

**Urban Rainwater Harvesting  
and Water Reuse**

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An FWR Guide

**FR/G0006  
(January 2008)**

*Revised by J Lamont, R Keirle &  
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**JANUARY 2015**

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**Price: £15.00  
(20% discount for FWR Members)**

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## Urban Rainwater Harvesting and Water Reuse



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## Abbreviations

BOD	Biochemical Oxygen Demand
BSRIA	Building Services Research and Information Association
CIBSE	Chartered Institution of Building Services Engineers (UK)
CIRIA	Construction Industry Research and Information Association
CLG	Department for Communities and Local Government (UK)
DEFRA	Department for Environment, Food & Rural Affairs (UK)
DWI	Drinking Water Inspectorate - England & Wales
DWINI	Drinking Water Inspectorate - Northern Ireland
DWQR	Drinking Water Quality Regulator for Scotland
EA	Environment Agency (England)
MBR	Membrane Bio-Reactor
NRW	Natural Resources Wales
SuDS	Sustainable Drainage Systems
UKWIR	United Kingdom Water Industry Research
US EPA	United States Environmental Protection Agency
UV	Ultra Violet
WHO	World Health Organization
WRAS	Water Regulations Advisory Scheme (UK)

## Glossary and definitions

Black water (also Blackwater)	Water, including that from toilets, urinals and bidets, discharged from a property as foul or combined sewage. See also <i>grey water</i> .
Grey water (also Greywater or US spelling Graywater)	Water originally supplied as <i>wholesome (tap) water</i> that has already been used for bathing, washing or laundry. Does not include toilet, urinal or bidet wastes. There is some dispute as to whether used water from a kitchen sink or dishwasher containing residual food wastes should be classed as grey water or black water. See also <i>black water</i> .
Public water supply	Water supplied by a company or organisation licensed for that purpose. Usually taken to mean water supply of drinking water quality i.e. wholesome tap water meeting national drinking water quality regulations.
Rainwater harvesting	Collection, storage and use of rainwater where it falls, usually within the boundaries of a property, from roofs and surrounding surfaces, intercepting the natural rainwater drainage system. Technically, not water reuse, recycling or reclamation as the water has not yet been 'used'.
Reclaimed water	Water, other than potable water direct from the mains which has been collected and treated so that its quality is suitable for its intended subsequent use, such as irrigation or toilet flushing. Source waters may include rainwater, grey water and highly treated black water or other sewage/wastewater effluents. See also <i>recycling</i> and <i>reuse</i> .
Recycling	(As applied to water) a managed or repetitive process to pass already used water through a system again prior to further use. May include additional treatment. See also <i>reclaimed water</i> and <i>reuse</i> .
Reuse	(As applied to water) the use of reclaimed water for a direct beneficial purpose. See also <i>reclaimed water</i> and <i>recycling</i> .
Sewage	Waterborne waste matter from domestic or industrial premises that is carried away in sewers or drains. See also <i>wastewater</i> .

Sewer	A pipeline, which normally conveys sewage and/or surface water run-off from more than one property.
SuDS or Sustainable Drainage Systems	Surface water collection and drainage methods that seek to balance quantity, quality and amenity issues, attempting to deal with rainfall run-off close to where the rain falls.
Wastewater	Used water that may also contain additional dissolved and suspended matter following use. Commonly used in an international context to mean sewage. See also <i>sewage</i> .
Wastewater effluent	Wastewater or sewage that has passed through a wastewater treatment plant that has removed a significant fraction of the original polluting material to enable discharge to a natural watercourse or coastal water.
Wholesome (tap) water	Water fit to drink and complying with national/international drinking water regulations. See also <i>public water supply</i> .



# 1. Introduction

With the ever growing need to conserve the UK's water resources, rainwater harvesting (RWH), grey water recycling (GWR) and water reuse solutions are receiving growing interest from politicians, planners, developers and the general public. To date, the UK has been relatively slow in the development of water recycling and reuse compared to more 'water scarce' regions, where the use of these systems is increasingly commonplace. Recent focus in the UK, by a more environmentally concerned public and those responsible for long term urban planning and development, questions the sustainability of current water use in our modern urban way of life, particularly our in-building use, 'personal water footprint' and recreational garden watering.

There are several reasons for this rising interest in urban water use and reuse. These include the global trend for migration from rural to urban environments, with per capita water use amplified by the subsequent changing lifestyles and habits. Media focus on climate change has also led to increased concern about higher drought frequencies and potential constraints on water use in domestic urban areas.

This guide is intended for readers interested in the topic of water harvesting, recycling and reuse for non-potable urban applications. It provides an introduction to:

- The water cycle and drivers to supplement this with RWH and water reuse systems;
- Regulations and guidelines on water reuse that apply throughout the UK and Europe;
- Technologies currently available for non-potable, urban water harvesting and reuse;
- Examples of water harvesting and reuse systems with a particular emphasis on UK practice for non-potable urban applications; and
- Sources of detailed information for those planning to implement water harvesting and reuse systems in a UK urban environment.

The guide does not cover in any detail water reuse for agricultural and industrial purposes as there are specific regulations and guidelines for these sectors, nor does the guide cover large municipal scale indirect potable water reuse schemes which are often subject to specific large-scale planning studies.

## 2. The water cycle and water resources

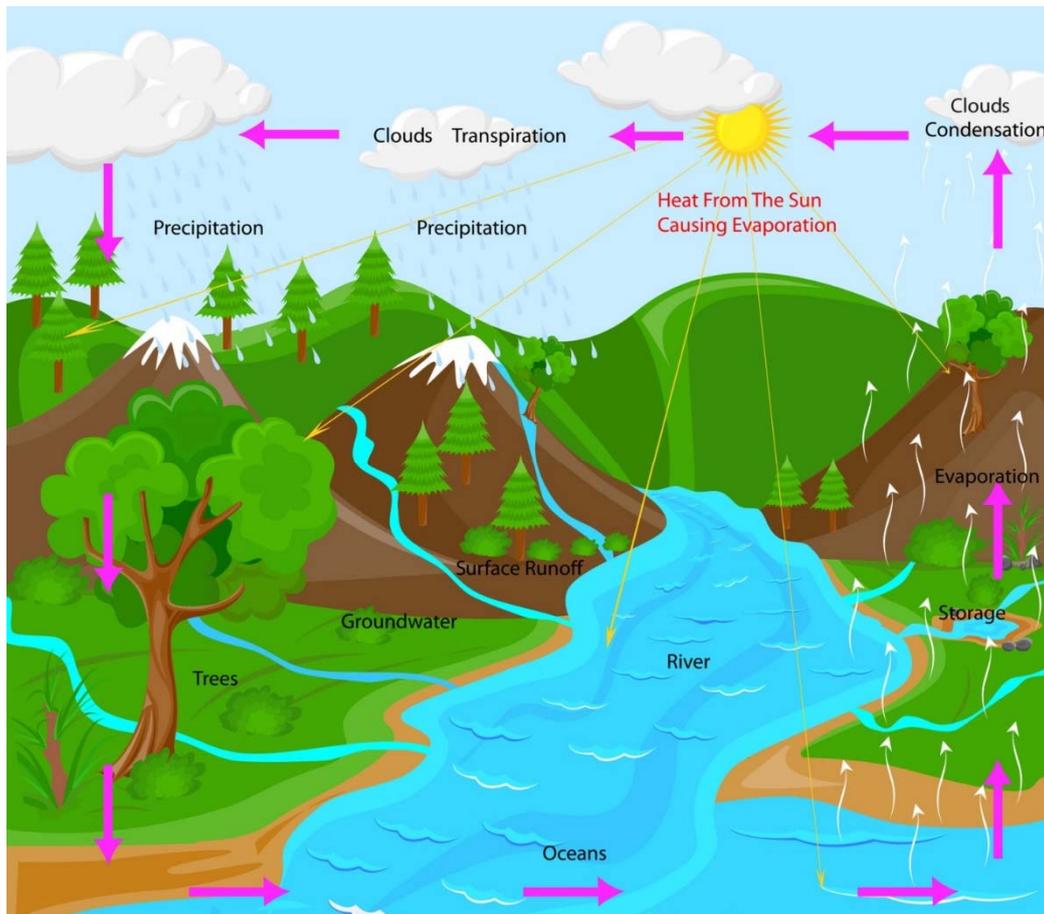
In a review of water recycling it is appropriate to first consider the water cycle (otherwise known as the hydrological cycle) and the role it plays in providing freshwater resources across the planet.

## ***Water cycle***

The basic processes of the water cycle are driven by solar radiation which evaporates water vapour from the earth's oceans, which in turn is precipitated as rain or snow by our weather patterns. The cycle time between a water molecule evaporating from the ocean surface and returning can be less than a day for oceanic rainfall to a million years or more in the Antarctic icecap. On average, a water molecule is estimated to spend 3,000 years in the oceans, 7-10 days in the atmosphere and a few weeks to months as freshwater in rivers or lakes before returning to the ocean. At any moment in time, most (97%) of the Earth's water resources is in the oceans or 'locked up' as icecaps (2%) leaving less than 1% as freshwater in groundwater aquifers or surface lakes and rivers.

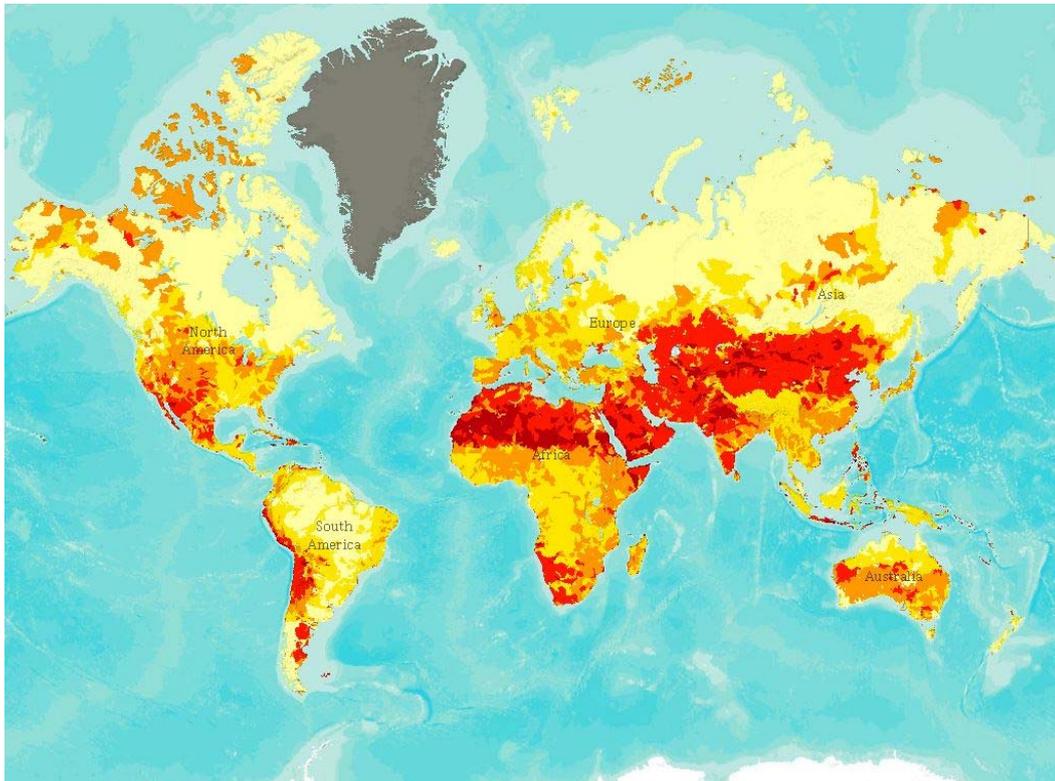
On a global scale, the water cycle involves solar energy driven evaporation amounting to some 0.5 million cubic kilometres (km<sup>3</sup>) of water per year requiring 45 million gigawatts of solar thermal energy, 3,000 times more than mankind's total global energy production in 2005 (World Bank, 2005). Most (80%) of the resulting water vapour falls as rainfall over the oceans and only an average of 2 mm / day or 715 mm / year falls as rain over land surfaces of which about one third (40,000 km<sup>3</sup> / year) becomes surface water run-off in streams and rivers. This water cycle is shown in Figure 1 below.

