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Innovation in on-site domestic water management systems in Australia:

A review of rainwater, greywater, stormwater and wastewater utilisation techniques

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1. Introduction

This report reviews new and innovative techniques of domestic scale water management. The purpose is to provide assessment and comment on new technological and system monitoring innovations in Australia, which promote the reduction in potable water usage or reuse of water at the single house scale. The outcome of this assessment is the identification of knowledge gaps and directions for future research in this area.

The installation of single house water and wastewater services is relatively common in Australia, with up to 17% of all households utilising rainwater with 13% as the main source of drinking water (ABS, 1998) and 18 to 20% using septic tanks or other on-site systems in non-sewered areas (O'Keefe, 2001). Many rural properties are independent of water and wastewater infrastructure. However, in the urban environment the percentage of water and wastewater autonomous properties decreases and in many states water companies or councils can charge for connection to reticulated water or stormwater and sewage collection, where the infrastructure passes within the locality of the property, even if the property is not connected. Legislation regarding the installation and reuse of treated water from different on-site systems also varies from state to state and these are reviewed in other sections of the Australian Water Conservation and Recycling Research Program Stage 1 review and by O'Keefe (2004).

The management of water and wastewater at single house scale in urban environments may currently be limited in application, but, as a component of integrated water management it is necessary to identify possible techniques at this scale for more detailed assessment, despite current regulatory requirements. For example, source control measures and reuse of water flows at the single house scale may prove a viable alternative or component of larger scale recycling processes.

The primary selection criterion for techniques reviewed in this report was innovation; utilisation of techniques, processes, methods or practices that are significantly different to traditional water management at the single house scale in both the urban and rural environment. Secondary selection criteria for the techniques reviewed, are that the technique is currently available or implemented in Australia and provides local water use reduction, water use or wastewater reuse.

In order to avoid a technology bias within this review the word 'technique' is used to describe technological, organisational, social and institutional innovations in water management at the single household level. This broader review scope recognises the importance of non technological innovation in moving towards longer term sustainability goals.

Technologies reviewed include those for the collection, treatment, storage, distribution and/or reuse of:

- Rainwater
- Stormwater
- Greywater
- Wastewater

In addition to the definition of 'technique', the term innovation also requires clarification of meaning in order to describe the assessment carried out in this review. Innovation can be defined as the process which occurs between invention, which is the initial idea for a new

or improved product, and diffusion, which describes the use and adoption of the innovation over time. The conventional understanding of the term innovation distinguishes between product, process and organisational innovation (OECD, 1997). Process innovations occur when a given amount of output can be produced with less input, product innovations occur when improvements to existing goods or services are required and organisational innovations include new forms of management. Whilst this definition includes both technological and organisational change, innovations at the household and institutional level are not included, nor are any improvements to 'bigger picture' impacts. Thus, this review assesses broader innovative techniques which develop new ideas, behaviour, products, and processes at all levels and produce a reduction of environmental burdens or contribute to ecologically specified sustainability targets.

The purpose of the review is to provide comment on areas of environmental innovation in allotment scale water management techniques and to provide quantitative and qualitative assessment of their appropriateness. When assessing new and innovative techniques the availability of quantitative information is often limited. Thus, for the purpose of this review surrogate measures are often used. For example, in the absence of long term case study data, the reliability of techniques is assessed in terms of the monitoring and control provided and the user maintenance required. Where no data exists regarding the potable water savings of particular techniques, data generated from computer modelling of case study sites is reported.

2. Structure of this report

In Sections 3 to 6 technologies identified are assessed in terms of the following criteria:

- Potable water savings
- End use options
- Materials of construction
- Operational and maintenance requirements
- Total water cycle impacts
- Other environmental impacts

Technology treatment trains are categorised primarily by water source; rainwater, stormwater, greywater and wastewater. A brief description of traditional techniques and technologies is given, followed by descriptions of specific innovative techniques which illustrate new approaches to the different functions of the treatment train; collection, treatment, storage and/or distribution of water and wastewater. There are overlaps between the different treatment train components, for example a storage may also provide treatment, and so innovative processes are described in combinations of the categories.

Detail of monitoring and control measures implemented in case study sites or as described in manufacturers literature is then provided. Potential water savings of the techniques are summarised from case study sites and detail provided on materials used and energy requirements where available. To complete the assessment of each technology type a summary of additional benefits and impacts on the water cycle and the environment is given.

In Section 7, social, organisational and institutional barriers to the uptake of technological approaches are described and commented upon in order to highlight the need for

integration of both structural and non structural techniques. A review of all non structural techniques was not considered in the scope of this review due to time limitations and the requirement for additional expertise and data to verify the benefits and impacts of these techniques.

Data was collected from a number of sources including:

- Technology manufacturers
- Other researchers
- Environmental organisations
- Published literature
- Unpublished literature

Quantitative information from system manufacturers is included in the review where no other verifiable source was available. Information from unpublished literature was verified with other sources where possible.

The final discussion provides comment on the review process itself and the availability of data. Knowledge gaps are identified which provide the basis for future research direction. The primary areas of innovation are discussed and possibilities for future water management techniques and technology integration and innovation are proposed. Comment is also provided on the optimum water saving combinations of different rainwater, greywater, stormwater and wastewater systems and a number of case studies are reviewed.

3. Rainwater

3.1. Traditional techniques

For the purposes of this review rainwater is defined as that collected from the roofs of properties.

Rainwater has been collected from the roofs of dwellings for use within the home since early settlement of Australia. Collection system and tank design have not changed much since this time and many properties in rural areas still rely on collected rainwater as their only source of supply. Additions have been made to the basic gutter and pipe collection system and tank, including gutter filters and guards, rain heads, vortex flow separation devices, mosquito screens and filters. First flush devices have also gained popularity although the effectiveness of these devices in improving stored water quality has not been thoroughly assessed.

3.2. Innovation

3.2.1. Collection and storage

Recent technical innovations in rainwater use have primarily been in the collection and storage of rainwater. The poor suitability and practicality of installing the traditional cylindrical tank to smaller urban gardens has been highlighted in community surveys examining the feasibility of rainwater use in urban areas (Pepperdine, 1995; Maheepala *et al.,* 2003) and innovation in design has followed.

