annum running costs - payback 8 - 11 years (at 6% annual interest rate) [59].
- $AUS 1500 (£710) - Domestic 'primary' greywater system (i.e. one only for irrigation, no storage or treatment), $AUS 5 (£2.4) per annum running costs - payback over 50 years (at 6% annual interest rate) [59].
- $995 (£601) plus $365 (£220) - $534 (£322) for a sub-surface irrigation package - Agwa Greywater system [86].

System costs assumed are:

		Capital Cost (£)	Running Cost (£/a)
HOUSE	New	240 (- 3000)	0
	Existing	240 (- 3000)	0
FLATS	New	-	-
	Existing	-	-
OFFICE	New	3000	20
	Existing	3000	20
HOTEL	New	3000	20
	Existing	3000	20
PRISON	New	3000	20
	Existing	3000	20

As the external use of water in flats is negligible, no assessment of this system relating to application on that building type has been made. Running costs are assumed to be very low, related only to treatment of the greywater, which would amount to simple settlement and filtration. The costs relating to the application of this system in building types other than dwellings are estimated on the basis of the likely additional cost for separate greywater drainage.

5.4.4 System D - Greywater Collection for External and Internal Uses

- $AUS 3000 (£1420) - Domestic 'secondary' greywater system (i.e. one with storage and treatment in which greywater can be used for WC flushing) [59].

- DM 14,000 (£5566) plus DM 2,000 (£795) for installation - domestic (6 family) system. Total annual costs DM 2450 (£974), total annual savings per family DM 327 (£130) [87].

- $ 87,500 (£52,825) - 250 room hotel, for 'Type A' greywater system (i.e. separate collection of greywater, treatment and supply for WCs). Annual water use is assumed to be 42,425,000 gal (192,868 m^3) [72].

- $3,500 (£2113) - $4,500 (£2717) - Aquabank domestic greywater recycling system. No information given on running costs, although further information sought from supplier [88].

- £1000 new build; £1500 retrofit - Pressure Butt.

System costs assumed are:

		Capital Cost (£)	Running Cost (£/a)
HOUSE	New	1000 (- 5000)	5
	Existing	1420 (- 6350)	5
FLATS	New	7000	50
	Existing	10000	50
OFFICE	New	7000	50
	Existing	10000	50
HOTEL	New	7000	50
	Existing	10000	50
PRISON	New	7000	50
	Existing	10000	50

As with system Type B the capital cost of retrofitting this system is significantly greater than that of incorporating it into a new building due to the extra internal pipework required. The capital costs for residential applications are based on those in the literature, but for the other building types are estimates based on the likely additional internal pipework and treatment systems required. Running costs are principally for pumping of water but also include the costs of treatment and maintenance.

5.4.5 System E - Rainwater and Greywater Collection for External Uses

- No specific system or product cost data available.

System costs are assumed to be the same as system C, as the addition of rainwater collection adds very little to either capital or running costs:

		Capital Cost (£)	Running Cost (£/a)
HOUSE	New	240 (-3000)	0
	Existing	240 (-3000)	0
FLATS	New	-	-
	Existing	-	-
OFFICE	New	3000	20
	Existing	3000	20
HOTEL	New	3000	20
	Existing	3000	20
PRISON	New	3000	20
	Existing	3000	20

5.4.6 System F - Rainwater and Greywater Collection for External and Internal Uses

- £1000 new build; £1500 retrofit - Pressure Butt (rainwater not actually collected, but cost likely to be similar to that of a combined system).

System costs assumed are:

		Capital Cost (£)	Running Cost (£/a)
HOUSE	New	1000	5
	Existing	1500	5
FLATS	New	7000	50
	Existing	10000	50
OFFICE	New	7000	50
	Existing	10000	50
HOTEL	New	7000	50
	Existing	10000	50
PRISON	New	7000	50
	Existing	10000	50

These costs are based on those for the Pressure Butt in the domestic application, but for other building types are assumed to be the same as system D, as the addition of rainwater collection adds very little to either capital or running costs.

5.5 DISCUSSION

The Tables below (Table 9 to Table 14) show the annual savings, capital and running costs, and simple payback times for each of the six systems, applied to each building type.

The effect of increasing the amount of available rainwater and greywater which it is assumed is reused to 80% is relatively slight. This only affects those systems which provide water for both internal and external uses (i.e. systems B, D and F) and for system D (for which the greatest difference is evident), the payback times are approximately halved. However, there is no effect on the payback time of system D when applied to hotels, and for the other building types the payback times remain well in excess of the life expectancy of the systems (25 years). For system F the payback when applied to an existing block of flats drops to 19 years, if 80% recovery rates are assumed.

By far the most cost effective systems are those applied to hotels. In all cases the payback times are below 10 years, and in the majority they are found to be below 5 years. The system type with the best overall financial performance is system A (rainwater collection for external uses) which has a payback of 6 - 9 years for a residential application, and just over 1 year for use on a hotel.

Table 9: Financial Assessment - System A

(rainwater collection for external uses)

		Gross Annual Saving (£/a)	Capital Cost (£)	Running Cost (£/a)	Payback (a)
HOUSE	Existing	5	30 - 712	0	6 - 144
	New - 7.5 l flush	3	30 - 712	0	9 - 210
	New - 6 l flush	3	30 - 712	0	9 - 210
FLATS	Existing	0	-	-	-
	New - 7.5 l flush	0	-	-	-
	New - 6 l flush	0	-	-	-
OFFICE	Existing	14	200	0	14
	New - 7.5 l flush	14	200	0	14
	New - 6 l flush	14	200	0	14
HOTEL	Existing	394	200	0	0.5
	New - 7.5 l flush	355	200	0	0.6
	New - 6 l flush	355	200	0	0.6
PRISON	Existing	31	200	0	6
	New - 7.5 l flush	31	200	0	6
	New - 6 l flush	31	200	0	6

Table 10: Financial Assessment - System B

(rainwater collection for external and internal uses)

		Gross Annual Saving (£/a)	Capital Cost (£)	Running Cost (£/a)	Payback (a)
HOUSE	Existing	27	700	5	32
	New - 7.5 l flush	27	625	5	29
	New - 6 l flush	25.4	625	5	31
FLATS	Existing	108	3000	20	34
	New - 7.5 l flush	108	2000	20	23
	New - 6 l flush	108	2000	20	23
OFFICE	Existing	171	7000	40	83
	New - 7.5 l flush	137	5000	40	80
	New - 6 l flush	107	5000	40	122
HOTEL	Existing	1882	7000	40	4
	New - 7.5 l flush	1882	5000	40	3
	New - 6 l flush	1882	5000	40	3
PRISON	Existing	369	7000	40	21
	New - 7.5 l flush	297	5000	40	19
	New - 6 l flush	231	5000	40	26

Table 11: Financial Assessment - System C

(greywater collection for external uses)

		Gross Annual Saving (£/a)	Capital Cost (£)	Running Cost (£/a)	Payback (a)
HOUSE	Existing	5	240 - 3000	0	48 - 606
	New - 7.5 l flush	3	240 - 3000	0	71 - 890
	New - 6 l flush	3	240 - 3000	0	71 - 890
FLATS	Existing	0	-	-	-
	New - 7.5 l flush	0	-	-	-
	New - 6 l flush	0	-	-	-
OFFICE	Existing	14	3000	20	-
	New - 7.5 l flush	14	3000	20	-
	New - 6 l flush	14	3000	20	-
HOTEL	Existing	394	3000	20	8
	New - 7.5 l flush	374	3000	20	9
	New - 6 l flush	355	3000	20	9
PRISON	Existing	31	3000	20	280
	New - 7.5 l flush	31	3000	20	280
	New - 6 l flush	31	3000	20	280

Table 12: Financial Assessment - System D

(greywater collection for external and internal uses)

		Gross Annual Saving (£/a)	Capital Cost (£)	Running Cost (£/a)	Payback (a)
HOUSE	Existing	22	1420 - 6350	5	86 - 386
	New - 7.5 l flush	16	1000 - 5000	5	90 - 448
	New - 6 l flush	18	1000 - 5000	5	80 - 401
FLATS	Existing	258	10000	50	48
	New - 7.5 l flush	194	7000	50	49
	New - 6 l flush	210	7000	50	44
OFFICE	Existing	64	10000	50	717
	New - 7.5 l flush	71	7000	50	340
	New - 6 l flush	76	7000	50	267
HOTEL	Existing	4330	10000	50	2
	New - 7.5 l flush	3657	7000	50	2
	New - 6 l flush	2984	7000	50	2
PRISON	Existing	133	10000	50	120
	New - 7.5 l flush	147	7000	50	72
	New - 6 l flush	159	7000	50	64

Table 13: Financial Assessment - System E

(rainwater and greywater collection for external uses)

		Gross Annual Saving (£/a)	Capital Cost (£)	Running Cost (£/a)	Payback (a)
HOUSE	Existing	5	240 - 3000	0	48 - 605
	New - 7.5 l flush	3	240 - 3000	0	71 - 890
	New - 6 l flush	3	240 - 3000	0	71 - 890
FLATS	Existing	0	-	-	-
	New - 7.5 l flush	0	-	-	-
	New - 6 l flush	0	-	-	-
OFFICE	Existing	14	3000	20	-
	New - 7.5 l flush	14	3000	20	-
	New - 6 l flush	14	3000	20	-
HOTEL	Existing	394	3000	20	8
	New - 7.5 l flush	374	3000	20	8.5
	New - 6 l flush	355	3000	20	9
PRISON	Existing	31	3000	20	280
	New - 7.5 l flush	31	3000	20	280
	New - 6 l flush	31	3000	20	280

Table 14: Financial Assessment - System F

(rainwater and greywater collection for external and internal uses)

		Gross Annual Saving (£/a)	Capital Cost (£)	Running Cost (£/a)	Payback (a)
HOUSE	Existing	48	1500	5	35
	New - 7.5 l flush	33	1000	5	36
	New - 6 l flush	25	1000	5	49
FLATS	Existing	365	10000	50	32
	New - 7.5 l flush	301	7000	50	28
	New - 6 l flush	265	7000	50	33
OFFICE	Existing	171	10000	50	83
	New - 7.5 l flush	137	7000	50	80
	New - 6 l flush	107	7000	50	123
HOTEL	Existing	4330	10000	50	2.3
	New - 7.5 l flush	3470	7000	50	1.9
	New - 6 l flush	2984	7000	50	2.4
PRISON	Existing	369	10000	50	31
	New - 7.5 l flush	297	7000	50	28
	New - 6 l flush	231	7000	50	39

6. OVERALL DISCUSSION

There is no doubt that substantial domestic water consumption savings can be achieved using greywater reuse and stored rainwater supply systems. There are now a relatively large number of proprietary systems available worldwide, with several designed and manufactured in the UK. However, questions remain as to whether systems are economically viable and concerns still exist about potential risks to public health and/or the environment.