**Figure 1: Water Cycle**

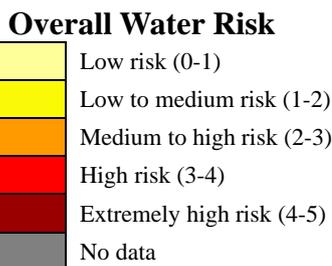


## ***Global water resources, water stress and water scarcity***

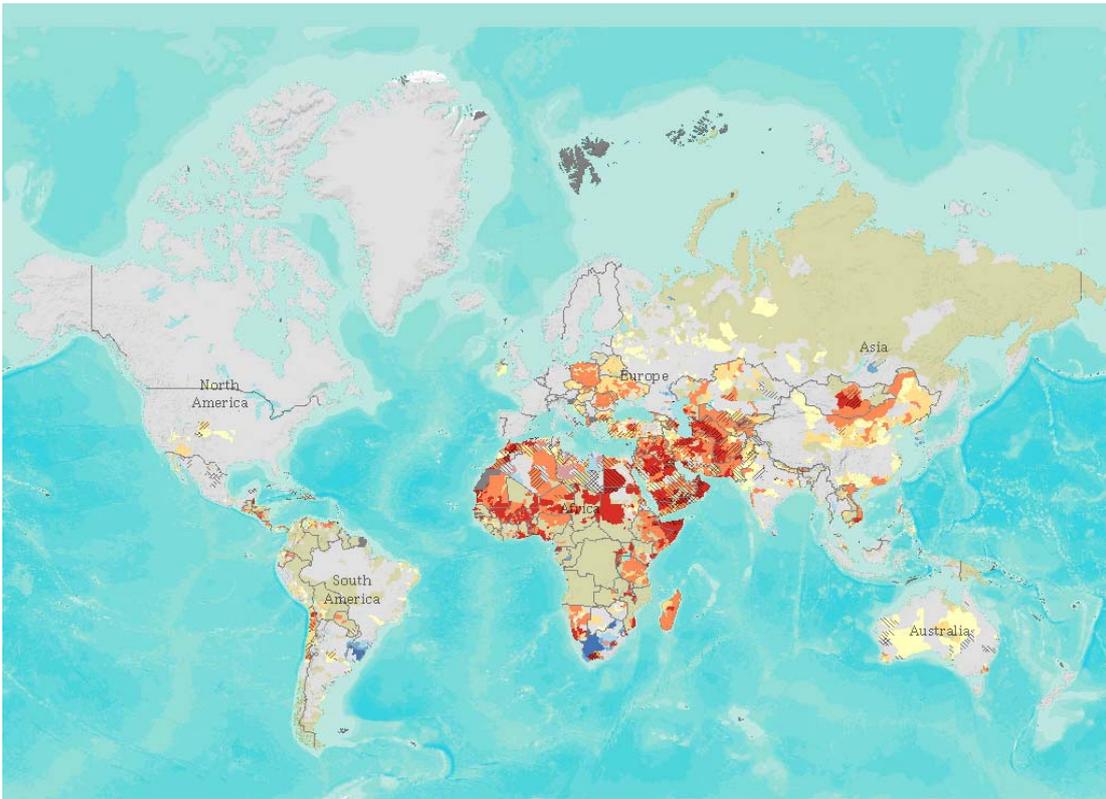
It has been estimated (Fischer & Helig, 1998) that, on average, 2,000 m<sup>3</sup>/person / year of freshwater is required to grow food crops, support industrial and environmental needs and provide domestic water supplies. Regions with less than 1,700 m<sup>3</sup>/person/year of freshwater are designated as ‘water stressed’ and regions with less than 1,000m<sup>3</sup>/person/year as ‘water scarce’ and potentially unable to sustain all human and environmental needs. In theory, at the current global population of approximately seven billion, there is a potential freshwater resource of about 5,000 m<sup>3</sup>/person year of freshwater. However, both rainfall and human population density vary considerably over the planet’s land surfaces and not all freshwater resources are easily accessible creating regions of water scarcity. The human population continues to grow and to migrate to urban areas which are often already in areas of higher water scarcity. Figure 2 illustrates the potential impact of this trend on regional water scarcity if water use remains at the baseline set. This is represented as a percentage change of the current water stress levels, which can be seen in Figure 3 which shows that, by 2050, potentially two-thirds of the global population could be living in water scarce or water stressed regions.



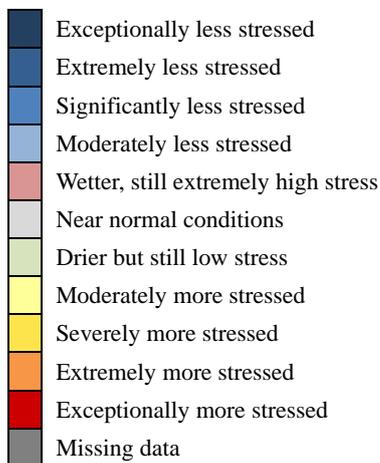
**Figure 2: 2010 baseline water stress (WRI Aqueduct, 2011)**



**Figure 3: 2050 predicted baseline water stress (WRI Aqueduct, 2011)**



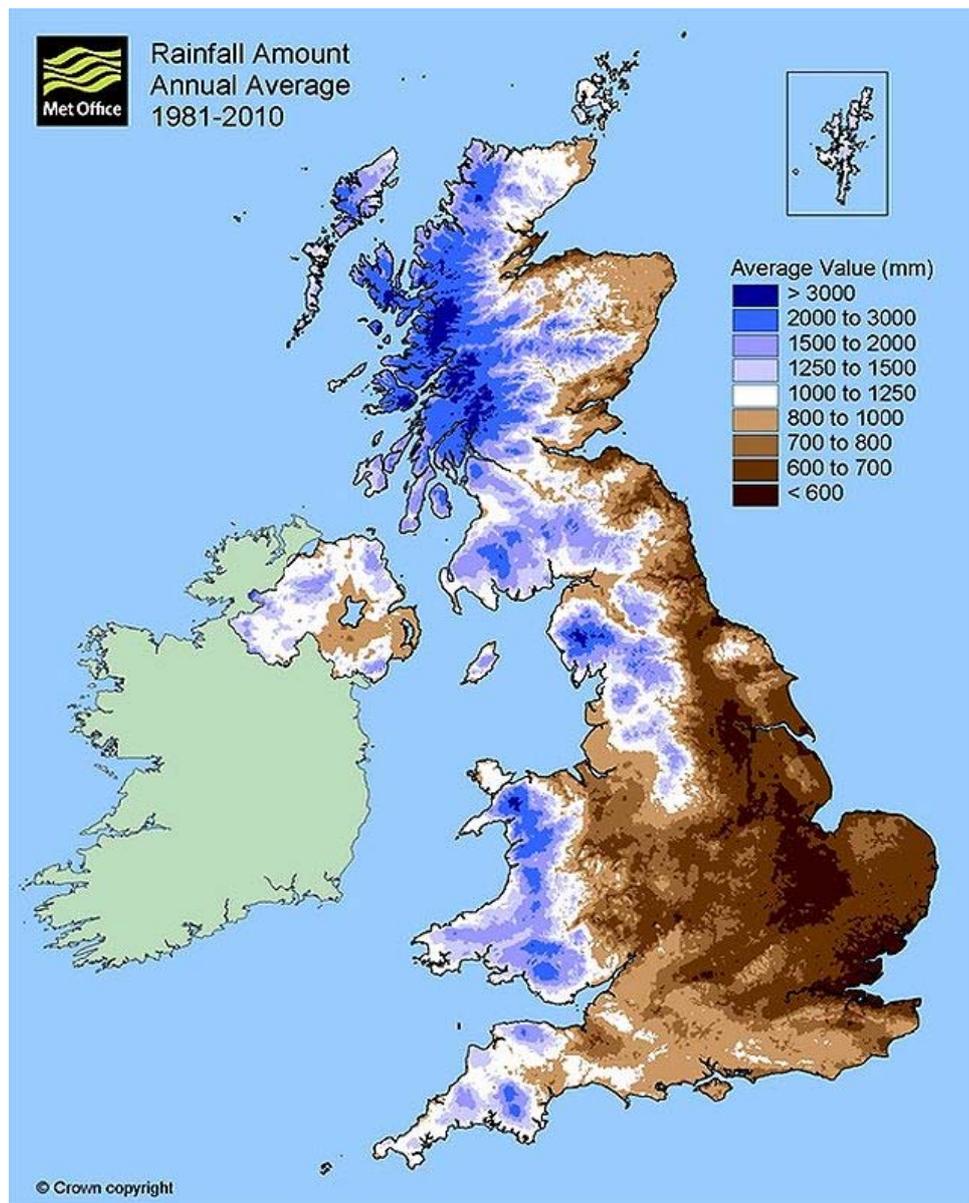
**2050 Projected Baseline Water Stress (Scenario B1)**



***UK regional water scarcity***

Rainfall in the UK is on average 1,130 mm/year (Met Office 2010), which is greater than the global average of 715 mm/year. However this is not evenly distributed (see Figure 4), with the high population density south-east region receiving a below-global-average of 600 mm of annual rainfall.