An example of such innovation is a rainwater collection, treatment and storage system which replaces all traditional guttering in the home (**Figure 1** www.rainsaver.com.au). A leaf guard is integral to the design and coarse filtration and sedimentation provide the treatment step. Manufacturers recommend the stored water can be used for toilet flushing or garden watering. Potable water backup is supplied directly to the guttering to provide a reliable supply. The standard storage capacity for this system is 26 L/m of guttering and so for a 250 m^2 house (16m x 16m) this would provide minimum storage of approximately 1650 L per property. A comprehensive investigation of the supply/demand patterns for different climatic regions and end use patterns is required to assess potential water savings for this technology. Assessment is currently being carried out by GHD.

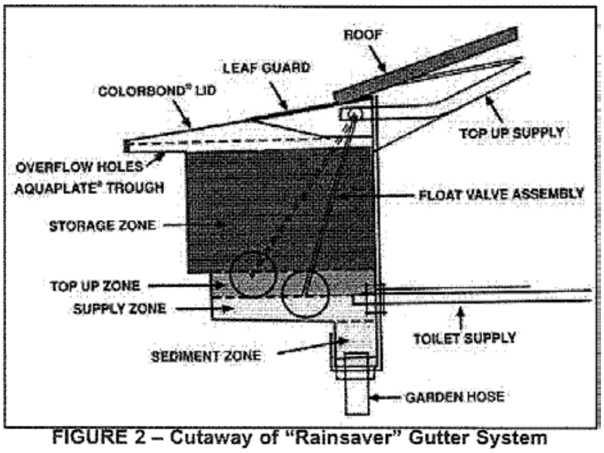


FIGURE 2 – Cutaway of "Rainsaver" Gutter System

(Courtesy: Frank Smith, Rainsaver Pty. Ltd.)

Figure 1 – Cutaway of Rainsaver Gutter System

Other storage options include fused polypropylene sacs that can be rolled or folded to fit through restricted openings, so can be installed underneath a house or decking (Figure 2 www.rainreviva.com.au). The sacs will contour to irregular foundations and this increased flexibility and reduction in area requirements is particularly suited to existing properties. These storage devices are available in standard capacities of 2,500 and 3,500 L with made to measure tanks available. The fabric of manufacture is puncture resistant but with ideal location underneath existing stumped houses or decks the detection of leaks may be difficult. Assuming only 25% of the area underneath a stumped house is suitable for storage a 250 m^2 property could have up to 20,000 L of storage (assuming 0.3 m depth).

Figure 2 – Rain reviva flexible rainwater storage

Storages that can be incorporated into boundary fences or built into the structural components of a building such as a shed, are also available (www.freewater. com.au). In the example in Figure 4 the capacity of each polyethylene panel is approximately 220 L, so for example a 250 m^2 house on a 1000 m^2 lot (32 m x 32 m) with two boundary fences, a minimum of 10,000 L could be stored (module width 0.72 m).

Figure 3 – Freewater™ module

3.2.2. Treatment and distribution

Use of existing hot water systems to disinfect rainwater is one recent end use innovation. A number of studies are examining the effectiveness of this type of disinfection under different heating system configurations (Spinks *et al*., 2003; Coombes *et al.,* 2000; CRC Water Quality and Treatment P2.6.0.4, 2003; 60L, The Green Building, Carlton, Victoria). Results have shown that water related bacteria rapidly die off in temperatures relevant to domestic hot water systems (60˚C) with this effect being observed in case study systems. However, this process does not provide residual disinfection.

In addition to the investigation of thermal disinfection techniques, the use of ultraviolet disinfection and point of use or entry filtration devices are being considered for treating water at the property boundary or at the tap. Many such systems exist but primary marketing has been in the improvement of potable water quality. They are now finding application in the treatment of rainwater (CRC Water Quality and Treatment, Project P2.6.0.4, 2003). Maintenance of point of use or entry devices is necessary in order to ensure correct operation, UV elements can fail and filters can foul. Neither UV nor filtration devices provide residual disinfection. Both the above techniques for rainwater disinfection, can treat all or a selected end use (i.e. kitchen tap) of collected rainwater prior to use.

Other advances have been made in source control measures, in which possible contamination is reduced by engineering the collection system. One example is Smartflo® guttering, designed for minimal maintenance, and is installed in the Sustainable House in Sydney (Mobbs, 1998).

3.2.3. Monitoring and control

A review of manufacturer's literature found few innovative control or monitoring measures for rainwater systems. Pump overpressure and backflow prevention in potable water backup are standard for most systems although these control measures are not always identified in marketing literature. Few case study sites have been monitored for quality of

pure rainwater, rainwater runoff from roofs or raintank outflow despite the high percentage of tanks used in the community (Thomas and Greene, 1993; Mobbs, 1998; Gardner *et al*., 2002(? Refs have 2001 and 2003 not 2002); Coombes, 2002) and no literature has been identified which recommends indicator parameters for on-line monitoring of quality.

3.3. Potable water saving and energy requirement

Climate, end use, collection area and storage capacity will all affect the achievable range of potable water savings from raintank installation and use. Results of modelling different climatic conditions has shown that areas with consistent higher rainfall patterns (i.e. Brisbane) provide improved water savings for the same end uses (Gray, 2004). In addition, increased savings are possible when temporally continuous end uses are supplied i.e. toilet flushing, as opposed to garden uses where demand is highest when supply is reduced. These modelling observations are demonstrated in some case study sites (Table 1).

The operating energy requirements and capital costs of rainwater tanks will depend upon a number of issues, primarily the end uses of the water, the required reliability and the siting of the storage. For example, generally garden irrigation systems do not require pumping for distribution, unless the storage is located underground or the topography dictates pumping.

Table 1 – Summary of potable water savings for case study sites and modelling investigations

Reference	***Location***	***End use***	***Tank description and size (kL)***	***% potable water reduction***
McAlister, 1999	Canberra, ACT	Irrigation & toilet flushing	Not stated	20%
Smith, 1999	Sydney, NSW	Irrigation & toilet flushing	Storage guttering (30 L of water/m)	27%
www.unisa.edu.au/water/prototypes/Regent_Gardens.html	Adelaide, SA	Hot water system & kitchen[1]	2 kL	30%[2]
Gardner et al., 2001	Gold Coast, Queensland	All household uses (with potable back-up)	22kL	32%
Apostolidis, 2003	Brisbane, Queensland	Laundry, toilet flushing and hot water supply	20kL	50%
Coombes, 2003(correct year?)	Newcastle, NSW	Irrigation, hot water system and toilet flushing	0.91kL	52%

[1] Ultra-violet disinfection system installed for kitchen uses
[2] Predicted value in combination with greywater

3.4. Other benefits and impacts

In addition to savings in potable water the installation of raintanks also provides the benefit of on-site retention of stormwater, which will reduce stormwater peak discharge flows and thus reduce the requirements of stormwater infrastructure. Also, where raintanks are supplied with backup by potable water, backup can be designed to provide a trickle feed, and thus reduce peak flows in potable water supply and infrastructure requirements. However, trickle feed backup will mix with residual rainwater in storage which may be of lower quality and so potable water will require a second treatment (in addition to that provided by reticulated system) to ensure drinking water quality is acheived. This water quality issue will need to be addressed to make this configuration feasible.