The investigation of the types of system available revealed considerable diversity of design, size and origin. For example, systems reuse greywater only, rainwater only or both greywater and rainwater. Systems range in size from those designed for single households to those designed for groups of multi-storey office blocks. They may be purchased as complete, ready-to-install units or as individual components for 'DIY' or specialist installation. Considerable flexibility can be incorporated into the design of such systems, which can therefore potentially be used in a wide range of applications and building types, albeit with varying degrees of safety and "success".

The reuse of rainwater and to a greater extent greywater, may potentially have a number of associated deleterious effects, including possible risks to public health, the environment and plumbing systems. As a result of health concerns, a number of countries have placed restrictions on the reuse of greywater. In several States of the USA, for example, greywater can only be reused in domestic dwellings for sub-surface landscape irrigation. However, it is suggested in this report that as public health risks are very application-specific and because of recent advances in wastewater treatment technology, similarly restrictive regulations on the end-use of recycled water should not be introduced in the UK. Instead, individual systems should be tested by an accredited test-house before they can be sold or installed.

The tests used could be based around NSF International, Standard 41 [55] for wastewater recycle/reuse and water conservation devices, and it is suggested that the water quality criteria used in the tests should be application specific. For example, if a system is designed to recycle water for an application such as sub-surface garden irrigation, in which human contact with the recycled water will be extremely limited, far less rigorous water quality criteria will be required than if the water is to be used as a potable supply. Therefore, in Chapter 3 of this report, end-uses of recycled greywater and rainwater have been categorised into three "Categories of Use", and corresponding water quality criteria for each of these categories have been proposed. The proposed criteria were selected following an assessment of relevant published water quality guidelines and standards from the UK and overseas. Likewise, lists of proposed requirements have been put forward for the design, construction, operation and maintenance of systems, that should be followed in order to protect public health and minimise deleterious effects to the environment and plumbing systems.

The analysis of the economics of systems in this study covers five building types, six generalised system types, two toilet cistern sizes and both new-build and retrofit installations. It was based on data from a comprehensive range of sources, although a number of assumptions were required where data were unavailable. It should be noted that the nature of these assumptions will have had a significant influence on the outcome of the analysis, but that this is an unavoidable situation in view of the limited data available.

Of particular interest is the fact that of all the building types considered, hotel applications appear to yield the shortest pay-back periods, suggesting that manufacturers might be advised to target hotel operators as an initial market for their products. Where hotels are situated in areas with unreliable or scarce water supplies, the economics might be even more favourable. Also notable was the observation that in order to be economically viable, it is not necessary to design systems in order to utilise a large percentage of the rainwater or greywater available, with a 50% recovery rate being generally acceptable. The analysis also showed, from an examination of the effects of using different toilet cistern sizes, that if other water conservation measures are taken in buildings, the installation of greywater or rainwater systems may become less financially attractive. When considering water saving opportunities, individual options should not be considered in isolation.

As yet there are relatively few system manufacturers in the UK. It is interesting that some of the system designs produced by UK manufacturers are amongst the most advanced of those examined in this study. It therefore appears that UK manufacturers are in a good position to take advantage of any widening of the market for water conservation products. Indeed, even if such an opening were not to take place in the UK market, it is quite possible that UK manufacturers could gain increasing shares in overseas markets.

7. CONCLUSIONS AND RECOMMENDATIONS

A number of factors are likely to affect the uptake of greywater reuse and stored rainwater supply systems in the UK:

Water charges

Current water charges in the UK are relatively low and do not fully take into account associated environmental costs. If prices were raised, even slightly, the use of water conservation devices would become significantly more economic. However, even with current water charges, the economic analyses carried out in this study reveals that in many circumstances systems can now be economically viable.

Approved standards for systems

General Product/Design Standards

At present in the UK there is no system of accreditation specifically for greywater reuse and stored rainwater supply systems. Systems must conform to the Water Byelaws and should comply with existing plumbing standards such as British Standard 6700. However, confidence in greywater and stored rainwater supply systems would benefit from a standard for their installation and use. It is therefore recommended that such a standard should be developed, possibly by adapting that already produced by NSF International in the USA for wastewater recycle/reuse and water conservation devices[55]. It is suggested that the resulting standard should be application specific (i.e. based on the category of use of the recycled water). It is also recommended that action should be taken to accredit test houses to certify systems, using the new standard.

Water quality criteria

There are no water quality standards in the UK specifically designed to relate to the use of recycled greywater and rainwater. It is recommended that application-specific water quality standards be introduced, and a set of criteria are proposed in this report (see Section 3.3). However, due to very limited risks, it would probably be inappropriate to insist that systems, once installed, should be constantly monitored to ensure that water quality is maintained. Instead, there should be a comprehensive water quality performance test included in the initial accreditation procedure, for each new system type marketed. This should be designed to ensure that systems, even when stressed or poorly maintained, are capable of consistently producing water of adequate quality.

Information exchange

Although comprehensive conferences have taken place within the UK on rainwater and greywater reuse, up to date information on overseas technology and practices tends to be difficult to obtain in the UK. It is therefore recommended that advances overseas should be monitored.

8. GLOSSARY

1986 Model Water Byelaws	The 1986 revision of the Model Water Byelaws. The byelaws subsequently made by statutory water undertakers in England and Wales are identical.
Aeration	The process which exposes a substance to the action of air, by forcing air through it.
Aerobic	Biological processes taking place in the presence of oxygen.
Aerosols	Minute particles suspended in gas.
Anthracite	A type of coal with a high carbon content.
Aquaculture	The rearing of aquatic animals or the cultivation of aquatic plants for food.
Aquifer	An underground water-bearing layer of porous rock.
Atmospheric particulates	Tiny particles of dust and dirt found in air.
Backflow	Flow in a direction contrary to the normal intended direction of the flow.
Backsiphonage	The backflow caused by the siphonage of liquid from a cistern or appliance into the pipe feeding it.
Back-up system	A system which is present in case of failure of the initial system, to allow a continuation of the service.
Bacteriological	Of or to do with bacteria.
Biocide	Any agent that kills living organisms
Biological oxygen demand (BOD)	Measurement of the amount of organic pollution in water.
BOD_5	A standard test to determine the biological oxygen demand of a sample, measured as the amount of oxygen taken up from a sample containing a known amount of dissolved oxygen kept at 20 °C for 5 days.
Chlorine (Cl_2)	A disinfectant frequently used in the treatment of water.
Cistern	A fixed container for holding water at atmospheric pressure.

Clostridia	Bacteria of the genus *Clostridium,* some species of which produce powerful toxins.
Coliform	Bacteria within the family Enterobacteriaceae typified by *Escherichia coli.* Their presence is used as a standard indicator of faecal pollution of water (a detailed microbiological definition is given in Reference 67).
Combined sewers	Sewers which take both foul water and storm water flows.
Cross-contamination	To pollute or infect from another source.
Dead legs	Stagnant dead ends of water pipes which do not have a ring system of flow.
Domestic water consumption	The consumption of water for 'domestic', i.e. non-process uses.
Drip irrigation system	A system that drips water onto the roots of plants at regular intervals.
Endemic disease	Disease present at relatively low levels in the population all the time.
Entero-viruses	Viruses of the intestine or gut.
Epidemiology	The study of the origin, occurrence and spread of diseases.
Facade	The face or outward appearance of a building.
Faecal coliform	A coliform of faecal origin (the microbiological definition is discussed in Reference 67).
Fail safe	Reverts to a safe condition in the event of a breakdown.
Flash point	The temperature at which a flammable liquid gives off sufficient vapour to catch fire when ignited.
Flocculation	The action of fine particles joining to form floc (a gelatinous mass) allowing solids to separate by sedimentation.
Flush volume	The volume of water flushed from a cistern down a toilet.
Galvanically compatible	Two metals being close in the galvanic series; corrosion can occur when two metals are very galvanically different, i.e. reactive to each other.

Greywater	The wastewater from water using domestic appliances and fittings, excluding WCs and bidets.
Greywater recycling	The reuse of greywater (see above).
Gross	Extreme.
Helminth	Parasitic flatworm or roundworm.
Hypochlorite	A solution which provides a means of chlorination when added to water.
Impoundment	Enclosed water body.
Ingestion	The action of taking in by swallowing.
Inhibitor	A substance which prevents or retards an action, process or biochemical reaction.
LC_{50}	A lethal concentration of a substance in air or water expressed as the concentration sufficient to kill 50% of a sample within a certain time.
LD_{50}	A lethal dose; a dose large enough to kill 50% of a sample of animals under test.
Legionella	Name given to the genus of bacteria which causes the condition commonly known as legionnaire's disease. Other diseases associated with the disease are Pontiac fever and Lochgoilhead fever.
Legionellosis	Generic term used to describe diseases such as legionnaire's disease, Pontiac fever and Lochgoilhead fever.
Membrane	A pliable sheet-like material or lining.
Methylene-blue	A green crystalline compound, blue in aqueous solution, used as a microscopic stain for bacteria.
Microbiological	To do with minute living beings, such as bacteria.
Municipal	Belonging to a town, city or district.
Nematodes	Roundworms, some of which are parasitic in humans.
New build	The construction of brand new buildings.
NTU	Tubidity unit (see turbidity).

Overflow pipe	A pipe which allows a containing vessel to overflow if the water level becomes too high inside it.
Ozone (O_3)	A form of oxygen with three atoms in a molecule, which is an effective disinfectant for water, leaving no residual.
Pathogen	A living organism which causes disease.
Particulates	Tiny particles.
Payback time	The time taken for the amount of money saved by installing an appliance to equal the cost of buying it initially.
Permeable	Allows the passing of fluid through.
Potable	Drinkable; fit for human consumption.
Proprietary	Manufactured.
Residual	Quantity left as residue.
Retrofit	The ability to fit something onto an existing appliance in order to update it or change it.
Salmonella	Bacterium of the genus *Salmonella* which includes species causing food poisoning and the causal agent of typhoid fever.
Scale	A short name for limescale, which is the build-up of calcium carbonate when hard water is used.
Sedimentation	The settling out of 'sedimentable' solids.
Sewerage	The system of drainage by sewers.
Stabilisation pond	Pond that provides treatment of wastewater by natural stabilisation processes.
Statutory	Of or for statutes (laws passed by Parliament).
Storm water	Rainwater which runs to sewer.
Streptococci	Bacteria of the genus *Streptococcus*, some of which are human pathogens, causing tonsilitis, scarlet fever and tissue destruction.
Sub-surface irrigation	Below ground irrigation system.

Surge Tanks	Small tanks installed on pipelines to relieve excess or negative water pressure if a valve on the pipeline is suddenly opened or closed. The water surface fluctuates up and down in the tank until damped down by fluid friction, and the pressure in the pipeline system stabilises again.
Toxicity	The nature or virulence of a poison.
Turbidity	The presence of small solids which give liquid a cloudy appearance.
Type A air gap	A 25mm space between an inlet pipe and the highest water level in a container, preventing the possibility of backflow or backsiphonage.
Ultra-violet (UV) light	Electromagnetic radiation just beyond the violet end of the spectrum which acts as an effective water disinfectant, leaving no taste or odour.
Wastewater treatment plant	Facility for treating wastewater, usually made up of a number of unit processes or operations in series.
Wholesome water	Water free from visible suspended matter, excessive colour, taste, odour, objectionable dissolved matter, aggressive constituents and bacteria indicative of faecal pollution.
µm	A micro (1×10^{-6}) metre = one millionth of a metre.