**Figure 4: Average rainfall in the UK (Met Office, 2010)**

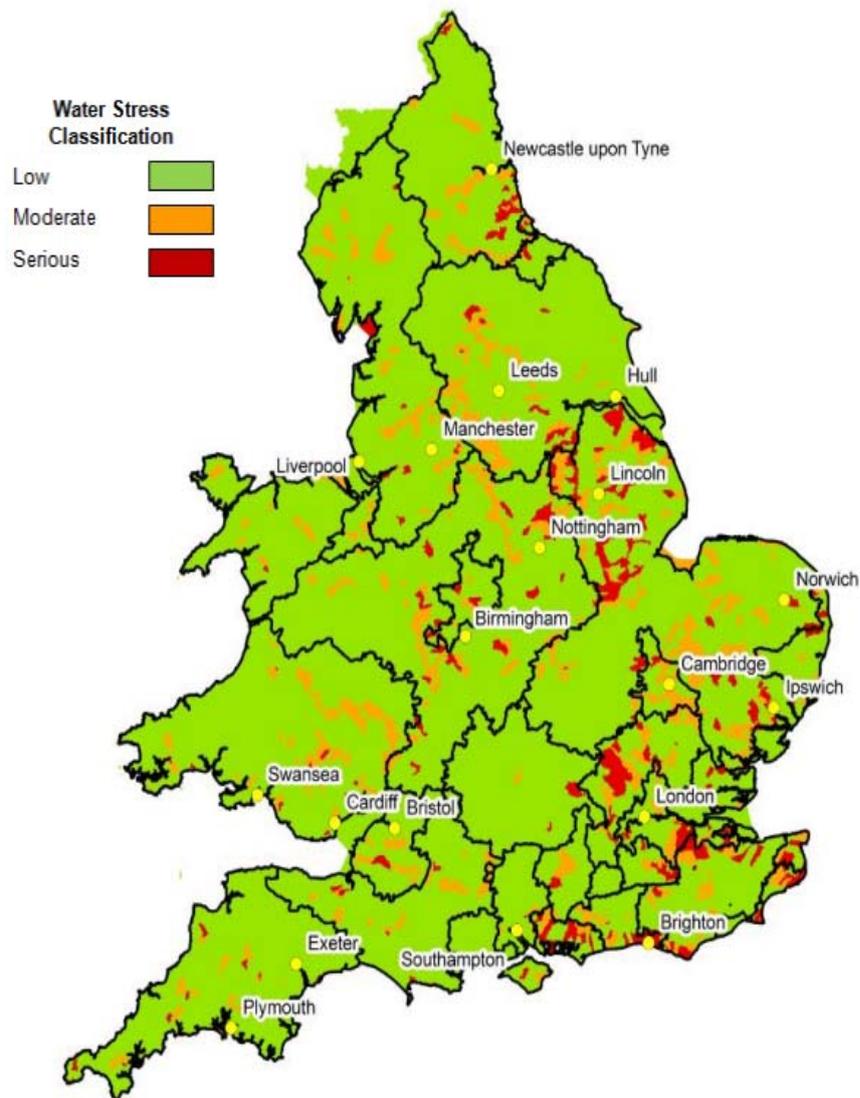


The Water Exploitation Index (WEI+) was developed by the European Environmental Agency and has been applied at water body scales across all catchments in England and Wales by the Environmental Agency (EA 2013). WEI+ is calculated with Equation 1, which can then be used as a base for calculating the water body stress. Environmental screening requirements are used to calculate thresholds for the WEI+ which categorises the result into three levels of water stress: low, moderate and serious. Figure 5 shows the levels of water stress based on this calculation for England and Wales, highlighting potential areas of water risk across England and Wales, particularly in the East of England

**Equation 1:** Calculation for the Water Exploitation Index (EA 2013)

$$WEI+ = \frac{Abstraction - Returns (Discharges)}{Natural\ Water\ Resource - Artificial\ Storage}$$

**Figure 5: Water stress in England and Wales (EA, 2013)**



### **3. History of water and wastewater management**

#### ***First urban water supplies***

The first known examples of RWH are from over 2,000 years ago in the water scarce Mediterranean region, where ancient Greek and Roman villas utilised rainwater along with water from nearby rivers and wells. The rain was collected from the sloping roofs and stored underground until needed. The Romans are also famous for developing long distance aqueducts and pipe networks to transport water from the water rich high grounds to the growing urban lowland areas (see Figure 6).

**Figure 6**



**Roman Aqueduct**



**Lead distribution pipes (left, Bath, 2014) and rainwater cisterna cover (right, Hydria, 2009)**

***Development of large-scale urban water and wastewater pipe networks for growing populations***

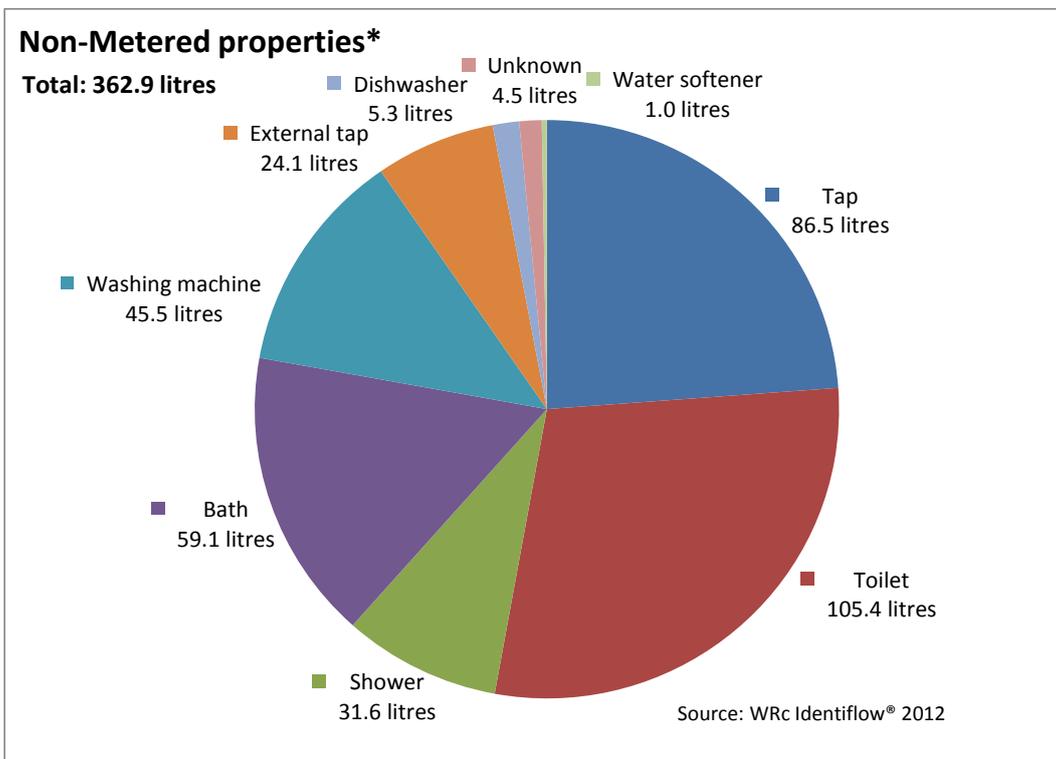
The growth of European medieval towns and cities was accompanied by poor sanitation and the pollution of local water-courses and shallow well sources, resulting in the rapid spread of water-borne diseases such as cholera, typhoid and dysentery. The industrial revolution increased the rate of migration from rural to urban areas but also enabled the economic production of iron pipes and the

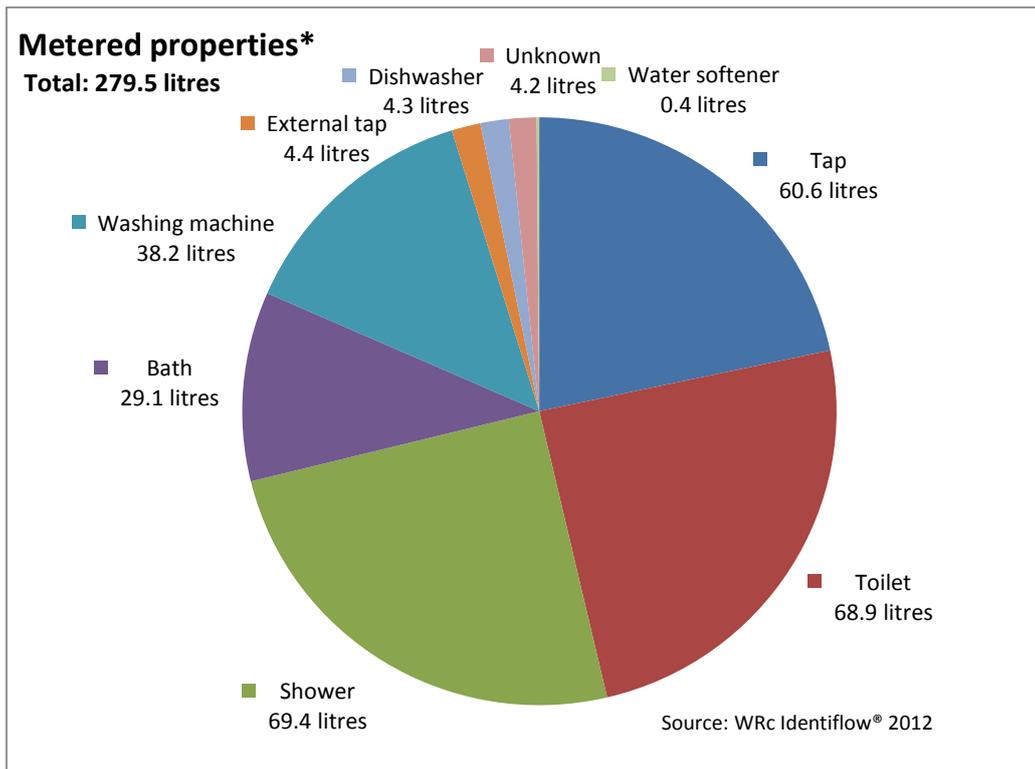
construction of brick and concrete sewers to provide a means of separating freshwater drinking sources from foul sewage and wastewaters. Over the past 200 years most major cities in the developed world have installed piped drinking water supplies, taken and treated from upstream water sources or protected groundwater sources. They have also constructed – usually many years after the first piped water supplies – a network of closed sewer pipes to convey wastewater, human waste and sometimes urban rainfall to down-stream wastewater treatment plants.

***Technological advancement effect on urban water usage and household demands***

Basic human needs for freshwater, excluding food crop irrigation, have not changed over the centuries with a daily requirement of 2-3 litres needed per person for drinking water and somewhere in the order of 10-20 litres per person for cooking. However the availability of relatively low cost, piped water supplies, together with wealth creation has enabled households to own many water using devices such as flushing toilets, baths, showers, washing machines and dishwashers. This has resulted in an increase in urban water use to, on average, around 150 litres per capita per day in the UK. A breakdown of the typical usage for different purposes in a UK home is shown in Figure 7.

**Figure 7 Breakdown of domestic water use in England (litres per day), for and non-metered and metered properties**





### ***Future urban water resource strategies***

Many water scarce regions are now reaching – or have exceeded – the capacity of their natural catchments’ water resources, even after implementing large scale, long-term storage in reservoirs. New water strategies are being examined in the UK (EA 2013, Water Resources SE 2013, EA 2012) to balance water supply and demand and to cope during periods of drought, including:

- Reducing water use through new building regulations;
- Effective water efficiency campaigns;
- Metering of existing domestic households and the possibility of variable demand tariffs;
- Improving efficiency between water companies by creating joint resource strategies; and
- Using alternative water resources including more local RWH and grey water reuse as well as municipal scale, indirect wastewater reuse and desalination.

## **4. Policy and drivers for harvesting and reuse, recent UK developments**

### ***Climate change***

The potential impact of future climate change should be added to the current water scarcity drivers described in Section 2. The impact of climate change on water

scarcity in the UK has been assessed by the Committee on Climate Change (CCC 2012) which shows the changes to different water scarcity indicators from 2000-2010. Models for the UK can be found on the website of the UK Climate Projection (UKC,P 2012). These models indicate that in 2080, on average, south east England will be several degrees warmer and will receive 30-40% less rainfall during the summer months. Both of these factors could increase summer water scarcity, reducing available water resources and increasing public demand for garden watering and showering. The Adaptation Sub Committee to the Committee on Climate Change is monitoring how well the UK is prepared for climate change and its effects and has undertaken work investigating the adaption measures for specific sectors.