Table 2 – Summary of traditional and innovative rain storage materials, costs, energy and maintenance requirements

System	*Materials/major components*	*Cost*	*Energy usage*	*Manufacturer's recommended operation and maintenance requirement*
Traditional raintank	Concrete, fibreglass, polypropylene, polyethylene, galvanised steel and Colourbond ®	Approx range for all $1500 - $2000[1] (5000 L) $1800 - $2400[1] (10000 L)	Pumping required[2]	Clear gutters, clean filters and desludge
Traditional guttering	uPVC, galvanised steel and Colourbond ®	$5-10/m		
Smartflo® guttering	Colourbond ®	$25-30/m	-	Minimal maintenance
Rain storage guttering	BHP galvanised steel	Not available	None as gravity fed	Removal of collected fine sediment and leaf guard
Rain sacs	Polypropylene	$1990 inc pump (website) (2500 to 3500 L)	Pumping required[2]	Clear gutters Manufacturer states minimal maintenance
Rain fencing	Polyethylene	$250 (quote) (220L approx)	Pumping required	Clear gutters Manufacturer does not specify

[1]Coombes *et al*., 1999 includes pump, fittings and installation
[2]Dependent on location of storage and end use

4. Stormwater

4.1. Traditional techniques

Stormwater is that collected from pervious and impervious surfaces around houses, exclusive of rainwater.

Traditionally stormwater collected from the boundaries of a property is directed via pipes or overland flow systems to the stormwater drainage system. The aim of this system is to provide quick and efficient removal of stormwater to reduce the possibility of flooding and property damage. Increased environmental awareness and a more integrated approach to water servicing have led to the development of stormwater sensitive urban design (SSUD) principles. The aim of SSUD is to consider the complete water cycle, protect biological diversity and ecological integrity, and provide mitigation of the effects of flooding and reduction in environmental impacts. However, to date SSUD treatment trains have been designed primarily to provide water quality suitable for discharge to the environment, and additional treatment may be required in order provide a quality suitable for reuse (Hatt *et al*., 2004).

4.2. Innovation

4.2.1. Collection, storage and treatment

There are few specific domestic scale stormwater collection and storage systems available on the market. The majority of systems are utilised at larger cluster or catchment scale. Porous pavements, ecosoils and drainage cells for replacement of streetscape impervious surfaces are recent innovations (Figure 4 www.atlantiscorp .com.au/Home). These techniques are suitable for replacement of any impermeable areas and so could be used to provide collection, storage and treatment of the stormwater at domestic scale.

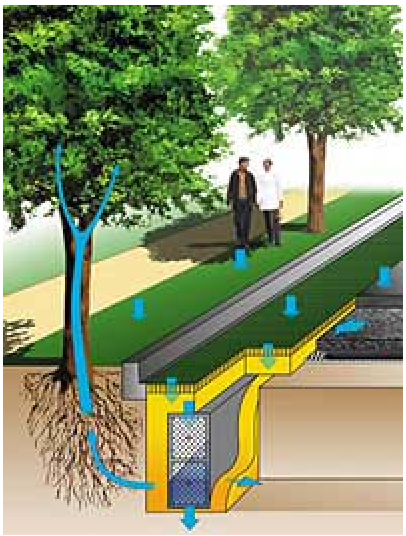


Figure 4 – Atlantis Kerb Infiltration System

Ecopaving is a relatively new concept in Australia and may provide the necessary pre-treatment for collection of stormwater from individual properties. Currently ecopaving has been used in landscaping, car parks and pedestrian areas (see Mitchell, 2004) but no case studies in individual lots have been identified.

Some processes traditionally used for water or wastewater treatment have been applied for the treatment of stormwater for reuse at a catchment scale i.e. microfiltration, reverse osmosis, dissolved air flotation, electrolysis, aeration and other biological treatments (Hatt *et al.*, 2004). Water quality, cost and operational assessment of these systems in comparison to SSUD concepts has not been carried out and the economics of the use of these water and wastewater technologies for stormwater reuse has not been assessed.

The majority of catchment or cluster stormwater reuse schemes distribute treated water for irrigation purposes. Distribution to homes through third pipe systems is also used especially for larger scale schemes (>500 ha) (Hatt *et al.*, 2004).

4.2.2. Monitoring and control

Similarly to rainwater techniques, detail of monitoring and control of stormwater reuse treatment trains have not been identified in marketing literature collated in this study. Specific medium scale case study sites have been monitored for water quality i.e., Powells Creek (www.epa.nsw.gov.au/stormwater/usp/grants/s1f0099.htm), Manly Council Stormwater Treatment and Reuse Project (www.deh.gov.au/coasts/pollution/usi/manly.html), and larger scale schemes with more complex treatment trains use centralised control systems. However, this monitoring does not appear to be standard for the different stormwater reuse techniques used and lack of adequate monitoring and maintenance has been identified as an issue for small scale sites (Hatt *et al.*, 2004).

Other schemes that continuously monitor quality are those that inject treated stormwater into underground aquifers for storage and subsequent recovery. One such scheme continuously monitors treated water, by automated turbidity monitoring as this determines whether the treated water is of a suitable quality for injection to the aquifer. (Regent Gardens, Adelaide, SA. Emmett *et al.,* 1996). Water is collected from roads and is treated through a series of lakes and reed beds before injection.

4.3. Potable water saving and energy requirements

As no stormwater use schemes were identified at household scale no information is available on actual water savings. In addition no literature was identified which quantifies potential water savings for reuse of household stormwater runoff, although many predictive models are available for assessment of rainwater use schemes. Of the larger neighbourhood or catchment stormwater collection and use schemes identified, the water saving potential is difficult to quantify as many case studies use the treated water for irrigation of open space or 'greening' of otherwise unirrigated environments. In addition, these schemes often combine the use of stormwater with greywater or rainwater and water savings are generally quoted as totals, giving no estimation of reductions in use due to stormwater alone.