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APPENDIX A1

List of Manufacturers and Suppliers

No. of pages: 10

LIST OF MANUFACTURERS, SUPPLIERS AND DEVELOPERS

This list is non-exhaustive.

RAINWATER SYSTEMS

Aqualta
20th Floor Capitol Square, 10065 Jasper Avenue, Edmonton, Alberta, T5J 3B1, Canada
Tel: (403) 944-7757, Fax: (403) 944-7926

Blackwall Products
Units 1 & 2, Riverside Industrial Estate, River Way, London, SE10 0BH, UK
Tel: 0181 305 1431, Fax: 0181 305 1418

Formpave Ltd (permeable paving)
Tufthorn Avenue, Coleford, Gloucestershire, GL16 8PR, UK
Tel: 01594 836999, Fax: 01594 810577

GEP-Umwelttechnik GmbH
Bogestraße 98, 53783 Eitorf, Germany
Tel: 0 22 43/92 06-0, Fax: 0 22 43/92 06-66

Jade Mountain
PO Box 4616, Boulder, Colorado, 80306-4616, USA
Tel: 800-442-1972, Fax: 303-449-8266

KC Pure
The Old Coach House, Greenbank Terrace, Greenbank, Plymouth, PL4 8QF, UK
Tel: 01752 224111, Fax: 01752 604078

Kiskic Enterprises Ltd
25 North Entrance, Saxmundham, Suffolk, IP17 1AS, UK
Tel: 01728 603202, Fax: 01728 602940

Rain Catcher
c/o Rototech Plastics Inc., Spruce Grove, Alberta, Canada
Tel: (403) 962-8812

Rain Drain Ltd
Albert Mills, Mill Street West, Dewsbury, West Yorkshire, WF12, UK
Tel: 01924 468564, Fax: 01924 465925

Stanley Associates Engineering Ltd
Stanley Technology Centre, 10160 - 112 Street, Edmonton, Alberta, Canada, T5K 2L6
Tel: (403) 423-4777, Fax: (403) 421-4300

T & D Trident (plastic tanks)
Bowling House, Bowling Iron Works, Bradford, BD4 8SX, UK
Tel: 01274 728285, Fax: 01274 390731

Vancouver Rain Barrel
c/o City Farmer, Canada's Office of Urban Agriculture, #801-318 Homer Street, Vancouver, BC V6B2V3, USA
Tel: (604) 685-5832, Fax: (604) 685-0431

Water Conservation Technology
PO Box 121, Sydenham, Ontario K0H 2T0, Canada

Wilo Salmson Ltd
Ashlyn Road, West Meadows Industrial Estate, Derby, DE2 6XE, UK
Tel: 01332 385181, Fax: 01332 44423

WISY
c/o The Green Shop, Bisley, Stroud, Gloucestershire, GL6 7BX, UK
Tel: 01452 770629, Fax: 01452 770629

GREYWATER SYSTEMS

Camphill Water
Oaklands Park, Newnham-on-Severn, Gloucestershire, GL14 1EF, UK
Tel: 01594 516063

Davy International Environmental Division (Kubota process)
Ashmore House, Stockton-on-Tees, Cleveland, TS18 3RE, UK
Tel: 01642 602221, Fax: 01642 341001

Ebara Seisakusho
11-1 Haneda Asahi-chô, Ôta-ku, Tokyo 144, Japan
Tel: (03) 3743-6111

Jade Mountain
PO Box 4616, Boulder, Colorado, 80306-4616, USA
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Kiskic Enterprises Ltd
25 North Entrance, Saxmundham, Suffolk, IP17 1AS, UK
Tel: 01728 603202, Fax: 01728 602940

Kôbe Seikôsho
Tekkô Building, 8-2 Marunouchi 1-chôme, Chiyoda-ku, Tokyo 100, Japan
Tel: (03) 3218 7066

Kubota
2-47 Shikitsu Higashi 3-chôme, Naniwa-ku, Osaka 556, Japan
Tel: (06) 648 3561

Kurita Kogyo
4-7 Nishi-Shinjuku 3-chôme, Shinjuku-ku, Tokyo 106, Japan
Tel: (03) 3347-3111

LOKUS GmbH
Silbersteinstraße 97, 12051 Berlin (Neukölln), Germany
Tel: +49 (30) 625 31 67, Fax: +49 (30) 626 71 55

Merpro Process Technologies
Court Lodge, 105 High Street, Portishead, Bristol, UK
Tel: 01275 845252, Fax: 01275 845258

Orugano
Hongô TS Building, 38-16 Hongô 2-chôme, Bunkyô-ku, Tokyo 113, Japan
Tel: (03) 5689 6131, Fax: (03) 5689 6157

Real Goods Trading Co. (supplier of Agwa System)
555 Leslie Street, Ukiah, CA 95482-5507, USA
Tel: +1 (707) 468-9292, Fax: +1 (707) 468-9394

Reserve Water Systems
1973 Cordilleras, Redwood City, CA 94062, USA
Tel: +1 (415) 369-7010, Fax: +1 (415) 369-8695

Reuser Ltd
Tanimark Oy, Makelininkatu 43, AN - 90100 Oulu, Finland
Tel: +358 81 3121 161, Fax: +358 81 3118 101

Roediger Anlagenbau - Gmbh
Kinzigheimer Weg 104-106, D-63450 HANAU, Germany
Tel: (06181) 309-260, Fax: (06181) 309-280

The Water Store
850 Spring Street, PO Box 2766, Friday Harbour, WA 98250, USA
Tel: (360) 378-8900, Fax: (306) 378-8790

Water Dynamics Ltd
Unit 2, Dew Farm, Peasmarsh, East Sussex, TN31 6DX, UK
Tel: 0179 723 0140, Fax: 0179 723 0141

COMBINED SYSTEMS

Aquasaver
No 3 Efford Farm Business Park, Vicarage Road, Bude, North Cornwall,
EX23 8LT, UK
Tel: 01288 354425

WATER TREATMENT

Amiad
d.n. korazim, 12335 Israel
Tel: 972-6-933581, Fax: 972-6-935337

Citmart Ltd
Lympne Industrial Park, Hythe, Kent, CT21 4LR, UK
Tel: 01303 262211, Fax: 01303 260057

Cross
Milford Road, Bath, BA2 5RR, UK
Tel: 01225 837000, Fax: 01225 834115

Elysium Environment
3 Elysium Gate, 126 New Kings's Road, London, SW6 4LZ, UK
Tel: 0171 371 9617, Fax: 0171 371 9521

Estec Environmental Ltd
Old Pump House, Elmer Works, Hawks Hill, Leatherhead, Surrey, KT22 9DA, UK
Tel: 01372 361451, Fax: 01372 361453

Franke UK Ltd
East Park, Manchester Int. Office Centre, Styal Road, Manchester , M22 5WB, UK
Tel: 0161 436 6280, Fax: 0161 436 2180

Hanovia Ltd
145 Farnham Road, Slough, Berkshire, SL1 4XB, UK
Tel: 01753 515300, Fax: 01753 534277

KK Water Purification Ltd
Victory House, Victory Park Road, Addlestone, Weybridge, Surrey, KT5 2AX, UK
Tel: 01932 852423, Fax: 01392 847170

Lacron Ltd
London Road, Teynham, Sittingbourne, Kent, UK
Tel: 01795 521733, Fax: 01795 522085

Superior Industrial Products
31a Cleveland Road, South Woodford, London, E18 2AE, UK
Tel: 0181 989 1171, Fax: 0181 530 1150

Triogen Ltd
Triogen House, 117 Barfillan Drive, Craigton, Glasgow, G52 1BD, Scotland
Tel: 041 810 4861, Fax: 041 810 5561

Trojan Technologies Inc
3020 Gore Road, London, Ontario, Canada, N5V 4T7
Tel: (519) 457-3400, Fax: (519) 457-3030

UV Systems plc
Constitution Hill, Sudbury, Suffolk, CO10 6QL, UK
Tel: 01787 376259, Fax: 01787 881452

COLIFORM TESTING

Idexx Laboratories Ltd.
Milton Court, Churchfield Road, Chalfont St Peter, Buckinghamshire, SL9 9EW, UK
Tel: 01753 891660, Fax: 01753 891520

PUMPS

Grundfos Pumps Ltd
Grovebury Road, Leighton Buzzard, Bedfordshire, LU7 8TL, UK
Tel: 01525 850000, Fax: 01525 850011

GUTTERING SYSTEMS

Alumasc Building Products Ltd
Apex Works, Llanbrynmair, Powys, SY19 7DU, UK
Tel: 01650 521496, Fax: 01650 521505

Dales Fabrications Ltd
Crompton Road Industrial Estate, Ilkeston, Derbyshire, DE7 4BG, UK
Tel: 0115 930 1521, Fax: 0115 930 7625

Fullflow Systems Ltd
Fullflow House, Holbrook Avenue, Holbrook, Sheffield, S19 5FF, UK
Tel: 0114 247 3655, Fax: 0114 247 7805

Klober
Pear Tree Industrial Estate, Upper Langford, North Somerset, BS18 7DJ, UK
Tel: 01934 853224, Fax: 01934 853221

Marley Extensions Ltd
Dickley Lane, Lenham, Maidstone, Kent, ME17 2DE, UK
Tel: 01622 858888, Fax: 01622 858725

LIST OF CONTACTS

INTERNATIONAL

International Rainwater Catchment Systems Association (IRCSA)
c/o Int Institute for Agriculture, 2F Science Building, Kyoto Research Park, 17 Chudoji, Minami-machi, Shimogyo-ku, Kyoto 600, Japan
Tel: (8175) 315 8617, Fax: (8175) 315 8618
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c/o International Water Resources Association, 1101 West Peabody Drive, Urbana, IL 61801-4723, USA

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3475 Plymouth Road, PO Box 130140, Ann Arbor, MI 48113-0140, USA
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The University of Arizona, 1955 East 6th Street, Tuscon, Arizona 85719, USA
Tel: 520-621-8589, Fax: 520-621-3816

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3rd Floor, Century Place, 9803 - 102A Avenue, Edmonton, Alberta, Canada, T5J 3A3

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City of Toronto
Public Works, 100 Queen Street West, 14th Floor, Toronto, Ontario, M5H 2N2, Canada
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Government Administration Building, 30 Parliament Street, Hamilton HM12, Bermuda
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APPENDIX A2

California and Florida Treatment and Quality Criteria for Non-potable Uses of Reclaimed Water

No. of Pages: 3

California Treatment and Quality Criteria[a] for Non-potable Uses of Reclaimed Water

Type of Use	Total Coliform Limits[b]	Treatment Required
Irrigation of fodder, fiber & seed crops, orchards and vineyards[c], and processed food crops; flushing sanitary sewers	None required	Secondary
Irrigation of pasture for milking animals, landscape areas[d], ornamental nursery stock, and sod farms; landscape impoundments; industrial or commercial cooling water where no mist is created; non-structural fire fighting; industrial boiler feed; soil compaction; dust control; cleaning roads, sidewalks, and outdoor areas	23/100 mL	Secondary & disinfection
Surface irrigation of food crops; restricted landscape impoundments	2.2/100 mL	Secondary & disinfection
Irrigation of food crops[e] and landscape areas[f]; non-restricted recreational impoundments; toilet and urinal flushing; industrial process water; decorative fountains; commercial laundries; snow-making; structural fire fighting; industrial or commercial cooling where mist is created	2.2/100 mL	Secondary, coagulation, clarification[g], filtration[h], & disinfection

Notes

[a]Includes proposed revisions.
[b]Based on running 7-day median.
[c]No contact between reclaimed water and edible portion of crop.
[d]Cemeteries, freeway landscaping, restricted access golf courses, and other controlled access irrigation areas.
[e]Contact between reclaimed water and edible portion of crop; includes edible root crops.
[f]Parks, playgrounds, school yards, residential landscaping, unrestricted access golf courses, and other uncontrolled access irrigation areas.
[g]Except for non-restricted recreational impoundments and cooling uses where mist is created, coagulation is not required if the turbidity prior to filtration does not exceed 5 NTU.
[h]The turbidity of filtered effluent cannot exceed an average of 2 nephelometric turbidity units (NTU) during any 24-hour period.