### ***EU and UK Government policies and strategies***

In England, the Department for Environment, Food & Rural Affairs (Defra) is responsible for developing policy on water with the Environment Agency (EA) responsible for developing water resource strategies. Natural Resources Wales (NRW), the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Environment Agency undertake the equivalent role for Wales, Scotland and Northern Ireland respectively. The Department for Communities and Local Government (CLG) is responsible for developing building regulatory mandates including water efficiency in new buildings (CLG, 2007). Following a review, the Building Regulations (Building Reg 2010) were amended to allow the provision of water of a suitable quality to sanitary conveniences fitted with a flushing device. Whilst detailed guidance was not provided and “suitable quality” has not yet been defined, for the first time harvested rainwater and reclaimed grey water are permitted as sources of water for specified uses in both domestic and commercial buildings. Other voluntary codes such as BREEAM (BREEAM,2010) also contain details as to the types of recycled grey and rainwater that can be used in domestic properties in the UK.

A UK government strategy for water ‘The Water White Paper’ was published in 2013 (EFRAC, 2013). It has a stronger emphasis on sustainable water resources due to increased pressures on water supplies, including RWH and grey water reuse. The Water Framework Directive also influences national water resource strategies to good effect; the assessment of river basin management plans showed that the 2015 targets are expected to be met (EC, 2012).

The EA has made available a range of publications and fact-sheets on RWH, garden watering and grey water reuse (EA RWH, 2010, EA GWR, 2011).

## **5. Introducing water harvesting, recycling and reuse options**

Although the main purpose of this guide is to focus on domestic and urban applications for rainwater harvesting, grey water recycling and water reuse, a short introduction is provided below on the wider spectrum of reuse options available to water resource planners, water utilities, irrigation bodies, industry and municipal authorities.

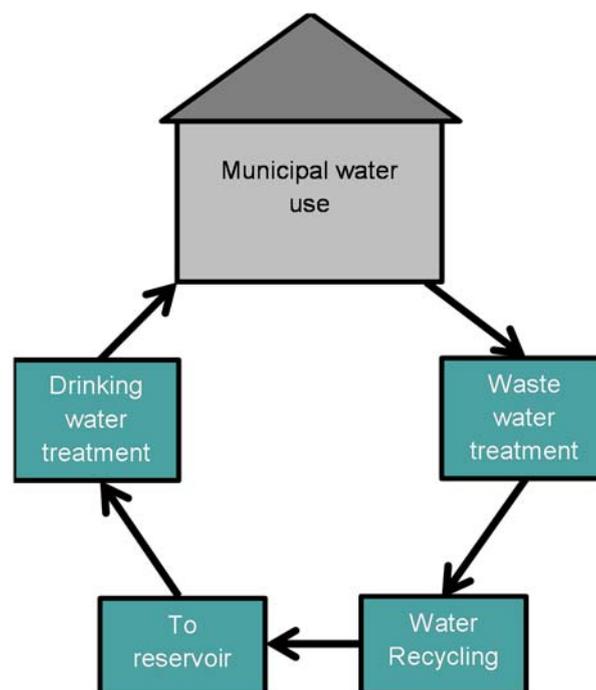
### ***Indirect potable reuse***

At a catchment level water is recycled and reused constantly, by reintroducing final effluent from wastewater treatment plants into the watercourse for significant dilution and to increase flows in rivers in order to make more water available for other uses downstream, including drinking water treatment plants. This is a form of indirect water reuse as the water is not directly sent to the point of use; it is instead discharged to the environment for potential collection later (CIWEM, 2008). Indirect reuse may be unplanned (as described above) or planned, where the route taken for discharge is modified to provide increased water resources for subsequent treatment as part of the public water supply. Recent UK examples are rare but include the Langford recycling scheme on the River Chelmer in Essex.

### ***Direct potable reuse***

In a direct potable reuse scheme, treated wastewater is directly reused as a potable supply. Direct potable reuse is very rare due to the increased potential risk to public health and negative public perception. Windhock, Namibia is currently the only place where direct potable reuse takes place on a municipal scale.

**Figure 8: Indirect water reuse**



### ***Direct non-potable reuse - agricultural irrigation***

Direct non-potable reuse in agriculture is the use of treated wastewater where control exists over the conveyance of the wastewater from the point of discharge from a treatment plant to a controlled area where it is used for irrigation. Many countries in the Middle East have developed large-scale irrigation schemes delivering reclaimed water for agriculture use.

### ***Direct non-potable reuse – industrial applications***

Direct non-potable reuse for industrial applications may involve the collection and treatment of wastewater for non-potable purposes such as cooling and heating or subsequent demineralisation for boiler feeds, steam generation and petro-chemical, steel or power production. This application is common in parts of the Middle East and Singapore (NEWater, 2007) but UK specific examples are rare. More commonly in the UK, non-potable water from industrial applications (e.g. mineral washing) may be reused at different process stages where the non-potable water quality is acceptable for the application.

### ***Direct non-potable reuse – municipal applications***

Direct non-potable reuse for municipal applications involves the collection and treatment of municipal wastewater for subsequent non-potable use. Application may include irrigation of parks and amenity land, vehicle washing and toilet flushing.

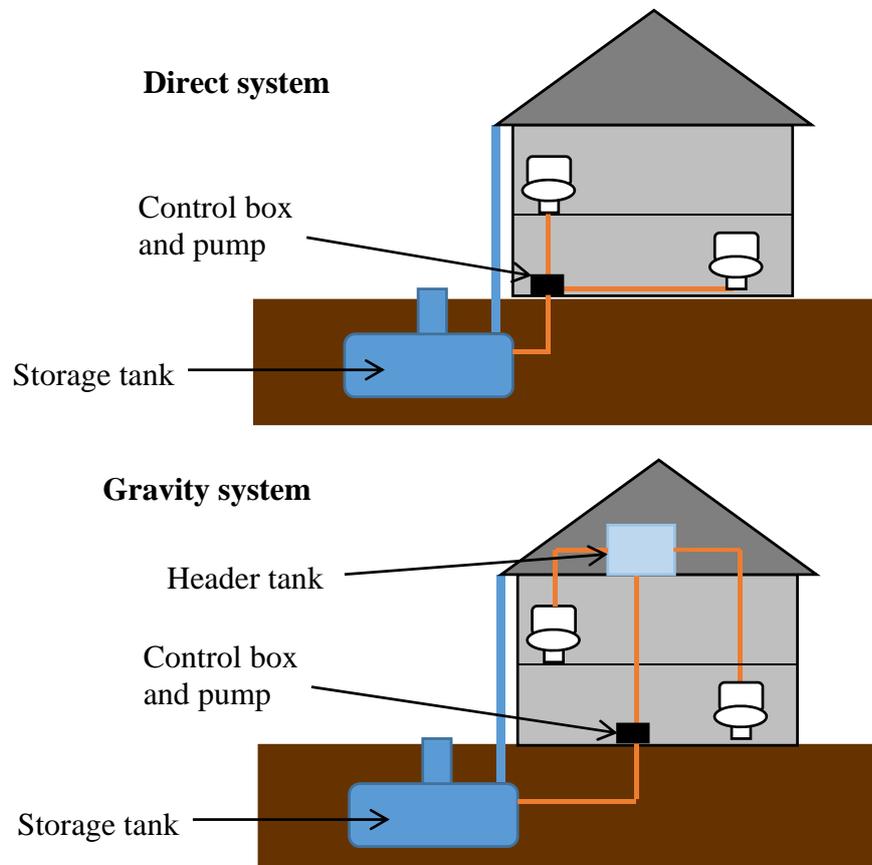
### ***Direct non-potable reuse at community and local scale***

Direct water harvesting, recycling and reuse in domestic, community and commercial premises (for domestic like uses) is very similar, the difference generally being the scale of the required system. It is possible to achieve potable water quality through significant treatment; however this is currently very rare in the UK due to the required levels of treatment and the negative public perception of this option, and so this area will not be covered in this guide.

Non-potable water reuse is more common in the UK and currently occurs on a variety of scales and uses a mixture of source water. After water collection from the source (rainwater or grey water) it is treated to the appropriate level where it can then be used in direct feed systems or gravity feed systems.

Direct feed systems use pumps to transport the water from the treated water storage to the point of use, such as toilet flushing or a garden hose (see Figure 9). For larger commercial / community systems booster pumps are often required to help get the water to where it is needed. Gravity feed systems use pumps to move the water to a second storage area (header tank), often located in the loft, where gravity is then used to transport the water to the point of use when required (see Figure 9).

**Figure 9: Domestic non-potable reuse systems. Direct feed (top) and gravity feed (bottom)**



## 6. Water quality regulations for urban reuse

### *Basis of water quality regulation*

The main objective of specifying reclaimed water quality requirements is to protect public health from microbial and chemical contaminants that may be present in the water intended for reuse. The general principle applied is that the greater the contact, or potential for contact, with humans, the greater the risk and the more exacting the water quality requirements. For agricultural, amenity and gardening applications, contaminants that are toxic or inhibit healthy plant growth are also of concern when establishing water quality goals prior to reuse. For owners and operators of buildings and water related infrastructure a third concern is that the reclaimed water should not be harmful to assets, for example being corrosive or leading to blocking and fouling of pipes and water-using devices or generating unpleasant odours.

### *Drinking water quality regulation*

Quality regulation of water intended for public supply of drinking water has a long established national and international framework. The World Health Organization (WHO) provides a risk context and global guidelines for incorporation into legislation by governments and standard setting bodies at regional and national level.

Where reclaimed water is intended for reuse in public drinking water supplies, whether unplanned indirect, planned indirect or direct potable reuse, regulations administered by the DWI (England and Wales), DWQR (Scotland) and DWINI (Northern Ireland) should apply, see Table 1. It is not the purpose of this guideline to explore any further water quality regulation for water reuse in potable supplies.

**Table 1: UK drinking water quality regulations**

Country	Regulation
England & Wales	The Water Supply (Water Quality) Regulations 2010 – available at: <a href="http://dwi.defra.gov.uk/stakeholders/legislation/wsr2010.pdf">http://dwi.defra.gov.uk/stakeholders/legislation/wsr2010.pdf</a>
Scotland	The Water Supply (Water Quality) (Scotland) Regulations 2010 – available at: <a href="http://www.legislation.gov.uk/ssi/2010/95/pdfs/ssi_20100095_en.pdf">http://www.legislation.gov.uk/ssi/2010/95/pdfs/ssi_20100095_en.pdf</a>
Northern Ireland	The Water Supply (Water Quality) Regulations (Northern Ireland) 2007 available at: <a href="http://www.legislation.gov.uk/nisr/2007/147/pdfs/nisr_20070147_en.pdf">http://www.legislation.gov.uk/nisr/2007/147/pdfs/nisr_20070147_en.pdf</a>

### *Current quality regulations and guidelines for reclaimed water intended for reuse*

Regulations and guidelines for water reuse vary across regions, with no one set standard. Current sources of water reuse quality standards and guidelines are listed in Table 2.