4.4. Other benefits and impacts

In addition to the benefits of reducing demand of potable water, stormwater reuse techniques also provide a reduction in the volume and peak flows of stormwater, thus reducing requirements of stormwater infrastructure. They also provide a reduction in environmental pollution, reducing flows of stormwater related contaminants to surface waters. At a catchment scale, the visual and recreational amenity value of open water courses should not be ignored, although the requirement for water in the storage at all times to fulfil this amenity value, means large variations in water levels will not be acceptable. The appropriateness of processes which provide a visual amenity at single house scale has not been assessed.

5. Greywater

5.1. Traditional techniques

Greywater is any effluent from a property excluding that from toilets and urinals.

The simplest form of greywater reuse is the use of a bucket or diversion device to reroute untreated greywater as it is produced to the garden. Previous studies have suggested a high proportion (one third) of non-approved greywater use occurs in specific cities in Australia (Stone, 1995). Most greywater systems are designed to collect and treat greywater from the bathroom and laundry only, as the kitchen wastewater usually contains higher concentrations of gross contaminants (Butler *et al.*, 1995).

5.2. Innovation

5.2.1. Collection, storage and distribution

The simplest technique for utilisation of greywater is the diverter valve. This can be coupled with and irrigation system or disposal field (Figure 5). This technique may include some storage capacity in order to even out the temporal variability of flow of greywater.

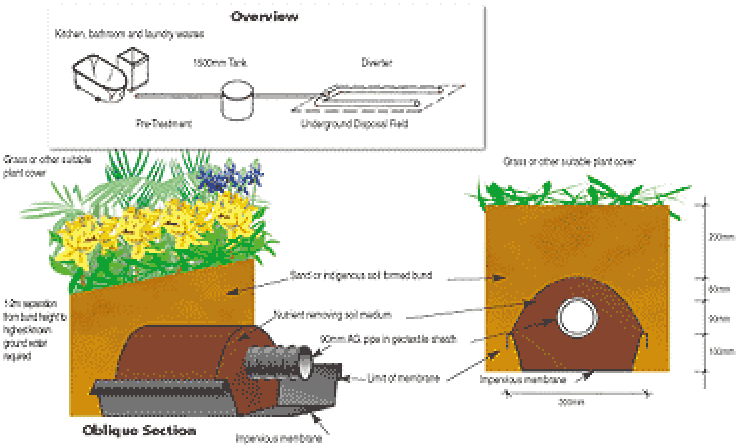


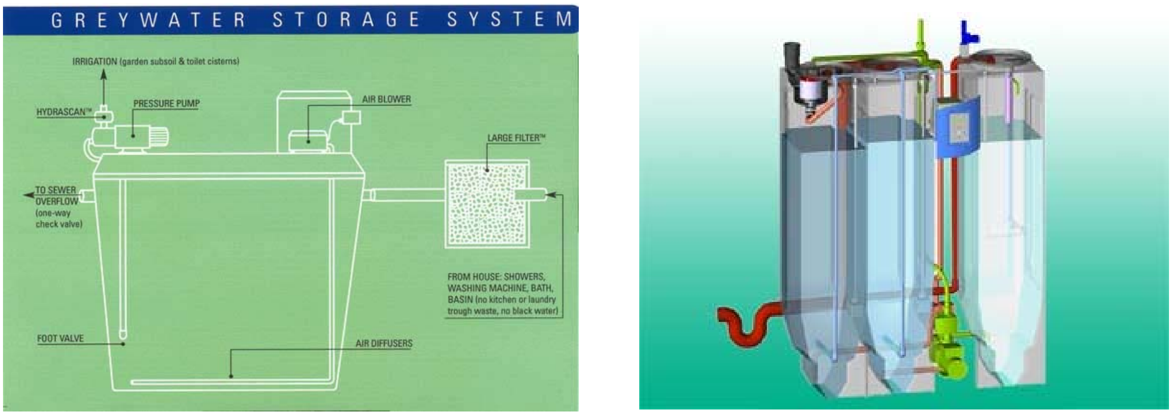
Figure 5 – Greywater collection and diversion for irrigation (Ecomax ™)

Sub surface drip irrigation systems are the recommended irrigation distribution method for greywater as they minimise human contact with the greywater. Current advances in the design include impregnating emitters with biocides and herbicides to reduce clogging and root ingress. For systems without impregnated emitters, chlorination of the treated water is often required in order to ensure plant or bacterial growth does not clog the distribution network. Examples of subsurface drip irrigation products are Netafim®, Geoflow® and Wasteflow ™.

5.2.2. Treatment

Most current innovation in greywater reuse techniques has been in the more complex treatment systems, which have been developed to provide a higher level of treatment and reliability of treated greywater quality. Systems are generally used for garden irrigation and toilet flushing although car and clothes washing are also possible, dependent on the state guidelines for greywater reuse.

Preliminary treatment of greywater can be achieved by aeration which activates the natural micro-organisms contained in greywater and provides degradation of organic components. Additional energy will be required to provide adequate aeration. Examples of two aerated systems are shown in Figure 6. The two systems have different levels of operational control, design and complexity of treatment and will thus have different maintenance requirements and treated water quality.



A B

Figure 6 – Examples of aerated biological treatment processes for greywater (A - Sunpower Design , B - Pontos®)

Higher levels of water quality can be achieved with extended treatment trains such as filtration, electroflotation and UV disinfection. An electroflotation system, previously used for the treatment of boat , car and truck wash water, rubbish bin washing and stormwater treatment (www.electropure.com.au/), is currently undergoing monitoring and testing in the Blue Mountains, NSW.

There have also been advances in the use of lo-tech treatment processes. For example the treatment of greywater from a café kitchen is currently being assessed (Figure 7). The waste contains a high concentration of fats, oils and detergents and has a variable temperature profile. Daily maintenance of the system is required to remove gross solids. Utilisation of this system at the household scale would require a high level of homeowner interaction and maintenance.