Source: State of California, 1994, 'Notice of Availability of Changes to Proposed Regulations Regarding Wastewater Reclamation Criteria' (as summarised by Crook and Surampalli, 1996[52]).

Florida Treatment and Quality Criteria[a] for Non-potable Uses of Reclaimed Water

Type of Use	Water Quality Limits	Treatment Required
Restricted public access areas[b], industrial uses	200 faecal coli/100 mL 20 mg/L TSS 20 mg/L BOD	Secondary & disinfection
Public access areas[c], food crop irrigation[d], toilet flushing[e], recreational impoundments[f], fire protection, aesthetic purposes, dust control	No detectable faecal coli/100 mL 5 mg/L TSS 20 mg/L BOD	Secondary, filtration, & disinfection

Notes

[a]Includes proposed revisions
[b]Sod farms, forests, pasture land, areas used to grow trees and fodder, fiber, and seed crops, or similar areas.
[c]Residential lawns, golf courses, cemeteries, parks, landscaped areas, highway medians, or similar areas.
[d]Only allowed if crops are peeled, skinned, cooked, or thermally processed before consumption.
[e]Only allowed where residents do not have access to plumbing system. Not allowed in single-family residences.
[f]For full body contact impoundments, reclaimed water must meet drinking water bacteriological standards if it constitutes > 50% of inflow to impoundment.

Source: Florida Department of Environmental Protection, 1995, 'Proposed Revisions to Reuse of Reclaimed Water and Land Application' (as summarised by Crook and Surampalli, 1996[52])

APPENDIX A3

California Greywater Law
November 1993

No. of Pages: 14

CALIFORNIA PLUMBING CODE
Title 24, Part 5, California Administrative Code

APPENDIX J: GRAYWATER SYSTEMS FOR SINGLE FAMILY DWELLINGS

Section J-1 Graywater Systems (General)

(a) The provisions of this Appendix shall apply to the construction, alteration and repair of graywater systems for subsurface landscape irrigation. Installations shall be allowed only in single family dwellings. The system shall have no connection to any potable water system and shall not result in any surfacing of the graywater. Except as otherwise provided for in this Appendix, the provisions of the Uniform Plumbing Code (UPC) shall be applicable to graywater installations.

(b) The type of system shall be determined on the basis of location, soil type, and ground water level and shall be designed to accept all graywater connected to the system from the residential building. The system shall discharge into subsurface irrigation fields and may include surge tank(s) and appurtenances, as required by the Administrative Authority.

(c) No graywater system, or part thereof, shall be located on any lot other than the lot which is the site of the building or structure which discharges the graywater; nor shall any graywater system or part thereof be located at any point having less than the minimum distances indicated in Table J-1.

(d) No permit for any graywater system shall be issued until a plot plan with appropriate data satisfactory to the Administrative Authority has been submitted and approved. When there is insufficient lot area or inappropriate soil conditions for adequate absorption of the graywater, as determined by the Administrative Authority, no graywater system shall be permitted. The Administrative Authority is a city or county.

(e) No permit shall be issued for graywater system which would adversely impact a geologically sensitive area, as determined by the Administrative Authority.

(f) Private sewage disposal systems existing or to be constructed on the premises shall comply with Appendix I of this code or applicable local ordinance. When abandoning underground tanks, Section 1119 of the UPC shall apply. Also, appropriate clearances from graywater systems shall be maintained as provided in Table J-1. The capacity of the private sewage disposal system, including required future areas, shall not be decreased by the existence or proposed installation of a graywater system servicing the premises.

(g) Installers of graywater systems shall provide an operation and maintenance manual, acceptable to the Administrative Authority, to the owner of each system. Graywater systems require regular or periodic maintenance.

(h) The Administrative Authority shall provide the applicant a copy of this Appendix.

Section J-2 Definition

Graywater is untreated household wastewater which has not come into contact with toilet waste. Graywater includes water from bathtubs, showers, bathroom wash basins, and water from clothes washing machines and laundry tubs. It shall not include wastewater from kitchen sinks, dishwashers or laundry water from soiled diapers.

Section J-3 Permit

It shall be unlawful for any person to construct, install or alter, or cause to be constructed, installed or altered any graywater system in a building or on a premises without first obtaining a permit to do such work from the Administrative Authority.

Section J-4 Drawings and Specifications

The Administrative Authority may require any or all of the following information to be included with or in the plot plan before a permit is issued for a graywater system:

(a) Plot plan drawn to scale completely dimensioned, showing lot lines and structures, direction and approximate slope of surface, location of all present or proposed retaining walls, drainage channels, water supply lines, wells, paved areas and structures on the plot, number of bedrooms and plumbing fixtures in each structure, location of private sewage disposal system and 100% expansion area or building sewer connecting to public sewer, and location of the proposed graywater system.

(b) Details of construction necessary to ensure compliance with the requirements of this Appendix together with a full description of the complete installation including installation methods, construction and materials as required by the Administrative Authority.

(c) A log of soil formations and ground water level as determined by test holes dug in close proximity to any proposed irrigation area, together with a statement of water absorption characteristics of the soil at the proposed site as determined by approved percolation tests. In lieu of percolation tests, the Administrative Authority may allow the use of Table J-2, an infiltration rate designated by the Administrative Authority, or an infiltration rate determined by a test approved by the Administrative Authority.

Section J-5 Inspection and Testing

(a) Inspection

1. All applicable provisions of this Appendix and of Section 318 of the UPC shall be complied with.
2. System components shall be properly identified as to manufacturer.
3. Surge tanks shall be installed on dry, level, well-compacted soil if in a drywell, or on a level, 3" concrete slab or equivalent, if above ground.
4. Surge tanks shall be anchored against overturning.
5. If the irrigation design is predicated on soil tests, the irrigation fields shall be installed at the same location and depth as the tested area.
6. Installation shall conform with the equipment and installation methods identified in the approved plans.
7. Graywater stub-out plumbing may be allowed for future connection prior to the installation of irrigation lines and landscaping.

(b) Testing

1. Surge tanks shall be filled with water to the overflow line prior to and during inspection. All seams and joints shall be left exposed and the tank shall remain watertight.

2. A flow test shall be performed through the system to the point of graywater irrigation. All lines and components shall be watertight.

Section J-6 Procedure for Estimating Graywater Discharge

The Administrative Authority may utilise the graywater discharge procedure listed below, water use records, or calculations of local daily per person interior water use:

(a) The number of occupants of each dwelling unit shall be calculated as follows:

First Bedroom	2 occupants
Each additional bedroom	1 occupant

(b) The estimated graywater flows for each occupant shall be calculated as follows:

Showers, bathtubs and wash basins	25 GPD/occupant
Laundry	15 GPD/occupant

(c) The total number of occupants shall be multiplied by the applicable estimated graywater discharge as provided above and the type of fixtures connected to the graywater system.

Section J-7 Required Area of Subsurface Irrigation

Each irrigation zone shall have a minimum effective irrigation area for the type of soil and infiltration rate to distribute all graywater produced daily, pursuant to Section J-6, without surfacing. The required irrigation area shall be based on the estimated graywater discharge, pursuant to Section J-6 of this Appendix, or a method determined by the Administrative Authority. Each proposed graywater system shall include at least two irrigation zones and each irrigation zone shall be in compliance with the provisions of this Section.

If the mini-leachfield irrigation system is used, the required square footage shall be determined from Table J-2, or equivalent, for the type of soil found in the excavation. The area of the irrigation field shall be equal to the aggregate length of the perforated pipe sections within the irrigation zone times the width of the proposed mini-leachfield trench.

No irrigation point shall be within five vertical feet of highest known seasonal groundwater nor where graywater may contaminate the ground water or ocean water. The applicant shall supply evidence of ground water depth to the satisfaction of the Administrative Authority.

Section J-8 Determination of Irrigation Capacity

(a) In order to determine the absorption quantities of questionable soils other than those listed in Table J-2, the proposed site may be subjected to percolation tests acceptable to the Administrative Authority or determined by the Administrative Authority.

(b) When a percolation test is required, no mini-leachfield system or subsurface drip irrigation system shall be permitted if the test shows the absorption capacity of the soil is less than 60 minutes/inch or more rapid than 5 minutes/inch, unless otherwise permitted by the Administrative Authority.

(c) The irrigation field size may be computed from Table J-2, or determined by the Administrative Authority or a designee of the Administrative Authority.

Section J-9 Surge Tank Construction (Fig. 1, 2, 3 and 4)

(a) Plans for surge tanks shall be submitted to the Administrative Authority for approval. The plans show the data required by the Administrative Authority and may include dimensions, structural calculations, and bracing details.

(b) Surge tanks shall be constructed of solid, durable materials, not subject to excessive corrosion or decay and shall be watertight.

(c) Surge tanks shall be vented as required by Chapter 5 of this Code and shall have a locking, gasketed access opening, or approved equivalent, to allow for inspection and cleaning.

(d) Surge tanks shall have the rated capacity permanently marked on the unit. In addition, "GRAYWATER IRRIGATION SYSTEM, DANGER - UNSAFE WATER" shall be permanently marked on the surge tank.

(e) Surge tanks installed above ground shall have a drain and overflow, separate from the line connecting the tank with the irrigation fields. The drain and overflow shall have a permanent connection to a sewer or to a septic tank, and shall be protected against sewer line backflow by a backwater valve. The overflow shall not be equipped with a shut-off valve.

(f) The overflow and drain pipes shall not be less in diameter than the inlet pipe. The vent size shall be based on the total graywater fixture units, as outlined in UPC Table 4-3 or local equivalent. Unions or equally effective fittings shall be provided for all piping connected to the surge tank.