**Table 2: Sources of information and guidelines on effluent and water reuse**

Source	Titles
WHO	Guidelines for the safe use of wastewater, excreta and grey water (WHO 2006a)
	Health aspects of plumbing (WHO, 2006b)
EU	EU Bathing Water Directive (EEA, 2006)
UK	Rainwater harvesting systems – code of practice (BS 8515, 2009)
	Grey water systems – code of practice (BS 8525-1, 2010)
	Grey water systems – domestic grey water treatment equipment, requirements and test methods (BS 8525-2, 2011)
	Marking and Identification of Pipe Work for Water Reuse Systems (WRAS, 2011)
	Rainwater and Grey Water in Buildings (BSRIA, 2001)
	Harvesting rainwater for domestic uses: An information guide (EA RWH, 2010).
	Grey water reuse for domestic use: An information guide (EA GWH, 2011)

Source	Titles
	Building Regulations for England and Wales Requirement G1 (Building Reg 2010)
USA	Guidelines for water reuse (EPA, 2012)
	US Green Building Council - Leadership in Energy and Environmental Design guidelines (USGBC, 2005)
Australia	Australian guidelines for water recycling (Phase 1 & 2) (AUS, 2006, 2008)
	Guidance on use of rainwater tanks, Third Edition (Aus Gov, 2011)
	Greywater fact sheets 1 to 5 (NSW 2014)

### ***World Health Organisation (WHO)***

In 2006 the World Health Organization (WHO) published the third edition of guidelines for the safe use of wastewater, excreta and grey water (WHO, 2006a). The guidelines are designed to protect the health of farmers (and their families), local communities and product consumers. They are adaptable to take account of national, socio-cultural, economic and environmental factors, in order to maximize overall public health benefits and the beneficial use of scarce resources. WHO and the World Plumbing Council have jointly released a publication on the health aspects of plumbing, which includes information on grey water systems (WHO, 2006b).

### ***European Union (EU)***

There are, at present, no water reuse standards for the European Union. Some countries and regions where water is often reused and recycled have adopted guidelines or regulations to ensure this is done to a safe standard. It has been recommended that while there are no specific guidelines, a suitable alternative for non-potable water reuse is the EU Bathing Water Directive (EEA, 2006) which set standards for the quality of water used for different types of bathing in the EU.

### ***United Kingdom (UK)***

In the UK there has been increasing interest in the use of grey water for garden watering and toilet flushing. The current British Standards (BS 8515:2009, BS 8525:2010) were introduced to combine sections of previous guidelines and regulations on different aspects of RWH and GWR.

## **7. Technologies, design factors and case studies**

### ***7.1 General considerations***

#### ***Objectives for a water harvesting and reuse project***

In planning for a water reclamation and reuse project a property owner, developer or planner should consider what their main objectives are. These may include:

- The demonstration of environmental concern by the reduced use of public drinking water resources and the adoption of ‘green and sustainable treatment solutions’, regardless of the specific project economics;
- The provision of watering facilities for gardens and amenity grounds during droughts and hosepipe bans;
- Compliance with an imposed planning or policy requirement for water efficiency and water reuse in a new development (see Section 4); and / or
- Cost savings in the provision of water and wastewater services for a specific property, development or water resource zone.

#### ***Basic technical considerations***

The basic technical steps for any water reclamation and reuse project are:

- Establish intended water source and reuse options and application(s);
- Consult and inform regulators, planners and water companies;
- Characterise the quantity, quality and variability of the source water(s);
- Find and adopt for the water source(s) and reuse application(s), the regulated or guideline water quality standards (see Section 6);
- Consider the need for source and treated water pipe work and storage and potential implications on source and reclaimed water quality including fouling and corrosion of pipe networks and water using devices;
- Select appropriate treatment technologies, noting that multiple-barrier treatment may provide a more reliable risk reduction than a single stage;
- Carry out a cost benefit and environmental impact analysis, including energy or carbon footprint, final wastes disposal, land requirements and impact on building and external ground design;
- Undertake a risk assessment to ensure protection of public health;
- Provide appropriate disinfection processes, effective through to point of use, where the application water quality goals require this; and

- Establish an appropriate monitoring, operations and maintenance regime, including who will be responsible for these actions, to ensure safe and reliable operation over the life-cycle of the system.

Further consideration must also be given to the relevant standards to ensure the implemented solution is built to the correct standard. BS 8515:2009 provides recommendations for the design, installation, testing and maintenance of RWH systems for non-potable water use systems in the UK. BS 8525-1:2010 relates to grey water systems and provides the code of practice and other general guidance and information on grey water reuse; this is a non-specific guide. BS 8525-2:2010 contains specific information relating to design, installation, testing and maintenance of grey water harvesting systems for non-potable water use in the UK.

## **7.2 Rainwater harvesting**

Before installing a RWH system it is important to determine the suitability of the system. Factors which need consideration are:

- The amount of rainwater that can be collected;
- How much water needs to be stored;
- The costs of the system; and
- Other water efficiency measures that could be introduced (increasing water efficiency)

The amount of water that can be collected depends on several factors. These are:

- Average rainfall;
- Collection area;
- Drainage coefficient; and
- Filter efficiency.

The average rainfall will depend on location within the UK and this data can be obtained from the Met Office (Figure 4).

In the UK the highest rainfalls are in the North West of England and Wales, with the lowest levels in the South East.

The collection areas typically consist of the roof of the property, with some systems also collecting from hard-standing areas such as driveways. Calculating the area of the roof gives a rough indication of the collection area; however not all water that falls in this area will be collected. This can be due to heavy rainfall causing overflowing of gutters, light rainfall resulting in increased evaporation of the rain from the roofs surface and down pipes meaning the water is not collected for harvesting. This water loss is known as the drainage coefficient. Typical values can be seen in Table 3.

**Table 3: Drainage coefficient for different roof types (EA RWH, 2010)**

Roof type	Drainage coefficient
Pitched roof	0.9
Pitched roof with tiles	0.8
Flat roof with gravel layer	0.8

The quality of water collected from a typical flat or sloping roof is not as clean as tap water, containing dust, debris and bird droppings flushed from a roof or guttering system. Filters are recommended to help remove these; however this reduces the amount of water collected. Most manufacturers give 90% efficiency for water flow through their filters.

Demand for rainwater needs to be calculated to ensure there is sufficient storage space without expending resources on storage that is oversized. It is generally estimated that the tank size should be 5% of the annual non-potable water demand or 5% of the annual rainfall that can be collected for the location. Therefore to calculate the amount of water that needs be collected Equation 2 and 3 can be used.

**Equation 2:** Calculation of required storage tank size for rainwater harvesting by demand (BS 8515:2009)

$$\text{Demand} = \text{daily requirement per person (l)} \times \text{number of persons} \times 365 \times 0.05$$

**Equation 3:** Calculation of required storage tank size for rainwater harvesting by rainfall (BS 8515:2009)

$$\begin{aligned} \text{Tank size} \\ = \text{eff. collection are (m}^2\text{)} \times \text{drainage coeff.} \times \text{filter eff.} \times \text{average rainfall (mm/yr)} \times 0.05 \end{aligned}$$

Systems should be sized on the lesser of the tank sizes derived from the demand equation (Equation 2) or the supply equation (Equation 3). “Equation 2 ensures that a system is not installed with a storage capability too large for the given roof area or grey water supply, thereby reducing system costs. Equation 3 helps mitigate the health risks associated with water stagnation in storage. This may occur in scenarios where the demand for water reuse is less than the supply available to the system.” In the UK, the EA suggest that 2 m<sup>3</sup> is an optimum size for a rainwater storage tank to serve a typical four-person household for both garden and toilet flushing

Once collected, rainwater can be used for a variety of domestic uses. The two main uses are for gardening and toilet flushing.

## ***Rainwater harvesting for gardens***

Capturing and using rainwater for garden watering is the most common and low cost form of RWH practised by households in the UK. In most cases the system consists of a 100-250 litre plastic storage tank or water butt, connected to an existing roof drainage down-pipe, stood on a 20-30 cm pedestal and fitted with a tap for easy filling of watering cans,

**Figure 10: Water butt**



In the UK the cost of a typical 200 litre rainwater butt and associated stand and fittings is about £30-£60 (or £50-£100 if installed by a builder or plumber). A single 200 litre water butt can make a small contribution to reducing use of tap water for garden watering, perhaps yielding 2 to 4 m<sup>3</sup> in total during the garden watering season or 1-2% of typical UK annual household usage. Cost savings will depend on property location, as water utilities charges vary, and whether the property is charged on rateable property value (no saving) or on metered consumption. Taking an average 2012/ 013 charge (OFWAT, 2014) of about £2 per cubic metre for metered water and wastewater services in drier regions of England, it is estimated that a typical water butt system could save a household £4-8 per annum, giving a payback time of around 7 years (range from 4 to 50 years).

The UK has a number of large scale examples of RWH for horticultural irrigation and glass house misting, including the Eden Project in Cornwall (EDEN, 2013), which claims that 70% of total site water usage is supplied by harvested rainwater and ground water.

### ***Rainwater harvesting for toilet flushing***

Using rainwater for toilet flushing is more common in larger, multi occupancy buildings in the UK rather than for domestic use. This is due to the added complexity in the design and installation. There is an additional need to understand and implement UK guidelines and regulations for internal plumbing systems (BS 8515:2009, Section 6 and WRAS, 1999), with the most important requirement being to ensure that back-flow into the mains supply is prevented and that an air gap exists between any mains top-up supply and a rainwater holding tank.

There are currently no UK guidelines on the quality of the water required for toilet flushing from harvested rainwater. However it is good practice to perform some level of cleaning to prevent blockages of debris in pipes; this can be achieved by placing a filter in the system. For most domestic RWH systems this is sufficient. However, for some sites where there are green roofs or the water is collected from paving additional levels of cleaning may be required. These add considerably to the cost of the RWH system; examples include oil interceptors and UV disinfection (BS 8515:2009).

### **7.3 Grey water recycling**

There is broad agreement, that in the domestic household context, grey water is defined as water that has been previously used for hand washing, bathing and showering and does not include kitchen, toilet, urinal or bidet water and wastes.

**Figure 11: Acceptable sources of grey water**

#### **Suitable grey water**



#### **Not suitable for grey water recycling**

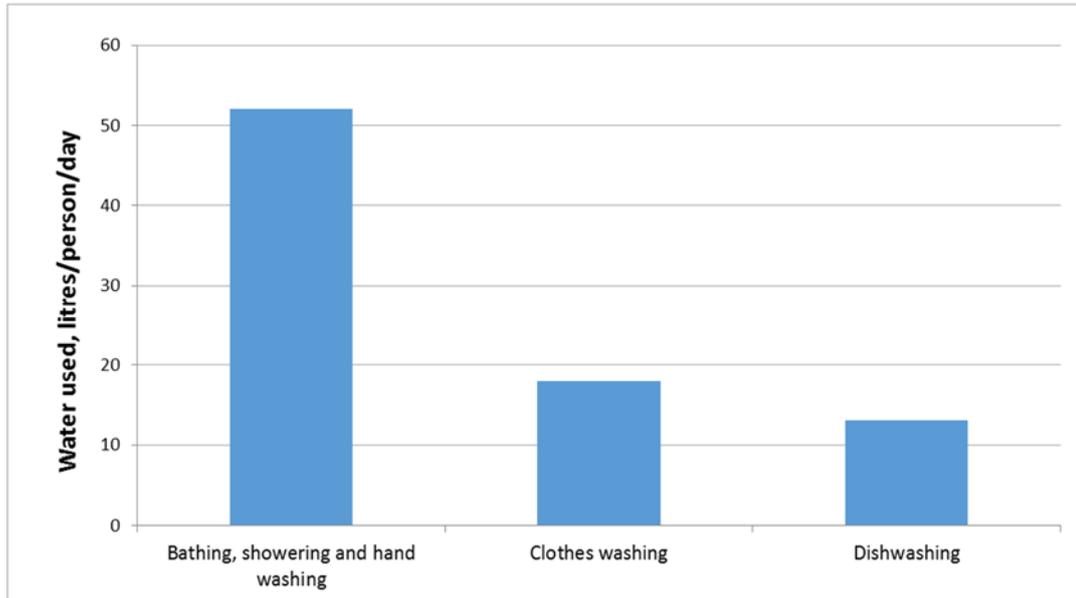


### ***Nature, quality and volumes of grey water***

The quantity of reclaimable grey water in a domestic household will vary widely, depending on occupancy, bathing habits and types of shower, bath, sink and washing devices. The average usage of water for these purposes may be published by water

utilities and urban public bodies, for example the EA (EA GWR, 2011) estimates can be seen in Figure 12 which represents 56% of an average total domestic water usage of 150 l/person /day.