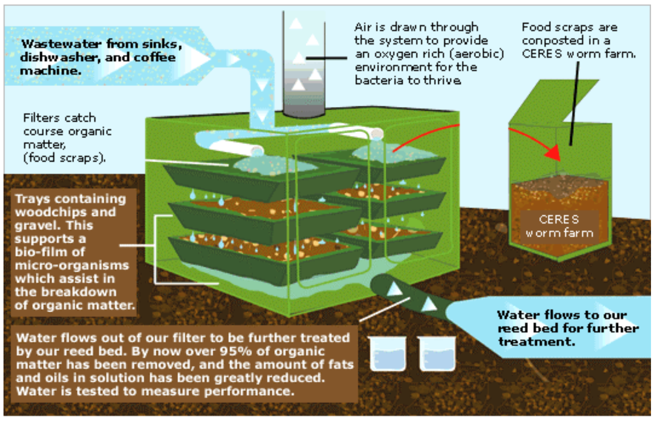


Figure 7 – Schematic of the CERES Biofilter for the treatment of café kitchen waste

Increasing complexity of treatment increases materials requirements and energy usage, but generally decreases the operation and maintenance requirement (Table 3). More complex treatment processes require a higher level of process control and feedback to users compared to the simpler tank and pump systems, as component failure and other operational parameters indicate failure of the system. The increased control of systems allows automation of most maintenance operations i.e. automatic desludging of tanks to sewer, and so the user maintenance requirement is reduced.

5.2.3. . Treatment

The majority of greywater systems identified in this study fall into two categories in relation to monitoring and control. Either there is minimal or no monitoring and continuous user maintenance and operation of the system is required, or operations are highly automated and controlled and user interaction is minimal. Lo-tech systems tend to fall into the former category and hi-tech systems into the latter (Table 3).

Table 3 – Greywater system materials, costs, energy and maintenance requirements

Process type	***Lo or Hi tech***	***Materials/major components***	***Capital cost per household***	***Energy usage***	***Operation and maintenance requirement***
Simple diverter valve	Low	uPVC pipe	$30-40	None - Gravity fed for irrigation	Minimal maintenance of valve. Continuous user control of irrigation area
Sedimentation tank and ecosoil irrigation field	Low	Standard piping Tank Gravel/ecosoil	$12000 (1000 L/day)	Gravity fed or pumped	Continuous user control of irrigation Desludging of sedimentation tank
Diverter valve, filtration, storage (drip irrigation)	Low	Piping Tank Pump Drip piping	$30-40 $250 $250 $1-2/m	Pumping required	Continuous user control of irrigation Filter cleaning
Sand filter[1] (for subsurface irrigation or toilet flushing)	Low	Tank Pump UV lamp	$5500	Pumping and UV 7.2 kWh/kL (80% for UV)[1]	Continuous user control of irrigation None specified UV lamp replacement?
Aeration (for toilet, garden and clothes)	High	Coarse filtration Tank Pumps Air blower UV lamp Microprocessor	$6500	Air blower Pumping UV Total 0.6 kWh/day (for 2400 L)	UV lamp replacement (annually)
Electroflotation (for toilet, garden and clothes)	High	Tank Pumps x2 Electrodes pH control Microprocessor	$7500	0.5-0.8 kWh/kL	Electrode replacement
Pressure filtration (toilet, garden and clothes)	High	Coarse filtration Tanks Pumps Filtration medium UV lamp Microprocessor	NA	Pumping required	Coarse filter cleaning (monthly) Replace filter media (annually) Desludge tank (annually) UV lamp replacement (annually)

1 Gardner et al., 2003

5.3. Potable water saving and energy requirements

The potable water savings associated with using treated or untreated greywater will be primarily dependent upon the end use. Greywater use for garden irrigation varies depending on the local climate, soil type and irrigation area, whereas use for indoor purposes is dependent upon water usage for specific appliances and the household occupancy. Data shows that as occupancy increases water usage per capita decreases and so higher savings per capita would be achieved for single occupancy properties.

As with stormwater schemes, potable water savings associated with greywater use for irrigation are often difficult to quantify as many case studies use the treated water for irrigation of open space or 'greening' of otherwise unirrigated environments. Some examples of potable water savings achievable with greywater reuse are given in Table 4. Most information identified in literature provides details of modelling outcomes for potential potable water savings. Many case study sites were identified but monitoring of actual water savings or the reporting of them is lacking.

Table 4 – Greywater system water savings

Reference	*Location*	*End use*	*% potable water reduction*
Gardner *et al*., 2003	Gold Coast, Queensland	Potential toilet flushing and irrigation but discharged to sewer[1]	36%[2]
WAWA, 1993	Western Australia	Garden irrigation with 'water wise' gardening	38%[2]
Priest *et al.,* 2003	Perth, Western Australia	Irrigation	4500 to 40,500 ML/year[3]
Christova Boal *et al*., 1996	Melbourne, Victoria	Garden irrigation Toilet Toilet and garden	21%[2] 20%[2] 31%[2]
Diaper *et al.,* 2003	Canberra, ACT	Garden irrigation	13% to 22%[2]

1 Queensland Sewage and Water Supply Act (1949) does not allow reuse
2 Potential saving
3 Potential saving for 100% utilisation and range of uptake

The energy usage associated with different greywater system options is dependent upon a number of factors including the location of the appliances from which water is being collected and where water is being utilised. All greywater applications can be either gravity or pump fed or distributed dependent on site specific conditions, although the high percentage of single storey properties suggests pumping will usually be required when greywater is used indoors.

5.4. Other benefits and impacts

Greywater provides a reliable supply of water but flow variations throughout the day requires storage to optimise the use. Wastewater flows and loads will be reduced but this will depend on the level of treatment and the end use. For example reuse of untreated greywater for toilet flushing will reduce wastewater flows but not wastewater contaminant loads. However, reuse of treated greywater for garden irrigation has the potential to reduce both flows and contaminant loads to the sewer.

Suitability of utilising greywater for irrigation purposes will depend upon a number of factors including climate, soil type and topography. In addition, the components of greywater will also have an impact on the environment in terms of:

- Increased salinity and sodicity
- Increased nitrate, phosphorous, boron and other contaminant loading to soil
- Increased groundwater or surface water contamination

There are two possible approaches to reducing these environmental impacts and controlling greywater quality, either a high level of treatment to ensure the range of

greywater qualities are adequately treated or source control by use of specific household products.