(g) Surge tanks shall be structurally designed to withstand anticipated loads. Surge tank covers shall be capable of supporting an earth load not less than 300 pounds per square foot when the tank is designed for underground installation.

(h) Surge tanks may be installed below ground in a dry well on compacted soil, or buried if the tank design is approved by the Administrative Authority. The system shall be designed so that the tank overflow will gravity drain to a sanitary sewer line or septic tank. The tank must be protected against sewer line backflow by a backwater valve.

(i) Materials

1. Surge tanks shall meet nationally recognised standards for non-potable water and shall be approved by the Administrative Authority.

2. Steel surge tanks shall be protected from corrosion, both externally and internally, by an approved coating or by other acceptable means.

Section J-10 Valves and Piping (Fig. 1, 2, 3 and 4)

Graywater piping discharging into a surge tank or having a direct connection to a sanitary drain or sewer piping shall be downstream of an approved waterseal type trap(s). If no such trap(s) exists, an approved vented running trap shall be installed upstream of the connection to protect the building from any possible waste or sewer gases. All graywater piping shall be marked or shall have a continuous tape marked with the words "DANGER - UNSAFE WATER". All valves, including the three-way valve, shall be readily accessible and shall be approved by the Administrative Authority. A backwater valve, installed pursuant to this Code, shall be provided on all surge tank drain connections to the sanitary drain or sewer piping.

Section J-11 Irrigation Field Construction

The Administrative Authority may permit subsurface drip irrigation, mini-leachfield or other equivalent irrigation methods which discharge graywater in a manner which ensures that the graywater does not surface. Design standards for subsurface drip irrigation systems and mini-leachfield irrigation systems follow:

(a) Standards for a subsurface drip irrigation system are:

1. Minimum 140 mesh (115 micron) one inch filter with a capacity of 25 gallons per minute, or equivalent, filtration shall be used. The filter back-wash and flush discharge shall be caught, contained and disposed of to the sewer system, septic tank, or with approval of the Administrative Authority, a gravel sump. A gravel sump shall be sized to accept all the back-wash and flush discharge water. Filter backwash water and flush water shall not be used for any purpose. Sanitary procedures shall be followed when handling filter back-wash and flush discharge or graywater.

2. Emitters shall have a minimum flow path of 1200 microns and shall have a coefficient of manufacturing variation (Cv) of no more than seven percent. Irrigation system design shall be such that emitter flow variation shall not exceed plus or minus ten percent. Emitters shall be recommended by the manufacturer for subsurface use and graywater use, and shall have demonstrated resistance to root intrusion. For emitter ratings refer to: Irrigation Equipment Performance Report, Drip Emitters and Micro-Sprinklers, Centre for Irrigation Technology, California State University, 5730N. Chestnut Avenue, Fresno, California 93740-0018.

3. Each irrigation zone shall be designed to include no less than the number of emitters specified in Table J-3, or through a procedure designated by the Administrative Authority. Minimum spacing between emitters is 14 inches in any direction.

4. The system design shall provide user controls, such as valves, switches, timers, and other controllers as appropriate, to rotate the distribution of graywater between irrigation zones.

5. All drip irrigation supply lines shall be PVC class 200 pipe or better and schedule 40 fittings. All joints shall be properly glued, inspected and pressure tested at 40 psi, and shown to be drip tight for five minutes, before burial. All supply lines will be buried at least eight inches deep. Drip feeder lines can be poly or flexible PVC tubing and shall be covered to a minimum depth of nine inches.

6. Where pressure at the discharge side of the pump exceeds 20 pounds per square inch (psi), a pressure reducing valve able to maintain downstream pressure no greater than 20 psi shall be installed downstream from the pump and before any emission device.

7. Each irrigation zone shall include an automatic flush valve/vacuum breaker to prevent back syphonage of water and soil.

(b) Standards for the mini-leachfield system are: (Fig. 5)

1. Perforated sections shall be a minimum 2 inch diameter and shall be constructed of perforated high density polyethylene pipe, perforated ABS pipe, perforated PVC pipe, or other approved materials, provided that sufficient openings are available for distribution of the graywater into the trench area. Material, construction and perforation of the piping shall be in compliance with the appropriate absorption field drainage piping standards and shall be approved by the Administrative Authority.

2. Clean stone, gravel, or similar filter material acceptable to the Administrative Authority, and varying in size between 3/4 inch to 2 1/2 inches shall be placed in the trench to the depth and grade required by this Section. Perforated sections shall be laid on the filter material in an approved manner. The perforated sections shall then be covered with filter material to the minimum depth required by this Section. The filter material shall then be covered with landscape filter fabric or similar porous material to prevent closure of voids with earth backfill. No earth backfill shall be placed over the filter material cover until after inspections and acceptance.

3. Irrigation fields shall be constructed as follows:

	Minimum	Maximum
Number of drain lines per irrigation zone	1	---
Length of each perforated line	---	100 feet
Bottom width of trench	6 inches	18 inches
Total depth of trench	12 inches	18 inches
Spacing of lines, centre to centre	4 feet	---
Depth of earth cover of lines	6 inches	---
Depth of filter material cover of lines	2 inches	---
Depth of filter material beneath lines	2 inches	---
Grade of perforated lines	level	3 inches/ 100 feet

Section J-12 Special Provisions

(a) Other collection and distribution systems may be approved by the Administrative Authority as allowed by Section 201 of the UPC.

(b) Nothing contained in this Appendix shall be construed to prevent the Administrative Authority from requiring compliance with stricter requirements than those contained herein, where such stricter requirements are essential in maintaining safe and sanitary conditions or from prohibiting graywater systems.

Section J-13 Health and Safety

(a) Graywater may contain faecal matter as a result of bathing and/or washing of diapers and undergarments. Water containing faecal matter, if swallowed, can cause illness in a susceptible person.

(b) Graywater shall not include laundry water from soiled diapers.

(c) Graywater shall not be applied above the land surface or allowed to reach the land surface, and shall not be discharged directly into or reach any storm sewer system or any water of the United States.

(d) Graywater shall be not be contacted by humans, except as required to maintain the graywater treatment and distribution system.

(e) Graywater shall not be used for vegetable gardens.

Table J-1 Location of Graywater System

Minimum Horizontal Distance (in feet) from	Surge Tank	Irrigation Field
Buildings or structures	5 ft[2]	8 ft[3]
Property line adjoining private property	5 ft	5 ft
Water supply wells	50 ft	100 ft
Stream and lakes	50 ft	50 ft
Seepage pits or cesspools	5 ft	5 ft
Irrigation field and 100% expansion area	5 ft	4 ft[5]
Septic tank	0 ft	5 ft[6]
On-site domestic water service line	5 ft	5 ft[6]
Pressure public water main	10 ft	10 ft[7]
Water ditches	50 ft	50 ft

Notes: When mini-leach fields are installed in sloping ground, the minimum horizontal distance between any part of the distribution system and ground surface shall be fifteen feet.

1. Including porches and steps, whether covered or uncovered, but does not include car ports, covered walks, driveways and similar structures.

2. The distance may be reduced to zero feet for above ground tanks if approved by the Administrative Authority.

3. The distance may be reduced to two feet, with a water barrier, by the Administrative Authority, upon consideration of the soil expansion index.

4. Where special hazards are involved, the distance may be increased by the Administrative Authority.

5. Applies to the mini-leachfield type system only. Plus two feet for each additional foot of depth in excess of one foot below the bottom of the drain line.

6. Applies to mini-leachfield type system only.

7. Applies to mini-leachfield type system only. For parallel construction or for crossings, approval by the Administrative Authority shall be required.

Table J-2 Mini-Leach Field Design Criteria of Six Typical Soils

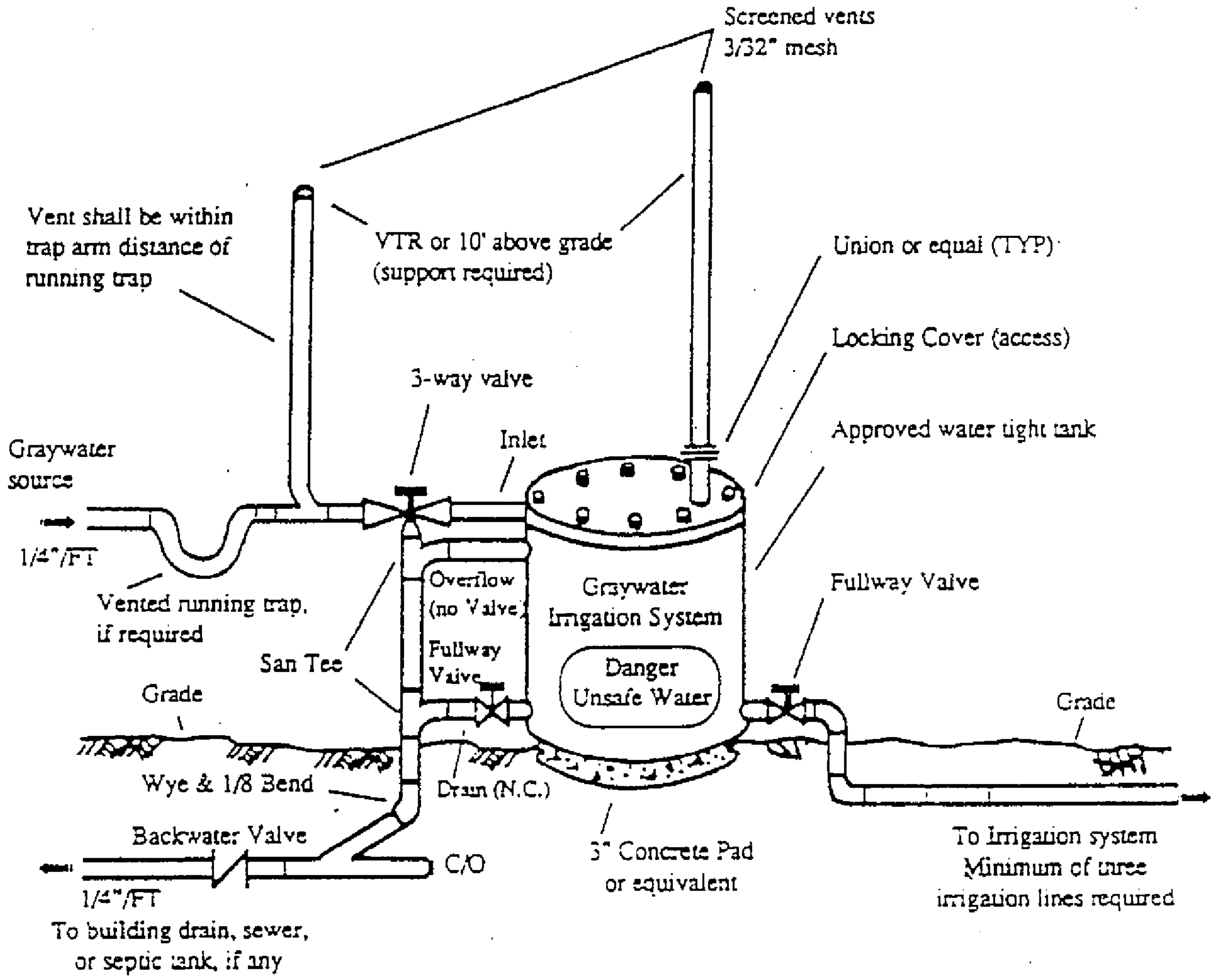
	Minimum sq. ft. of irrigation area per 100 gallons of estimated graywater discharge per day	Maximum absorption capacity, minutes per inch, or irrigation area for a 24 hour period
1. Coarse sand or gravel	20	5
2. Fine sand	25	12
3. Sandy loam	40	18
4. Sandy clay	60	24
5. Clay with considerable sand or gravel	90	48
6. Clay with small amount of sand or gravel	120	60

Table J-3 Subsurface Drip Design Criteria of Six Typical Soils

	Minimum sq. ft. of irrigation area per 100 gallons of estimated graywater discharge per day	**Maximum absorption capacity, minutes per inch, or irrigation area for a 24 hour period**
1. Sand	1.8	.6
2. Sandy loam	1.4	.7
3. Loam	1.2	.9
4. Clay loam	.9	1.1
5. Silty clay	.6	1.6
6. Clay	.5	2.0

Use the daily graywater flow calculated in Section J-6 to determine the number of emitters per line.