**Figure 12: EA estimates of domestic water use**



The nature of grey water is usually a cloudy suspension including hair, fibres and particles and a dilute solution of dissolved inorganic and organic materials including soaps, detergents, cleaning chemicals and material washed from skin and soiled fabrics and clothing. Although grey water does not include toilet waste there is the potential for some faecal contamination from hand washing and rinsing of nappies in the bathroom. Compared to public water supplies and tap water, grey water is likely to be more alkaline (due to soaps), contain more salt and contain increased phosphate from detergents, which may have a deleterious long-term impact on some types of garden plants (WERF, 2005). As grey water usually contains nutrients and material of biological origin, storage is likely to lead to further biological activity and possible formation of bio-films and odorous anaerobic breakdown products. It is generally recommended that some form of treatment, starting with a hair and fibre collector, is applied to grey water prior to storage or the ultimate reuse application (BS 8525:2010, BSRIA, 2002b).

### ***Collection of grey water***

The simplest method of grey water collection, practised by some households during droughts and hosepipe bans, is to bail out the bath water with a bucket and tip the contents onto ornamental (but not edible) garden plants. This may provide temporary, low cost alleviation during water shortages but creates some new in-home risks in terms of lifting, spilling and slipping as well as being time consuming. Siphoning bath water through a hose removes the lifting and carrying effort and risk but can be a challenge to get started. Hand operated bilge pumps, which were designed for baling out boats, are also commercially available for the energetic or to

start the siphoning process. Temporary electric or petrol pumps should not be used in a bathroom on grounds of health and safety.

Long term collection of grey water is recommended via plumbed-in diversion or valve systems and a dedicated and labelled grey water collection pipe network, with guidelines and regulations published in the UK (BS 8525:2010, WRAS, 2011). Note that each country may adopt different colours and labelling guidelines. In the UK, WRAS advises BS 1710 compliant banding of green / black / green bands and the words 'GREY WATER' on the grey water collection pipes. After treatment the pipes may be labelled as 'RECLAIMED WATER' with an additional white band on the black banding described for grey). Any outlets supplying the reclaimed grey water must be clearly labelled 'NOT DRINKING WATER' and 'RECLAIMED WATER'. Grey water systems must have back-flow prevention devices and air gaps where connected to public water supply and drainage systems.

**Figure 13: Pipe labelling for reclaimed water (WRAS, 2011)**



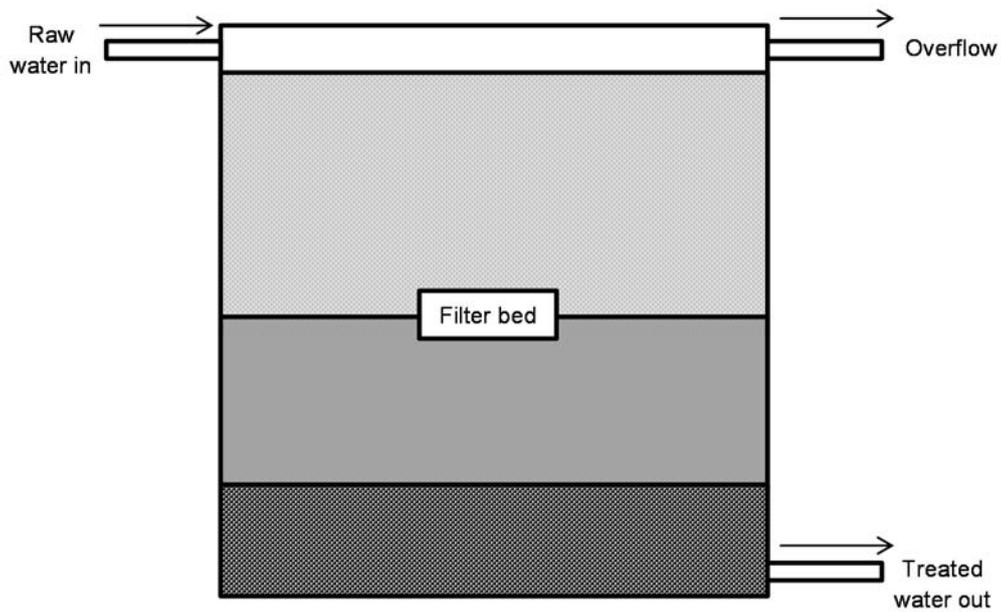
### ***Treatment of grey water***

Selection of treatment processes for grey water should follow the basic steps described in Section 7.1 and will depend on the applications and source waters. In all plumbed-in applications a removable hair and fibre trap is essential to prevent blockages of subsequent pumps, pipe work, treatment units and application orifices. Disposable bag filters are one convenient solution for this. There are four main types of treatment systems for grey water. These are: short retention, chemical, biological and bio-mechanical.

Where the source grey water does not include significant waste then short retention storage and settlement tank followed by a simple sand filter, planted soil filter or removable cartridge filter should remove most particles likely to block garden applications, such as trickle irrigation pipe orifices or toilet flushing devices (Figure 14).

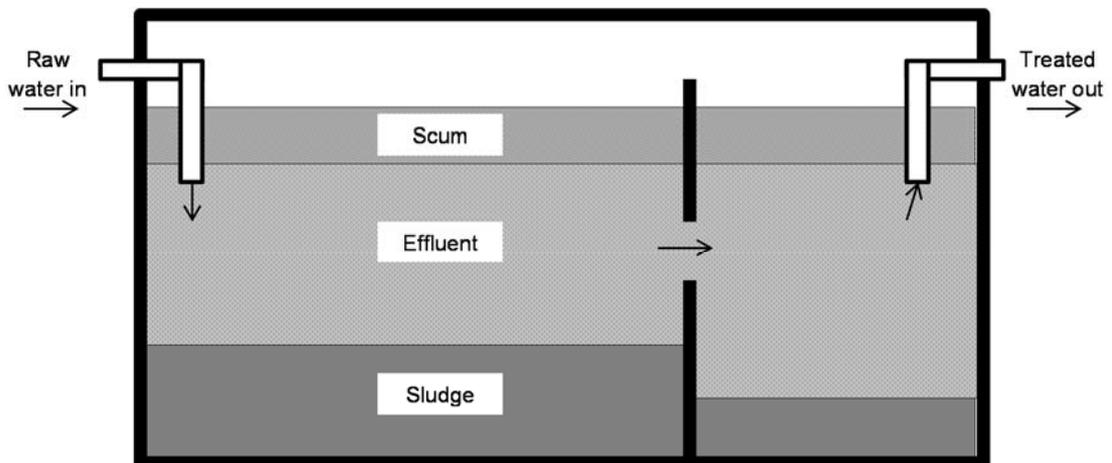
This can then have chemicals such as chlorine added to convert this to a chemical system which will provide longer term storage (it is recommended that untreated grey water be stored for no longer than 24 hours).

**Figure 14: Short retention treatment for grey water with a sand filter system**



For grey water that contains more waste and other rapidly biodegradable material the use of an anaerobic septic tank (Figure 15) or an aerated biological filter is suggested to prevent rapid biological fouling and odour formation in physical filtration units.

**Figure 15: Anaerobic septic tank**

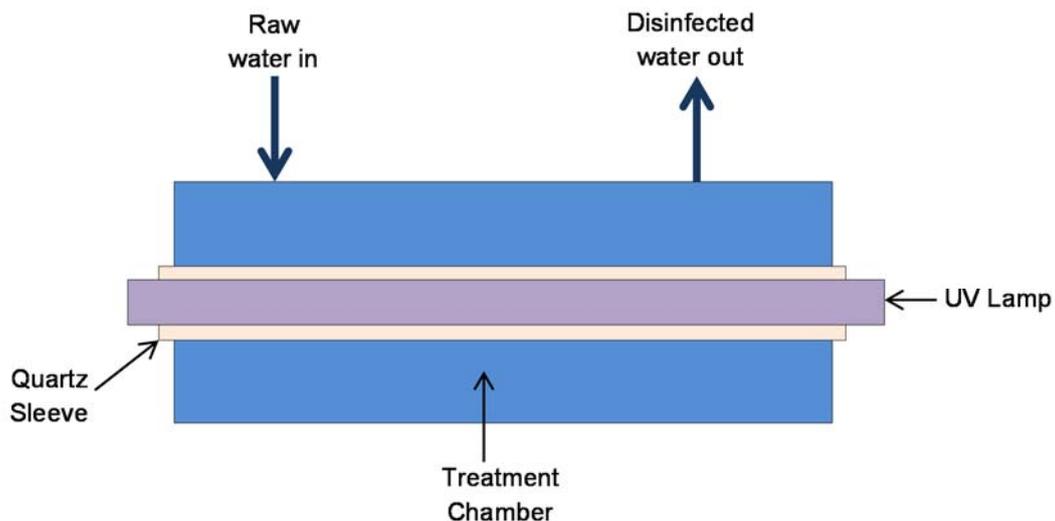


Bio-mechanical systems combine pre-treatment, aerobic treatment and mechanical filtration stages into one unit. This is generally much more expensive but produces the highest quality of water and may be considered in applications such as reuse in medical or care facilities.

### ***Disinfection***

Traditional chemical disinfectants can be used to further treat grey water; these are usually based on compounds of chlorine, such as sodium hypochlorite, found in domestic bleach. UV radiation (Figure 16) may also be used to cleanse water of harmful microorganisms. The UV process is an attractive option in many cases as it is chemical-free; however, it requires more energy to operate and may not achieve sufficient penetration in turbid, particle-rich water. Those considering UV disinfection should also consider its limited protection time. Exposure to UV rays is a one-time process that kills microorganisms but does not prevent them from returning again.

**Figure 16: UV disinfection system**



### ***Grey water case studies***

Grey water recycling has become more popular in recent years and there are now a number of case studies in the UK where GWR systems have been successfully installed. Some systems that have been installed have failed due to poor design, meaning they cannot provide sufficient storage for water and so rely heavily on mains water supplies, or due to poor maintenance of equipment. This highlights the importance of planning and design when building a grey water reuse system.