6. Wastewater

6.1. Traditional

Traditional on-site treatment of wastewater includes septic tanks and aerated wastewater treatment systems (AWTS) combined with leachfields or wetland systems. Many rural areas in Australia are not sewered and use these technologies for treatment of all household wastewater. Design life of septic tanks is generally quoted at around 25 years, although older systems were not necessarily designed for the increased hydraulic and contaminant load from greywater or today's water using appliances, and so failure can occur sooner than expected in terms of design life.

In urban areas, traditional practice is to collect all wastewater from properties and pipe or pump via the sewerage network to large treatment plants, usually at the periphery of urban development.

6.2. Innovation

6.2.1. Treatment and storage

There are many new treatment technologies for household wastewater. One current example of an innovative treatment technology is a wet composting unit, which combines treatment of household wastewater with the optional degradation of household food wastes. Wastewater flows into the treatment chamber (which can be retrofitted to an existing septic tank) and onto a filter bed. It then flows through the filter bed and is then pumped to an irrigation network without disinfection. Household food wastes can be added to a composting chamber that feeds into the filter bed (Figure 8 Hertle *et al*., 2002 www.biolytix.com/aust.htm).

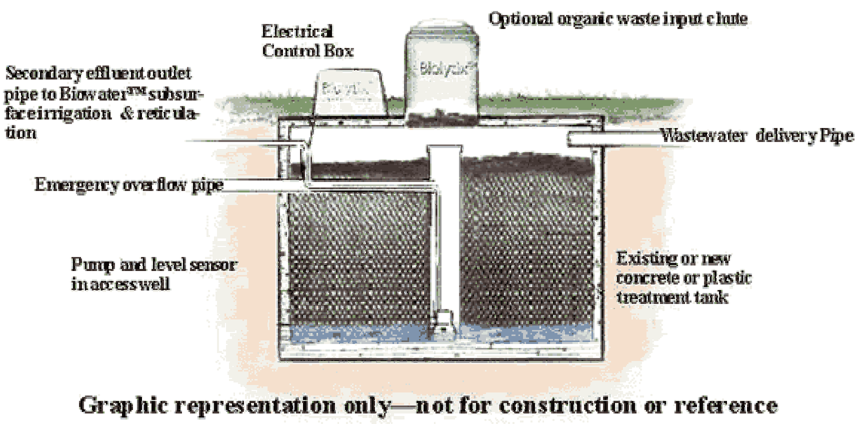


Figure 8 – Biolytix™ filter schematic

The use of composting systems in the urban environment is not widespread in Australia. A recent feasibility study by GHD (DSE, 2003) has examined the technical, economic, environmental, regulatory and public acceptance issues associated with the installation of composting toilets with urine separation in 12 two storey apartments in Melbourne. The study concludes that the dry composting toilets will;

- o Have similar or lower costs compared to conventional sewerage
- o Have the potential to be more energy efficient
- o Provide 19% reduction in potable water use and 28% reduction in wastewater
- o Reduce pollutant loads from a household, 25% for BOD, 55% for salts and 80% for nutrients

The study is likely to progress to demonstration in 2005 when the accuracy of the above predictions can be tested.

The use of sand filters or mounds for the treatment of wastewater is also a relatively new technology in Australia, although these systems have been used in America for some time. Examples of these systems include Envirotech used at The Healthy Home, NSW (Gardner, 2003), Reflection used at Managawhai Northland in NSW (West, 2003) and Natureflow used in Pethers Resort in Queensland (West, 2003). However, the only single house system identified is at the Healthy Home which treats greywater, as other case study systems treat the combined outlet from a number of septic tanks. In the Healthy Home site the sand filter provided water of a quality suitable for toilet flushing and irrigation although capital and operating costs outweighed the water saving cost benefit.

6.2.2. Collection and treatment

Source and post house separation of the solid and liquid portions of wastewater are possible alternatives to traditional combined collection. An example of source separation is the separating toilet, in which urine is collected separately from the faeces and the toilet may not require flushing with water. The public acceptability of these alternative sanitary appliances has not been thoroughly assessed.

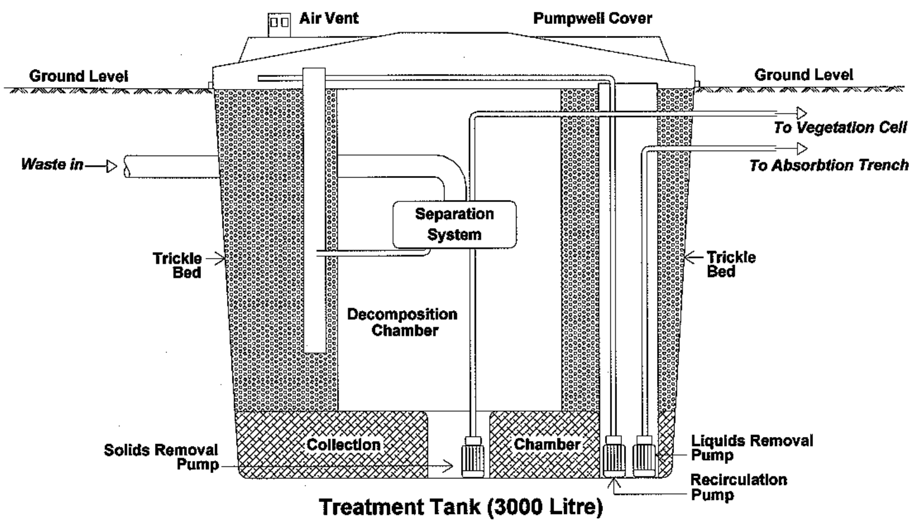


Figure 9 – Schematic of the Aquaclarus Simply Natural ® wastewater treatment system

In an example of post house separation and treatment for reuse, solids are separated from liquids using a cyclonic separator within the treatment tank (Figure 9 www.aquaclarus.com). Solids fall into a wet composting chamber and liquids are further processed through an aerobic trickle bed. In a recent upgrade of the process the liquid component is then tertiary treated to provide effluent suitable for above ground irrigation and other approved domestic non-potable reuse such as toilet flushing, clothes and car washing, garden watering and hosing pavements. After decomposition, solids are pumped to a vegetation cell.

6.2.3. Wastewater systems

Watertight collection, storage, primary treatment and distribution of household wastewater are suggested to provide a significant improvement in the overall sustainability of decentralised sewerage schemes (West, 2003). West (2003) suggests a best practice model of watertight collection and septic tanks on each property, which act as primary treatment for a reticulated sewerage system collecting septic tank outlet to an advanced treatment process. Advanced treatment processes include sand, textile and other trickling filters. End use is dependent upon the level of advanced treatment and other technical site specific issues such as topography, soils, geology, climate, vulnerability of groundwater and surface water, land use, demographics and water usage profiles. In addition, the acceptability to the public of different end uses of wastewater needs to be considered.