GRAYWATER SYSTEM
Single Tank - Gravity (conceptual)

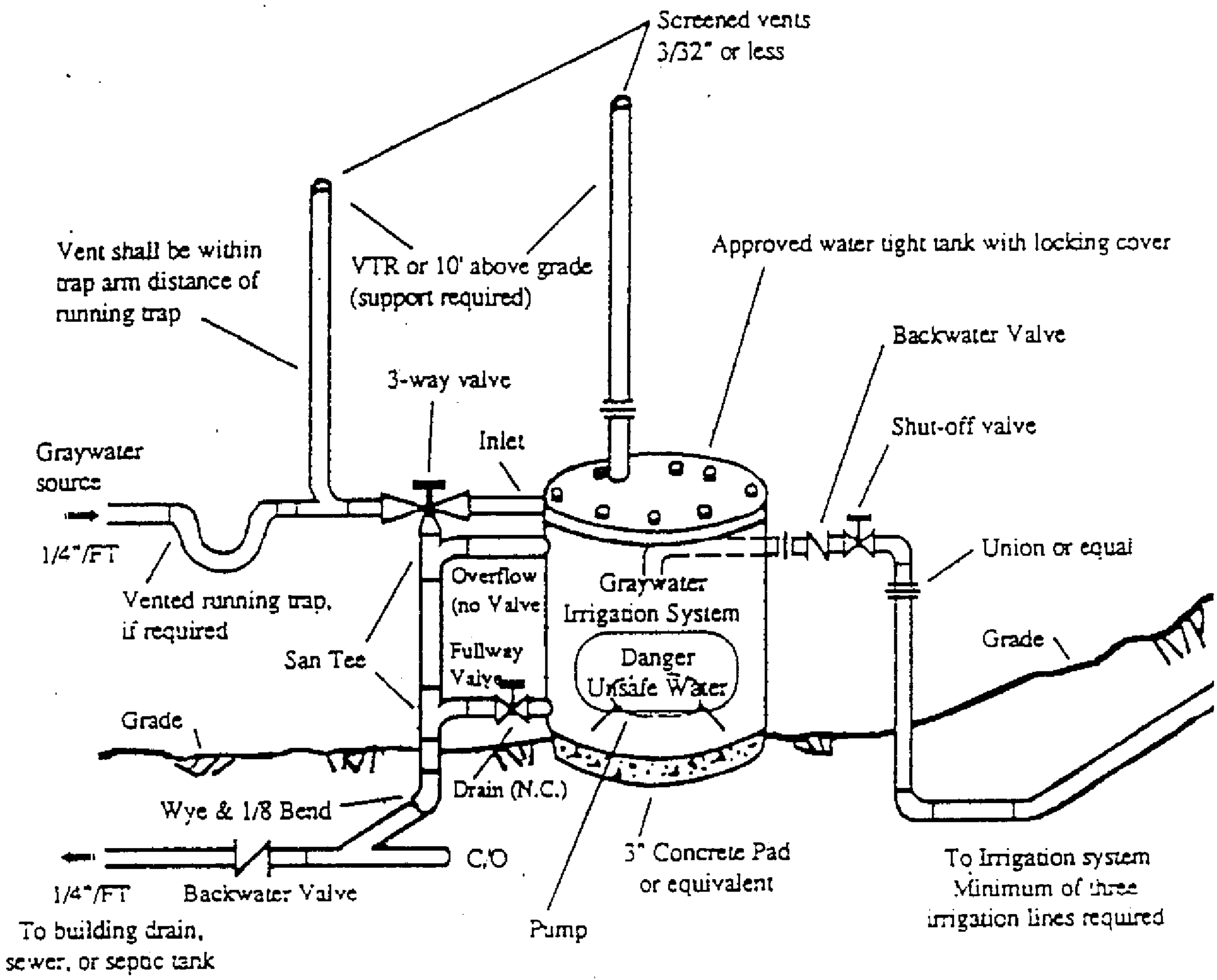


Abbreviations

C/O	Cleanout
N.C.	Normally Closed
VTR	Vent Thru Roof

California Plumbing Code Appendix J	Figure 1 Date: 4-93 Revised: DRAFT

GRAYWATER SYSTEM
Single Tank - Pumped (conceptual)



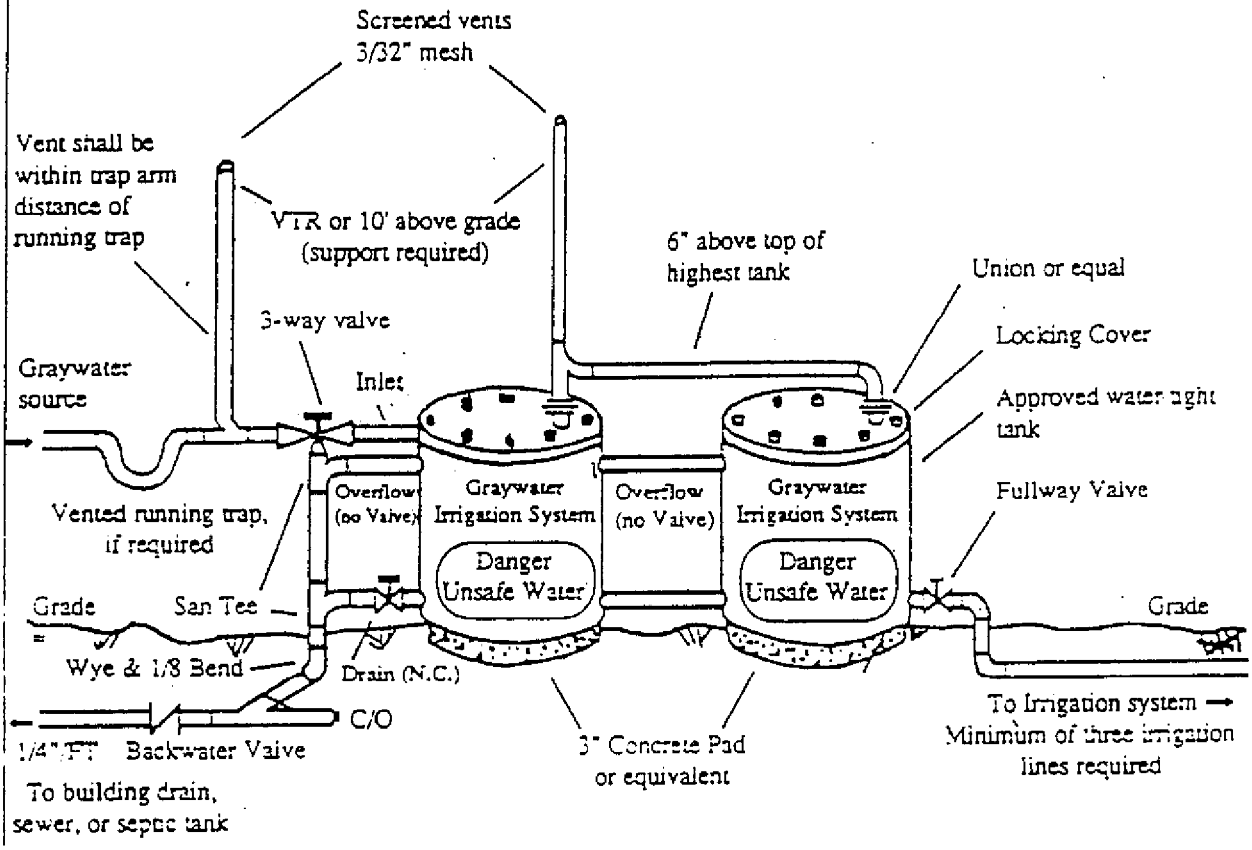
Abbreviations

C/O	Cleanout
N.C.	Normally Closed
VTR	Vent Thru Roof

California Plumbing Code
Appendix J

Figure 2
Date: 4-93
Revised: DRAFT

GRAYWATER SYSTEM
Multiple Tank (conceptual)