**Wellington House** – In Victoria London the Wellington House apartment building (Aquaco, 2013), containing 59 private apartments has been fitted with an Aquaco GWR system. This collects water from baths, showers and hand basins which is then filtered and sterilized before being used for toilet flushing. It is expected that the total mains water savings will be up to 50% compared to not having the GWR system.

**Figure 17: Wellington House, Victoria London**



**Queen Elizabeth Olympic Park** - The Queen Elizabeth Olympic Park (QEOP, 2014) was built for the London 2012 Olympics and set high standards for sustainability. The buildings contain both rainwater and grey water harvesting systems. The London Aquatics Centre Design team looked into recycling the swimming pool backwash water to flush WCs and urinals. Using reclaimed backwash water was considered feasible because of the reliable source and quantity. Through the incorporation of low flow showers, wash hand basin taps and low flush WCs, the Centre is expected to achieve potable water savings of 32% over the building's 25-year lifespan.

**Figure 18: Queen Elizabeth Olympic Park**



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## **7.4 Black water, sewer mining and sewage reclamation**

### ***Definition and nature of black water***

The term black water is a relatively recent one used by the water reuse community to describe water and waterborne wastes, including toilet, urinal and bidet, discharged from a property as foul or combined sewage. In principle, a black water reclamation system is a more compact and local version of conventional municipal sewage or wastewater collection and treatment, with the resulting wastewater effluent reclaimed for local reuse applications. Sewer mining is a new term to describe a variant whereby sewage from other connected properties is 'mined' or pumped out of a public sewer, close to a new property or development, for local treatment and reclamation as a reuse water source.

In theory black water reclamation has several advantages compared with grey water reclamation:

- Connection to public sewers may not be required for new properties reducing both developer and utility sewer infrastructure costs, especially where no current public sewers exist;
- Volumes of water for reclamation are greater than for grey water;
- Collection pipe work may be simpler with no duplication of grey and black water collection pipes from bathrooms and toilets; and
- Biological treatment processes are more likely to receive an acceptable balance of pH, cleaning chemicals and nutrients.

The disadvantages of black water compared with grey water systems include:

- More complex and costly treatment with disinfection essential to reduce risks associated with human pathogens of faecal origin;
- More routine maintenance procedures are required especially to ensure continuous viability and operation of the biological treatment stage that is usually required;
- Greater potential risk of blockages, bio-fouling and production of undesirable odours from black water;
- Costs for screening and disposal of non-biodegradable materials (disposable nappies, sanitary wear, condoms) and residual solid wastes of faecal and toilet origin that require ultimate collection and transport via a tanker to a municipal treatment plant; and
- Property resale values could be reduced as subsequent owners may not want the on-going operational obligations and seek a contribution to public sewer connection if not present.

### ***Treatment of black water***

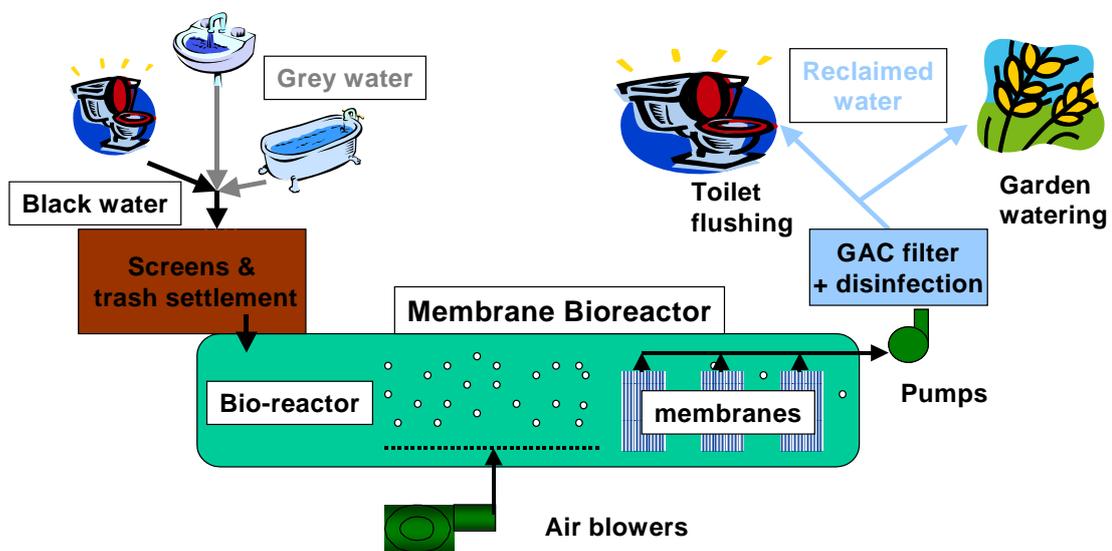
Selection of treatment processes for black water should follow the basic steps described in Section 7.1 and will also depend on the reclaimed water applications. Well documented references for individual household or buildings with urban reuse applications, such as toilet flushing, are becoming more frequent in the UK with the most recent development being the Queen Elizabeth Olympic Park, built for the 2012 Olympics. Here sewage from North London homes was diverted and sent to a black water treatment plant to turn it to a non-potable standard that was then used for toilet flushing across the park. Combined with the RWH and grey water treatment this reduced the park's need for potable water by 58% (QEOP, 2013). Many examples of black water recycling both in the UK and internationally are based on a compact form of wastewater treatment technology called a membrane bioreactor. It is beyond the scope of this document to go into great detail about black water treatment processes for domestic or commercial reuse; however a brief overview of membrane bioreactors will now be given.

### ***Membrane bioreactors***

Conventional wastewater treatment to produce an effluent suitable for non-potable reuse applications is usually achieved through multiple separate stages. These may

include primary settlement of raw sewage solids, secondary aerobic biological treatment followed by settlement of resulting biomass and a tertiary sand filtration stage with chemical or UV based disinfection. These treatments require significant land area and are expensive to cover for odour control. Membrane bioreactor (MBR) technology has been developed to potentially combine all of these stages in a compact and covered, single stage process reactor, suitable for installation within conventional buildings. They are essentially a combination of conventionally aerated, biological activated sludge treatment and semi-permeable membrane filtration designed originally to filter sub-micron sized particles such as bacteria from milk, beer and high value industrial fluids (see Figure 19).

**Figure 19: Schematic of membrane bioreactor**



The membranes are usually made from polymers and cast as sheets or hollow fibres fitted in structures that enable pressure or suction from pumps to drive clean water through the membrane whilst particles are retained for subsequent backwash removal. The compactness of membrane bioreactors may give reduced capital and installation costs compared to small-scale, multi-stage conventional treatment but the process is more energy intensive which is a current disadvantage for larger municipal scale applications. Screens and a settlement tank are required before the MBR and the reclaimed water produced is usually treated with an activated carbon filter to remove a residual yellow/brown colour, prior to disinfection with chlorine. Some installations have used ozone, or a combination of ozone and UV for these MBR effluent polishing stages.

The British Standard BS8595:2013 provides recommendations for selecting water reuse systems, taking into account water resources, surface water management and sewerage infrastructure. It is applicable to new and existing developments in residential and non-residential premises.

## 8. Conclusions

Water scarcity, droughts, flooding and concerns about longer-term climate change are driving the development of new urban water resource strategies and policies. These include a drive for greater water efficiency, demand management through metering and options for rainwater harvesting, grey or wastewater (black water) reclamation, and recycling for non-potable reuse applications at municipal, community or individual household scale.

The UK has been slower to adopt non-potable reuse than some other developed countries but interest and implementation at a community and household level is increasing. With the introduction of British Standards for GWR and RWH there are now clear guidelines to help ensure that systems are fit for purpose and achieve the necessary performance and safety standards.

RWH for garden watering in urban areas is simple, low cost and in common practice throughout the UK, particularly following recent droughts and public water supply hosepipe bans. However, the storage potential offered by conventional rainwater butts of only 100-250 litres is inadequate to fully exploit the rainfall run-off potential of UK urban areas. Rainwater harvesting for toilet flushing and other non-potable uses is increasingly popular in the UK as technology develops and the associated costs reduced.

The recycling of grey water from wash-basins, baths and showers is also possible and may be combined with RWH for garden watering and toilet flushing. Generally, the need for treatment systems and additional pipe work increases the unit cost of these systems, meaning it is more commonly found in larger scale projects rather than for domestic properties. Black water, wastewater or whole sewage reclamation at individual household scale is rarely practiced due to the cost and complexity of the systems required. The best example of all of these systems is in the Queen Elizabeth Olympic Park. This used a combination of RWH harvesting, GWR and black water reuse to provide vast quantities of non-potable water for the London 2012 Olympics, the most sustainable Olympic Games to date.

## REFERENCES

- Aquaco (2013) 'Multi-Residential Grey Water Recycling – Case Studies'. Aquaco available at <http://www.aquaco.co.uk/Grey-Water/Grey-Water-Recycling-Multi-Residential> [accessed December 2014]
- AUS (2006) 'Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1), available at <http://www.environment.gov.au/system/files/resources/044e7a7e-558a-4abf-b985-2e831d8f36d1/files/water-recycling-guidelines-health-environmental-21.pdf> [accessed December 2014]
- AUS (2008) ' Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies, available at <http://www.environment.gov.au/system/files/resources/9e4c2a10-fcee-48ab-a655-c4c045a615d0/files/water-recycling-guidelines-augmentation-drinking-22.pdf> [accessed December 2014]
- AUS Gov (2011) Guidance on use of rainwater tanks, Third Edition, The Department of Health, available at <http://www.health.gov.au/internet/publications/publishing.nsf/Content/ohp-enhealth-raintank-cnt-1~ohp-enhealth-raintank-cnt-1-preface> [accessed December 2014]
- Bath (2014) 'Roman Baths Behind the Scenes Gallery', My Bath and NE Somerset, available at [http://www.myquestbathnes.org.uk/content/catalogue\\_item/roman-baths-behind-the-scenes-gallery](http://www.myquestbathnes.org.uk/content/catalogue_item/roman-baths-behind-the-scenes-gallery) [accessed October 2014]
- Building Reg (2010) 'Sanitation, hot water safety and water efficiency, Requirement G1', HM Government.
- BREEAM (2010) 'Design and assessment method for sustainable homes', BREEAM, available at <http://www.breeam.org> [accessed October 2014]
- BSRIA (2001) 'Rainwater and Grey water in Buildings – Project report and case studies', BSRIA Technical, published as BSRIA Technical Note TN/2001.
- BSRIA (2002a) 'Water Reclamation Guidance design and construction of systems using grey water', BSRIA Technical, Published as BSRIA Technical Note TN6/2002.
- BSRIA (2002b) 'Water Reclamation Standard, Laboratory testing of systems using grey water', BSRIA Technical, published as BSRIA Technical Note TN7/2002.
- BS 8515 (2009) 'Rainwater harvesting systems – code of practice', British Standards Institution.
- BS 8525-1 (2010) 'Grey water systems – code of practice', British Standards Institute.
- BS 8525-2 (2011) 'Grey water systems – domestic grey water treatment equipment, requirements and test methods', British Standards Institute.
- BS 8593 (2013) 'Code of practice for the selection of water reuse systems, British Standards Institute.
- CCC (2012) 'Water scarcity indicators', The Committee for Climate Change, available at <http://www.theccc.org.uk/charts-data/adaptation-indicators/water-scarcity-indicators/> [October 2014]
- CFSH (2010) 'Code for sustainable homes', Department for Communities and Local Government.
- CIBSE (2005). Reclaimed Water (CIBSE Knowledge Series). ISBN 1903287545. Available at <http://www.cibse.org/> order code KS01 published 2005, UK.