Other distribution system advances have occurred in parallel with those for greywater, the main area of innovation in the design of subsurface irrigation techniques.

6.2.4. Monitoring and control

Monitoring and control of wastewater treatment processes is the most advanced of all the water reuse options, with telemetric monitoring of systems ensuring problems are dealt with by experienced professional as they arise, rather than when they are spotted by the householder. The implementation of telemetric monitoring for wastewater systems is currently being implemented in Australia.

6.3. Potable water saving and energy requirements

As with stormwater and greywater schemes, potable water savings associated with wastewater use for irrigation are often difficult to quantify as many case studies use the treated water for irrigation of open space or 'greening' of otherwise unirrigated environments. This end use option is usually seen as a disposal route rather than reuse.

One case study where wastewater is reused within the home is the Sustainable House in Sydney (Mobbs, 1998). Wastewater is treated by a Biolytix process (Figure 8) and UV treated prior to reuse for toilet flushing, clothes washing and garden irrigation. This system is integrated with rainwater collection and use (Table 5).

Quantitative information on the energy requirements of wastewater systems was obtained from system manufacturers but it was found that this information did not provide a comparative assessment or was an ideal value not related to a case study. With many of the recent innovations not yet installed or only recently tested, reliable long term data was not available.

6.4. Other benefits

There is the obvious additional benefit of treating wastewater on-site in that there is no requirement for sewerage infrastructure. In addition, if the treated waste is used for irrigation or fertiliser, nutrients can be recycled to the soil. However, as with greywater use for irrigation, this will depend upon soil conditions and detailed assessment of environmental impacts of treated wastewater contaminants on soils and other water courses is required before the suitability of this technique can be verified.

7. Social, organisational and institutional barriers

The previous sections of this report have described specific technological innovations in water management at the single house scale. This section briefly examines social, organisational and institutional barriers to the implementation of the previously discussed technologies. These barriers can be broadly grouped as follows:

- Regulation
- Economics
- Organisational and institutional
- Public perception

Regulatory, economic, policy and institutional barriers and incentives to efficient urban water management in Australia have been reviewed in other reports of the Australian Water Conservation and Reuse Research Programme (Workman, 2004; Hatton McDonald, 2004). At the single house scale the National Plumbing and Drainage Code AS/NZS 3500 applies to domestic stormwater and rainwater harvesting, wastewater treatment and greywater reuse. This code, in combination with State regulations, conveys a complex regulatory framework through which householders must navigate if they want to do things differently. Collaborative and discursive approaches between householders and regulatory bodies have proved successful in ensuring projects are implemented (Mobbs, 1998).

High costs are often cited as a barrier to uptake of systems at the household scale but full assessment of externalities associated with real systems has not been carried out. A desk top study of alternative water servicing options in a Greenfield development has indicated that when preliminary analysis of externalities is included in detailed capital, operating and maintenance and on-going water servicing charges, the cost variation between the traditional water servicing and alternative options (which include single house scale treatment) is minimal (Mitchell et al., 2003).

There are currently many financial incentive schemes throughout Australia to encourage the installation of raintanks and greywater systems. Householders obtaining funding through the some incentive schemes must have systems installed by a licensed plumber and the costs of fulfilling this requirement has been cited as a barrier to uptake. A more detailed assessment of behavioural costs and incentives for the uptake of alternative water servicing options is required. In addition, a detailed assessment of the environmental impact of high levels of uptake of currently available technologies in urban areas is needed.

The development of market based instruments to address water management issues specific to particular local conditions may provide a more targeted approach to encouraging water saving and reuse than generic wide ranging incentives. The feasibility and development of these techniques requires further research.

Public acceptance of alternative sanitary appliances, such as composting toilets in urban properties has not been assessed. A recent survey has shown that community support for such systems is high (DSE, 2003) but this was a limited sample (55 respondents). In order to educate and inform the community of these new techniques installation in public buildings may provide better communication to the community than installation in private dwellings.

8. Disucssion

8.1. Techniques

So far this report has categorised on-site systems by their source stream; rainwater, stormwater, greywater and wastewater. Many innovative management systems at the single house scale combine sources to provide an integrated approach to water conservation and use within the home. This section of the report firstly summarises the data collected for individual water management techniques and then describes some of the case studies where combinations of techniques have been used.

Data on potable water savings for rainwater tanks (Table 1) shows that optimum savings are achieved when stored water is used for continuous demands such as toilet flushing, hot water services and potable water. These end uses are commensurate with the quality of rainwater but further studies are required in order to ensure rainwater quality is maintained and controlled adequately when used for these purposes (CRC WQT 2003).

There is a lack of stormwater management and treatment techniques applicable to single house reuse despite the fact that stormwater reuse is more acceptable to the public than wastewater reuse (ARCWIS, 2002). Single house wastewater reuse technologies have been developed, in which tertiary treatment of wastewater provides water of a quality suitable for toilet flushing, clothes and car washing, garden watering and hosing pavements but at present no such stormwater technology exists at this scale.

Greywater use for irrigation appears to be the most common practice for this source water, be it legally or illegally, and is publicly acceptable. This end use doesn’t necessarily promote the highest water savings as these will be climate specific. Other factors that need to be considered when using greywater for irrigation are soil type, plant types, topography, the possibility of groundwater or surface water contamination and the components of the greywater. Source control of greywater components will decrease the degree of treatment required, but this requires user control and responsibility. An example of source control is the use of low sodium detergents and household products to mitigate possible salinity problems.

Further research is required to clarify situations where greywater use should be promoted or discouraged as a source of water for urban landscape irrigation. Greywater for toilet flushing will be a viable option in higher density dwellings where irrigation requirements are low and this end use is predicted to provide 20% or more water savings. Further development of greywater recycling techniques in this type of urban form is required.

Wastewater reuse options carry similar restrictions to greywater systems in terms of utilisation for irrigation. At single house scale, dry composting toilets may provide the most suitable alternative. However, larger scale neighbourhood schemes, as those suggested by West (2003), in which septic tank overflow is collected in a common system are also a feasible option and the potential for a mix of on-site and cluster or catchment scale techniques should be investigated further. This process provides a new approach

to wastewater treatment and management in that it is not ‘end of pipe’ and provides appropriate treatment at appropriate scale. This philosophy could be used to generate new ‘outside the box’ ideas in the treatment of other wastewater and water sources.