Abbreviations

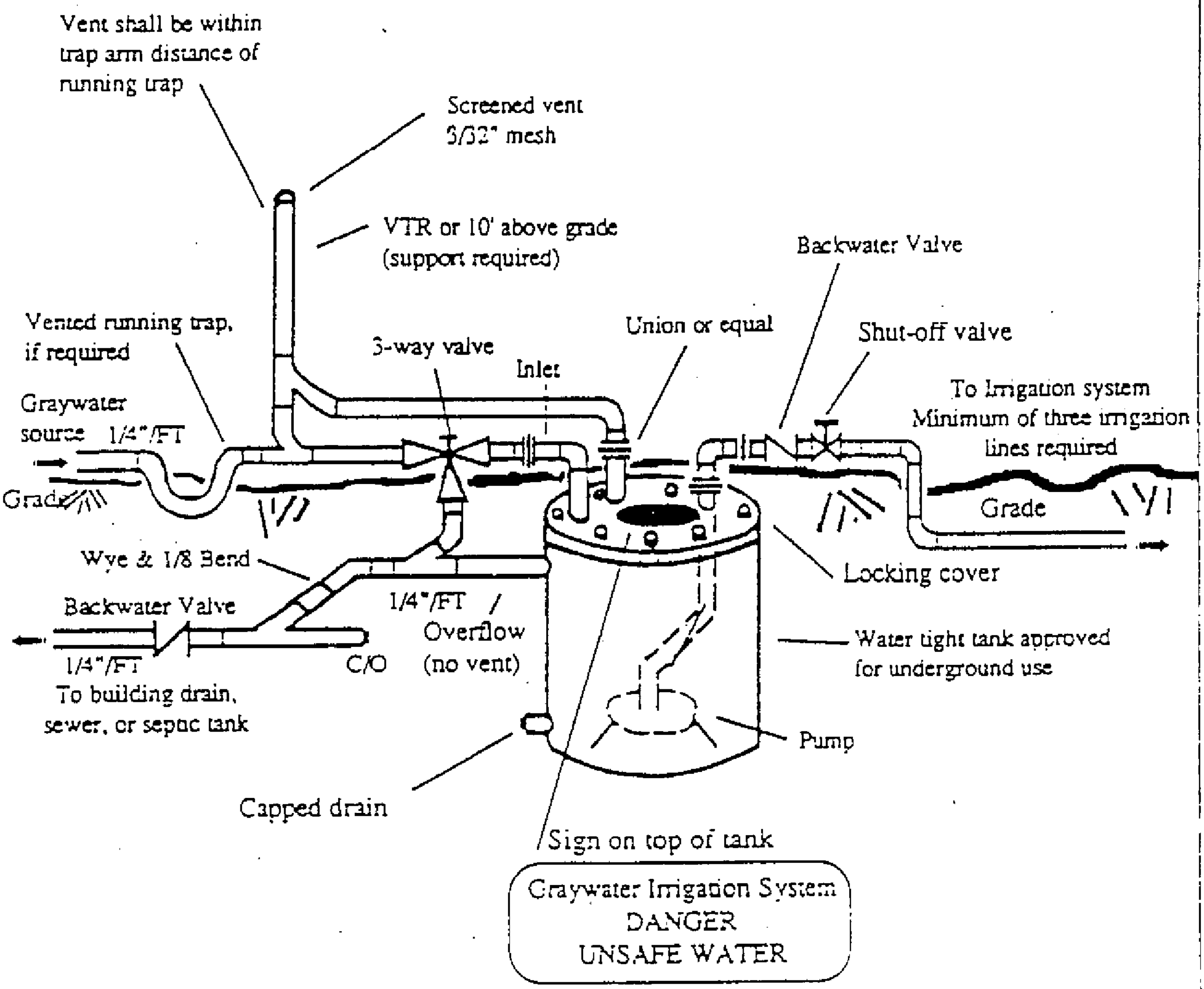
C/O	Cleanout
N.C.	Normally Closed
VTR	Vent Thru Roof

California Plumbing Code
Appendix J

Figure 3

Date: 4-93
Revised: DRAFT

GRAYWATER SYSTEM
Underground Tank (conceptual)

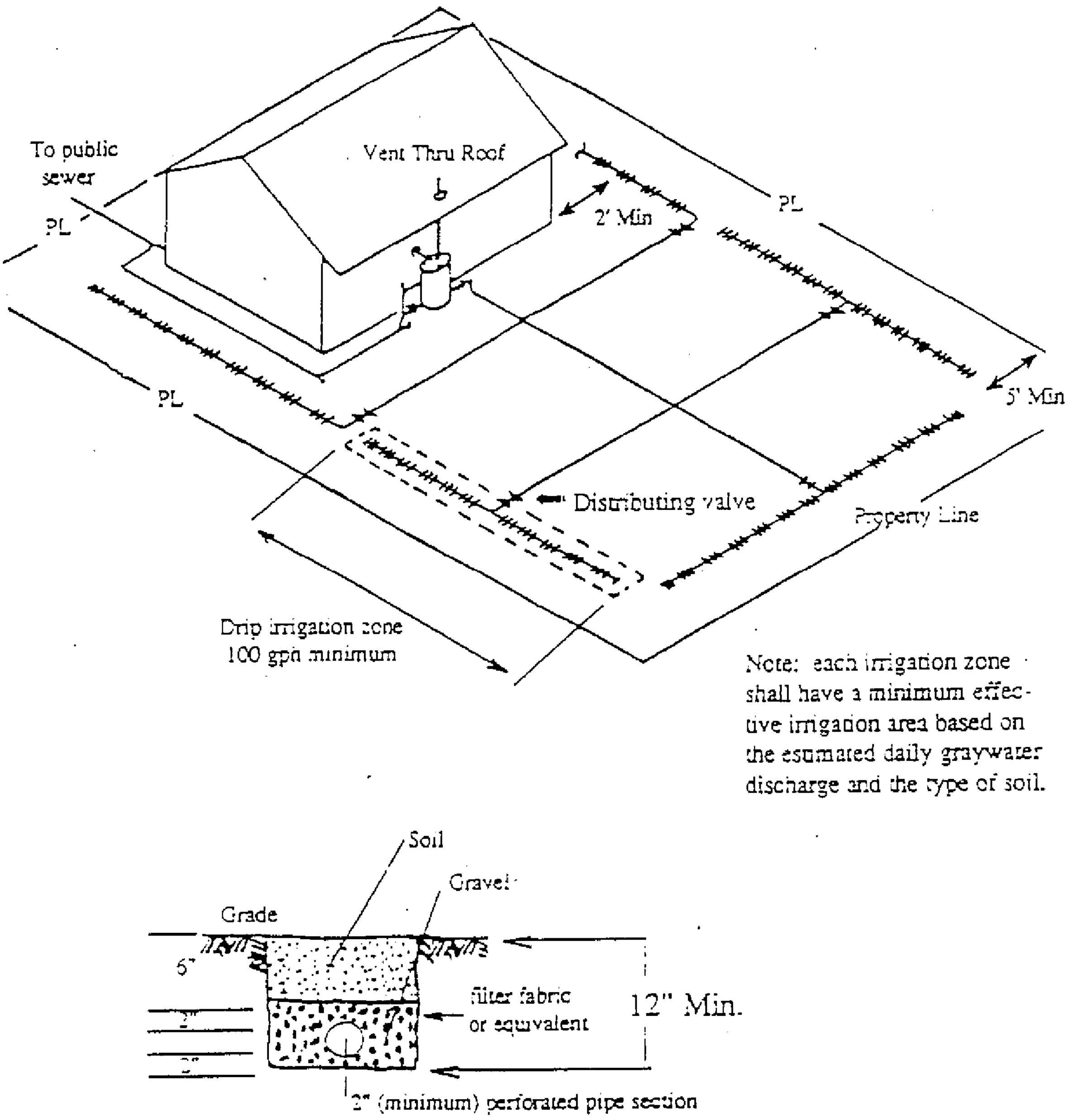


Abbreviations

C/O Cleanout
VTR Vent Thru Roof

California Plumbing Code Appendix J	Figure 4
	Date: 4-93 Revised: DRAFT

GRAYWATER SYSTEM
Irrigation Layout (conceptual)



California Plumbing Code
Appendix J

Figure 5

Date: 4-93
Revised: DRAFT

APPENDIX A4

Requirements of DIN 1988 in
respect of rainwater utilisation facilities

Translated from:
Rainwater utilisation in housing, Part 1, (in German)
IKZ- Haustechnik, October 1992, no 19, pp 21-23.

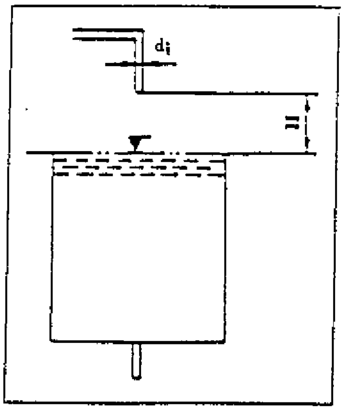
No. of Pages: 7

Requirements of DIN 1988 in respect of rainwater utilisation facilities

The water collected from roof gutters is not for human consumption and belongs to Class 5 in accordance with DIN 1988, Part 4 [3]: "risk to health due to pathogens of infectious diseases". The following is stipulated in DIN 1988, Part 4, Section 3.2.1, "Connection with facilities for non-drinking water": "It is not permitted to connect drinking water facilities directly to facilities for non-drinking water." For long-term purposes, an indirect connection only via an open outlet is permitted due to the great risk posed to drinking water supplies by non-drinking water systems. This is described in more detail in DIN 1988, Part 4, Section 4.2.1 (Figure 2).

Figure 2: Open outlet in accordance with DIN 1988, Part 4 [3]

Key: ♦ = the highest possible water level, a limiting water level for safety alone (See DIN 1988, Part 1); d_i = internal pipe diameter, inlet; H = safety distance $H > 2\ d_i$, but no less than 20 mm between the lower edge of the inlet and the highest possible water level.



The open outlet for the supply of drinking water in dry seasons can in practice be implemented by means of a solenoid valve fitted with a float switch. However, it is imperative that the distance for an open outlet be maintained here also.

It must be noted that the open outlet must be arranged above the limiting backpressure level specified by the local authority (local government law). If the backpressure level has not been specified, the street level at the point of connection will apply as the backpressure level (see DIN 1986, Part 1, Section 7.1 [4]).

The backpressure level must likewise be noted for the connection of the tank overflow and the tank outlet. If necessary, an automatic lifting device must be provided (see DIN 1986, Part 1, Section 7.2.1 [4]).

Operation of the rainwater utilisation facility

DIN 1988 states in Appendix A to Part 8 [5] that the open outlet (level control unit) must be inspected at least once every year. During this inspection, the safety distance (water level adjustment) of the inlet valve and overflow with the inlet open fully must be checked. In addition, a visual inspection of the aeration and venting must be carried out. This inspection may be undertaken by the operator or by an installation company.

As DIN 1988 deals only with drinking water installation facilities, the construction and operation of rainwater utilisation facilities are, of course, not described in this standard. At a seminar on rainwater utilisation facilities which took place at the beginning of February 1991 in Berlin [6], planners demanded that regular inspections of rainwater utilisation facilities should be undertaken by the water companies. However, the water companies have opposed this, with some justification.

In a document issued by the *Bundestag* [German Parliament] [7], the Federal Government gave the following answer to a question: "Private water procurement facilities for rainwater or grey water must, in the opinion of the Federal Government, be subject to continual monitoring by the public health department. This would result in a considerable expansion of the responsibility of the public health service, the success of which cannot be guaranteed due to a lack of staff and high costs.

As the user of a rainwater utilisation facility is likely, as a rule, to be a non-professional, it is essential that inspection and maintenance timetables are issued (Table 3). However, the actual implementation of this work, in particular the cleaning work, cannot be ensured with any degree of certainty without monitoring. Therefore, the system installer should recommend to the building owner that he conclude a maintenance contract.

Table 3: Inspection and maintenance plan

Part of facility	Inspection	Cleaning and maintenance
Gutter	Every two months	Twice a year (Spring and Autumn)
Leaf trap/leaf-capturing trap	Every two months	Twice a year (Spring and Autumn)
Fine-mesh filter	Every two months	Every two months
Storage tank	Every two months	At least once a year
Pressure increase unit	Once a year	Once a year
Pipelines	Once a year	As required
Drinking water supply	Once a year	As required

Examples of rainwater utilisation facilities

The individual components of a rainwater utilisation facility have already been described at the beginning of this article.

Rainwater utilisation facilities are basically distinguished by the position and number of traps or filters. Figure 3 shows the arrangement of a storage tank in a basement, and Figure 4 shows the arrangement of a storage tank outside the building.