CIRIA (2001) Buildings That Save Water. Publications set SP160, CIRIA 2001 including:- Leggett D, Brown R, Brewer D, Stanfield G, Holliday E. (2001). Rainwater and grey water use in buildings. Best practice guidance, CIRIA C539. available from <http://www.ciria.org>

CIRIA (2003) or Schaffer, P, Elliot, C, Reed J, Holmes J, and Ward, M. (2003). Model agreements for sustainable management systems. Review of existing legislation. CIRIA report no 664 (2003)

CIRIA (2006) Duggin, J and Reed, J. (2006). Sustainable water management in schools. CIRIA Key Performance Indicator water-resources series W012. Available from <http://www.ciria.org>

CIWEM (2008) 'Water Reuse for People and the Environment', Chartered Institution of Water and Environmental Management, available at <http://www.ciwem.org/knowledge-networks/panels/water-resources/water-reuse.aspx> [October 2014]

CLG (2007) Mandating water efficiency in new buildings – a consultation. Available from:- <http://www.communities.gov.uk/index.asp?id=1505175>

Defra (2002) Directing the Flow. Priorities for Future Water Policy. Defra publications, November 2002 available from <http://www.defra.gov.uk>

Defra (2007a) BNWAT 19: Alternative sources of water – grey water and rainwater: Innovation Briefing Note. Updated April 2007 and available from [www.mtprog.com](http://www.mtprog.com)

Defra (2007b) Water Technology List – Enhanced capital allowances. Available from:- [www.eca-water.gov.uk](http://www.eca-water.gov.uk)

Defra (2011) 'Future water', Department of Environment, Food and Rural Affairs, available at <https://www.gov.uk/government/publications/future-water-the-government-s-water-strategy-for-england> [October 2014]

EA (2012) 'Water resources planning guide', Environmental agency, OFWAT, Defra and Welsh Government, available at <http://www.environment-agency.gov.uk> [accessed October 2014]

EA (2013) 'Water stressed areas – final classification', Environmental Agency, available at <http://www.environment-agency.gov.uk> [October 2014]

EA GWR (2011) 'Grey water reuse for domestic use: an information guide', Environmental agency, available at <http://www.environment-agency.gov.uk> [accessed October 2014]

EA RWH (2010) 'Rainwater harvesting for domestic use: an information guide', Environmental Agency, available at <http://www.environment-agency.gov.uk> [accessed October 2014]

EC (2012) 'Assessment of River Basin Management Plans', European Commission Water Framework Directive, available at [http://ec.europa.eu/environment/water/water-framework/impl\\_reports.htm#third](http://ec.europa.eu/environment/water/water-framework/impl_reports.htm#third) [accessed October 2014]

EDEN (2013) 'Saving water at Eden', Eden Project, available at <http://www.edenproject.com/whats-it-all-about/climate-and-environment/sustainability-at-eden/saving-water-at-eden> [accessed October 2014]

EEA (2006) 'EU Bathing Water Directive', European Environment Agency, available at [http://ec.europa.eu/environment/water/water-bathing/index\\_en.html](http://ec.europa.eu/environment/water/water-bathing/index_en.html) [accessed October 2014]

EFRAC (2013) ‘The Water White Paper’, Environment Food and Rural Affairs Committee, available at <http://www.publications.parliament.uk/pa/cm201213/cmselect/cmenvfru/374/374.pdf> [accessed December 2014]

EPA (2012) Guidelines for Water Reuse, EPA/600/R-12/618 September 2012, available at <http://nepis.epa.gov/Adobe/PDF/P100FS7K.pdf> [accessed December 2014]

EU (1998) or European Council Directive 98/83/EC (1998) Quality of water intended for human consumption directive.

EU (2006) or European Council Directive 2006/7/EC (2006) Bathing Water Directive.

Fischer, G. and Helig, G.K. (1998) Population momentum and the demand on land and water resources. Report IIASA-RR-98-1. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Hills, S., Rachwal, A.J. and Clerico, E. (2002b) Thames Water’s global reuse experience – from London to Manhattan via Adelaide. Proceedings of IWA biennial conference, September 2002, Melbourne, Australia.

Hills, S., Birks, R., Grant, E. and Aitken, V. (2007) Feasibility studies of planned indirect reuse for augmenting future water supplies in London. Presented at IWA Wastewater Reclamation, Reuse & Sustainability Conference, Antwerp, Belgium. October 2007.

Hydria (2009) ‘Water supply in Roman Carthage’, Hydria Project, available at <http://www.hydraproject.net/en/the-water-management-in-the-region-of-tunis-through-history/water-works-ancient-carthage/> [accessed October 2014]

Kandel, R. (1998) Water from Heaven. Columbia University Press, New York, USA ISBN 0-231-12244-6

Lunn, M. (2004) Planned effluent reuse to enhance potable supplies. Presented at CIWEM conference “Wastewater reuse- recapturing a waste resource”, May 2004, SCI, London.

Met Office (2010) ‘UK climate averages for 1981-2010’, Met Office, available at <http://www.metoffice.gov.uk/climate/uk/averages/key-features-1981-2010> [accessed October 2014]

NEWater (2007) Singapore Government Public Utilities Board Used Water, available at <http://www.pub.gov.sg/general/usedwater/Pages/default.aspx> (accessed November 2014)

NSW (2014) ‘Greywater Fact Sheets 1 – 5’, New South Wales Government Office of Water, available at <http://www.water.nsw.gov.au/Urban-water/Recycling-water/Greywater/Greywater/default.aspx> [accessed November 2014]

OFWAT (2014) ‘Charges and Bills 2012/2013’, Water Services Regulating Authority, available at [http://www.ofwat.gov.uk/regulating/charges/prs\\_web\\_charges2012-13](http://www.ofwat.gov.uk/regulating/charges/prs_web_charges2012-13) [accessed October 2014]

QEOP (2013) ‘Olympic Gold for London's water recycling’, Water World, available at <http://www.waterworld.com/articles/2012/07/olympic-gold-for-londons-water-recycling.html> [accessed October 2014]

QEOP (2014) ‘Environmental Sustainability Report 2014’, London Legacy Development Corporation, available at <http://queenelizabetholympicpark.co.uk/~media/queop/files/public/201314%20your%20park%20our%20planet.pdf> [accessed October 2014]

RHS (2007) Royal Horticultural Society. Web site <http://www.rhs.org.uk>

Rose, J.B., Sun, G-S., Gerba, C.P. and Sinclair, N.A. (1991) Microbial quality and persistence of enteric pathogens in gray water from various household sources. *Wat. Res* 25 (1) 37-42.

SI No.3184 (2000) Water Supply (Water Quality) (England and Wales) Regulations.

SI No.1297 (2001) Drinking Water (Undertakings) (England and Wales) Regulations.

UKCP (2012) 'UK-wide climate maps', UK Climate Projections, available at <http://ukclimateprojections.metoffice.gov.uk/21731> [accessed October 2014]

USGBC (2005) US Green Building Council – Leadership in Energy and Environmental Design (LEED) guidelines, available at <http://www.usgbc.org/leed> [accessed December 2014]

Water Resources SE (2013) 'Progress towards a shared water resources strategy in the South East of England', Water Resources in the South East, available at <http://wrse.org.uk/sites/default/files/pdfs/WRSE Phase 2B Final report 24Apr2013.pdf> [accessed October 2014]

WERF (2005) 'Long-Term Effects of Landscape Irrigation Using Household Grey water', Water Environment Research Foundation, available at <http://www.werf.org/WERFDownload.aspx?ContentKey=03070e17-283c-4b37-b4ec-cd099384eca9&ContentItemKey=7b08d2d1-7f4e-4f7f-ab74-066304ad1e74> [accessed October 2014]

WHO (2006a) 'Guidelines for the safe use of wastewater, excreta and grey water'

WHO (2006b) 'Health aspects of plumbing', World Health Organisation

World Health Organisation, Vol 1 Policy and regulatory aspects

WORLD BANK (2005) Electricity Production (kWh)

<http://data.worldbank.org/indicator/EG.ELC.PROD.KH?page=1> (accessed December 2014)

WRAS 9-02-04 (1999a) 'Reclaimed Water Systems: Information About Installing, Modifying or Maintaining Reclaimed Water Systems', Water regulation advisory scheme.

WRAS (2011) 'Marking and identification of pipe work for water reuse systems' Water regulation advisory scheme

WRI Aqueduct (2011) 'Measuring and mapping water risk', World Resources Institute, available at <http://www.wri.org/our-work/project/aqueduct> [accessed October 2014]

## Contact details for relevant organisations

Organisation	Internet & UK telephone number
British Standards Institution (BSI)	<a href="http://shop.bsigroup.com/">http://shop.bsigroup.com/</a> 0845 086 9001
Building Services Research and Information Association (BSRIA)	<a href="http://www.bsria.co.uk">http://www.bsria.co.uk</a> 0134 446 5600
Chartered Institute for Building Services Engineers(CIBSE)	<a href="http://www.cibse.org/">http://www.cibse.org/</a> 0208 675 5211
Construction Industry Research and Information Associations (CIRIA)	<a href="http://www.ciria.org">http://www.ciria.org</a> 0207 549 3300
Department for Communities and Local Government (CLG)	<a href="http://www.communities.gov.uk">http://www.communities.gov.uk</a> 0207 944 4400
Department for the Environment, Food & Rural Affairs (Defra)	<a href="http://www.defra.gov.uk">http://www.defra.gov.uk</a> 0845 933 5577
Department for Business, Innovation and Skills	<a href="https://www.gov.uk/government/organisations/department-for-business-innovation-skills">https://www.gov.uk/government/organisations/department-for-business-innovation-skills</a> 020 7215 5000
Drinking Water Inspectorate for England & Wales (DWI)	<a href="http://www.dwi.gov.uk">http://www.dwi.gov.uk</a> 0207 082 8024
Environment Agency (EA)	<a href="https://www.gov.uk/government/organisations/environment-agency">https://www.gov.uk/government/organisations/environment-agency</a> 0870 850 6506
Mayor of London	<a href="http://www.london.gov.uk">http://www.london.gov.uk</a>
Meteorological Office (UK)	<a href="http://www.metoffice.gov.uk">http://www.metoffice.gov.uk</a> 0139 288 5680
Royal Horticultural Society (RHS) (UK)	<a href="http://www.rhs.org.uk">http://www.rhs.org.uk</a> 0845 260 5000
UK Rainwater Harvesting Association(UKRHA)	<a href="http://www.ukrha.org/">http://www.ukrha.org/</a>
Water Regulations Advisory Scheme (WRAS)	<a href="http://www.wras.co.uk">http://www.wras.co.uk</a> 0149 524 8454
Water Services Regulation Authority (OFWAT)	<a href="http://www.ofwat.gov.uk">http://www.ofwat.gov.uk</a> 0121 625 1300
Water UK	<a href="http://www.water.org.uk">http://www.water.org.uk</a> 0207 344 1844
World Health Organization (WHO)	<a href="http://www.who.int/en/">http://www.who.int/en/</a>