Combining the options into an integrated water management system for the home requires an understanding of the goals and ambitions of the householder or developer in ‘doing things differently’ with regard to water management. If, for example potable water saving is the priority then utilising raintanks for hot water and potable purposes, greywater for toilet flushing and laundry use and wastewater and stormwater (either at single house or neighbourhood scale) for garden irrigation is a possible optimum scenario. However, there are other restrictions and site specific issues which need to be considered i.e legislation, soil type and the development of a robust selection procedure for alternative water management selection is required.

Table 5 – Examples of Integrated single house water management case studies

Reference	*Location*	*Techniques used*	*End uses*	*% potable water reduction*
The Sustainable House (Mobbs,1998)	Sydney, NSW	Rainwater tank Wastewater reuse	Drinking, cooking, washing, washing machine Washing machine, toilet flushing, garden irrigation	Up to 100%
The Healthy Home (Gardner and Milllar, 2003)	Gold Coast, Queensland	Rainwater tank Greywater reuse	Potable water use Toilets and irrigation[1]	73%
www.abc.net.au/rn/science/earth/handouts/houses.htm	Melbourne, Victoria	Rainwater tank *Greywater reuse* Laundry Kitchen, bathroom & laundry excess	Potable and hot water Toilet flushing Irrigation	68%
GHD composting toilet demonstration site (DSE, 2003)	Melbourne, Victoria	Composting toilets with urine separation	Compost and urine for agricultural reuse	19%
Intelligent Home www.unisa.edu.au/water/Prototypes/Regent_Gardens.html	Adelaide, SA	Rainwater tank Greywater	Hot water system and potable Toilet flushing	50%[2]

1 Proposed as Queensland Sewage and Water Supply Act (1949) does not allow reuse
2 Predicted savings

Of the case studies identified the most common combination of techniques is rainwater for potable water use and/or hot water servicing and greywater for irrigation and toilet flushing (Table 5). This combination can provide over 70% reduction in potable water usage.

8.2. Data availability

An original objective of this review was to provide quantitative information on reliability, lifetime, capital and operating costs and cost per kL water for the alternative water and wastewater servicing options identified. Although many manufacturers were willing to provide their estimations of operating requirements, energy usage and operating costs, this data is often incomplete, applicable to different scales of treatment, changes between states or not verified through independent laboratory or field trials. Thus, it was felt that independent review and collection of this information was required to ensure objectivity and comparison of “apples with apples”.

In order to provide the information required for this comparison a national monitoring programme is suggested. The programme should be applicable to both new build and current innovative water management systems. A preliminary template of data required for this programme is given in Table 6.

Table 6 - Proposed systems data requirements for comparison of alternative water management systems

Assessment process	**Data required**
Economic – life cycle costing	Capital cost, operating cost, lifetime of components
Environmental – life cycle assessment, environmental impact assessment	Materials of construction, weights, energy usage, effect of water stream components on soil structure or plant growth, effect of water stream components on other surface and subsurface water streams
Technical – water quality monitoring (all input and output streams)	Water quality, reliability of quality, failure modes for poor water quality, strategies to manage failures.
Social/Operational	Maintenance requirements, control measures, behaviours in operating systems, acceptance of technologies

The lack of comprehensive and comparable data for quantifying the economic, environmental and technical performance of innovative systems resulted in an additional outcome of this review. During this research a relationship between aspects of innovation in domestic water management treatment trains (collection, storage, treatment, distribution and monitoring and control) and the source of the feed water stream (rainwater, stormwater, greywater, wastewater) was noted (Table 7). For example, there are many new storage techniques for rainwater whereas the only identified storage technique for wastewater is a sub-surface tank. This section of the report focuses on the possibilities integration and transfer of techniques used for different feed stream suggests some new areas for technology development.

Table 7 – Innovation in on-site systems

Technique	**Source control**	**Collection**	**Treatment**	**Storage**	**Distribution**	**Monitoring and control**
Rainwater				✓		
Stormwater		✓		✓		
Greywater			✓		✓	✓
Wastewater	✓	✓	✓		✓	✓

From Table 7 and the review of different technology types the following areas for technology innovation are identified:

- Source control, collection and treatment of rainwater
- Rainwater and stormwater on line quality monitoring
- Allotment scale stormwater treatment and use
- Source control and collection systems for greywater to improve quality
- Alternative wastewater and greywater storage options

Some of these technology gaps could be filled by transfer of techniques between applications, for example, the innovative storage options for rainwater may be applicable to wastewater or greywater.systems.

Other gaps require a change of thinking away from the ‘end of pipe’ treatment principle, and a more integrated approach to the treatment solution. For example monitoring of temporal variations in greywater quality with collection and reuse of higher quality streams may minimize the level of treatment required.

9. Conclusions and Recommendations

Of the many new and innovative on-site water managements systems available, comprehensive and comparable information regarding the sustainability criteria of economic, environmental and social impacts is not available. Of the many techniques reviewed there appears to be little forethought regarding their design and implementation and many systems at the single house scale are designed as a ‘technology fix’ and are of the old ‘end of pipe’ water management paradigm. There are many technology gaps, especially in regard to retrofit solutions.

An integrated approach to technology development in all aspects of domestic scale water treatment systems, from collection to distribution and monitoring and control, is required. Transfer of systems and innovations between rainwater, stormwater, greywater and wastewater management techniques and a move away from ‘end of pipe’ treatment philosophies, may provide a basis for future scoping and development of new water technologies at the allotment scale. Source control of pollutants needs further investigation and comparison to end of pipe processing. For example a change in the manufacture of household washing products to reduce salt loads may reduce the level of treatment required of greywater systems. Finally, integration with other disciplines is also required, such as the building and construction industry, or sanitary appliance manufacturers to ensure rational system design.

Many specific areas of future research identified in this review are being addressed through a range of National projects. Independent review and collection of operating, maintenance, performance, economic and environmental data relating to on-site domestic management systems is required to ensure objectivity and comparison of techniques is equitable. A national programme to monitor and compare all aspects of alternative urban water management systems will address some of these data gaps (Water for a Healthy Country: Sustainable Water - Schemes and Technologies, 2004).

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