Figure 3: Internal rainwater utilisation facility with storage tank [8].

Blättersieb = Leaf trap
Fallrohr = Downpipe
Stadtwassernetz = Municipal water main
Magnetventil = Solenoid valve
Frischwassernachspeisung = Fresh water supply
Überlauf zum Kanal = Overflow to drain
Feinfilter = Fine-mesh filter

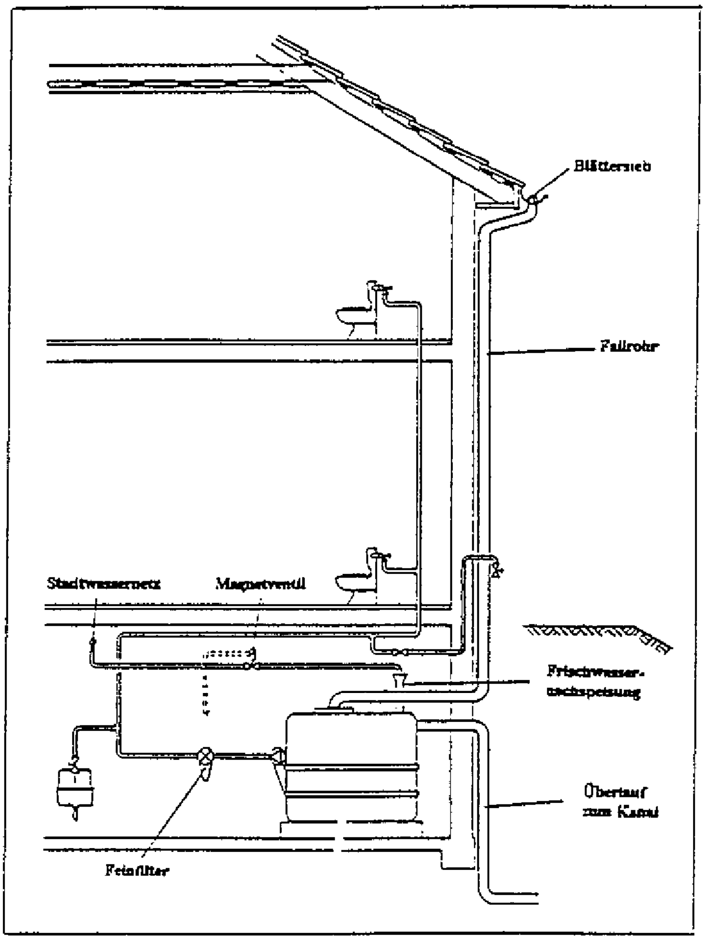
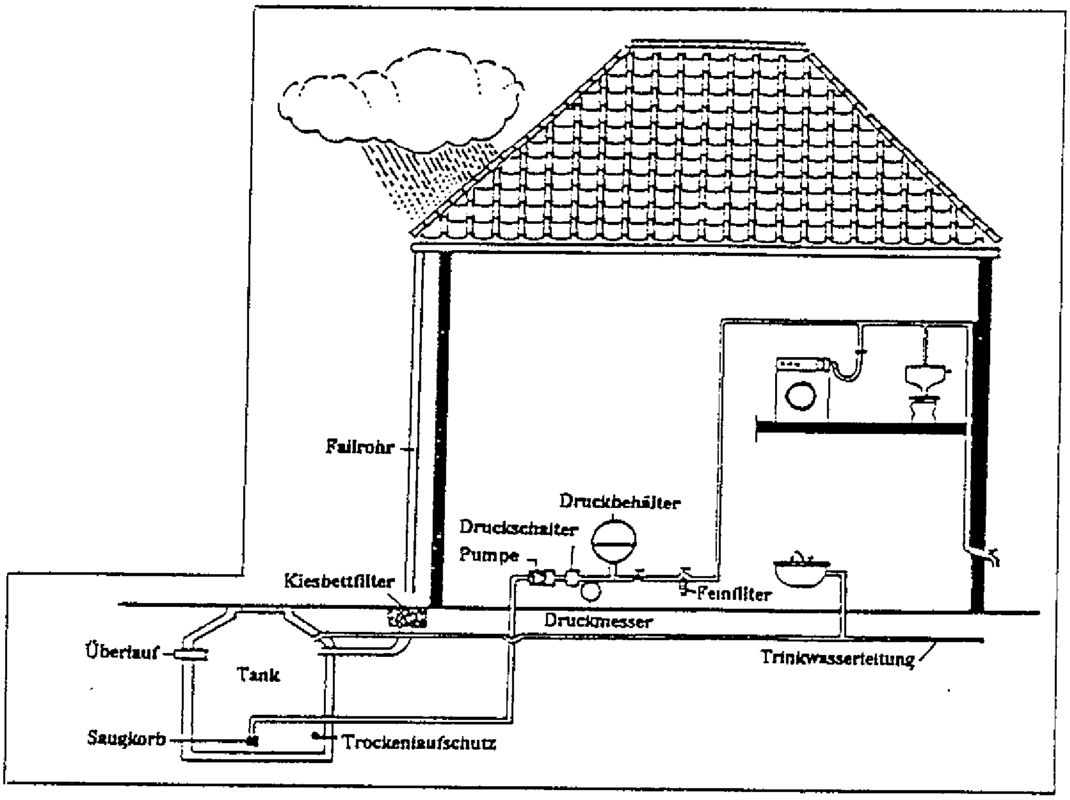


Figure 4: External rainwater utilisation facility with storage tank [9].

Fallrohr = Downpipe
Druckbehälter = Pressure tank
Druckschalter = Manostat
Pumpe = Pump
Feinfilter = Fine-mesh filter
Kiesbettfilter = Gravel filter
Druckmesser = Pressure gauge
Trinkwasserleitung = Drinking water pipe
Überlauf = Overflow
Tank = Tank
Saugkorb = Pump strainer
Trockenlaufschutz = Protection against running dry

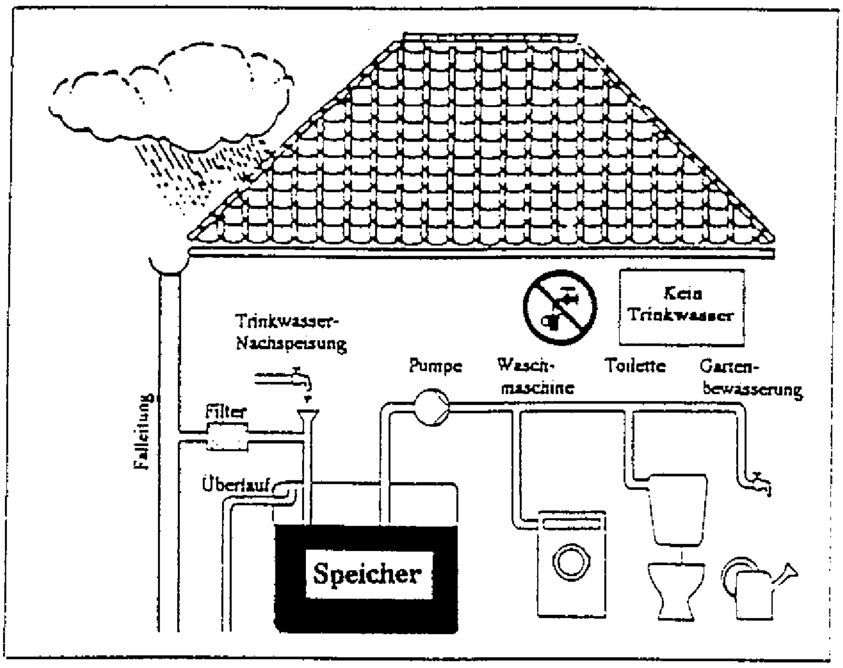


Labelling rainwater utilisation facilities

According to DIN 1988, Part 2, Section 3.3.2, supply points for non-drinking water (including rainwater) must be marked, in writing or by means of a picture, with the words "Not for drinking" (prohibitive sign V 5 in accordance with DIN 4844, Part 1 – see Figure 1). It is recommended that the points at which water is tapped off from rainwater utilisation facilities on the outer walls of buildings (garden tap) be protected (childproofed) against improper use by removable turning handles or other means.

Figure 1: Diagram of a rainwater utilisation facility [1].

Kein Trinkwasser = Not for drinking
Trinkwassernachspeisung = Drinking water supply
Pumpe = Pump
Waschmaschine = Washing machine
Toilette = Toilet
Gartenbewässerung = Supply for watering garden
Falleitung = Downpipe
Überlauf = Overflow
Speicher = Storage tank



Compact facilities

Various companies are already offering compact rainwater utilisation facilities; that is to say, facilities in which only the power supply plug has to be inserted in a socket and the connections for drinking water and overflow water have to be fitted.

Summary

The piped domestic utilisation of rainwater (water collected from roof gutters) is assessed as follows from a technical point of view:
Rainwater utilisation facilities are technically possible.
The direct connection of rainwater utilisation facilities to drinking water installations is forbidden. The rainwater utilisation facility must be separated from the drinking water installation by means of an open outlet or an anti-vacuum device A I (see DIN 1988).

The risk of confusing rainwater with drinking water is specified, in particular as far as children are concerned (such as at the garden tap).
Cross-connection (direct connection) of the rainwater utilisation facility to the drinking water installation at a later stage is to be avoided.
Maintenance carried out by non-professionals on rainwater utilisation facilities is questionable. ❑

References

[1] Twin-Informationen des DVGW zur Trinkwasserinstallation, No. 5, 10/91.

[2] DIN 1988, Part 5: Technische Regeln für Trinkwasser-Installationen (TRW1): Druckerhöhung und Druckminderung: Technische Regel des DVGW, 12/88.

[3] DIN 1988, Part 4: Technische Regeln für Trinkwasser-Installationen (TRW1): Schutz des Trinkwassers, Erhaltung der Trinkwassergüte: Technische Regel des DVGW, 12/88.

[4] DIN 1986, Part 1: Entwässerungsanlagen für Gebäude und Grundstücke: Technische Bestimmungen für den Bau, 6/88.

[5] DIN 1988, Part 8: Technische Regeln für Trinkwasser-Installationen (TRW1): Betrieb der Anlagen: Technische Regel des DVGW, 12/88.

[6] Fortbildungszentrum Gesundheits- und Umweltschutz Berlin e.V.: Wasserspuren im häuslichen Bereich. Seminar held on 4.2.1991 in Berlin.

[7] German *Bundestag*: Novellierung der Trinkwasserverordnung erschwert Regen- und Grauwassernutzung als wesentliche Elemente eines sparsamen Umgangs mit Wasser. Document 11/8031 of 2.10.1990.

[8] Handbuch Regenwassernutzung, Wilo-Werk GmbH & Co., Dortmund.

[9] Broschüre Regenwassernutzung im Haus, Hamburg Environmental Authority/Hamburger Wasserwerke GmbH.

[10] Moll, B: Regenwassernutzung, Fachliche Berichte, Hamburger Wasserwerke GmbH 9 (1990), No. 2.