# Appendices

# Contents

**A1 Review of rainwater harvesting systems and technologies in the UK ..... 2**

A1.1 Introduction ..... 2
A1.2 Approach ..... 2
A1.3 Background ..... 5
A1.4 Characteristics of RWH systems ..... 8
A1.5 Types of RWH systems ..... 11
A1.6 Application of RWH systems ..... 16
A1.7 Considerations when installing a RWH system ..... 18
A1.8 Barriers and challenges to the technology ..... 24
A1.9 Costs and performance ..... 25
A1.10 Water quality and contamination ..... 30
A1.11 Regulation and guidance ..... 31
A1.12 Use of RWH systems in other countries ..... 36
A1.13 Conclusions ..... 37
A1.14 References ..... 39

**A2 Review of grey water recycling systems and technologies in the UK ..... 42**

A2.1 Introduction ..... 42
A2.2 Approach ..... 42
A2.3 Background ..... 44
A2.4 Household and non-household water demand ..... 46
A2.5 GWR systems, designs and technologies ..... 49
A2.6 Application of GWR systems ..... 56
A2.7 Barriers and challenges to the technology ..... 59
A2.8 Costs and performance ..... 60
A2.9 Water quality ..... 64
A2.10 Regulation and guidance ..... 66
A2.11 The use of GWR in other countries ..... 72
A2.12 Conclusions ..... 74
A2.13 References ..... 76

# A1 Review of rainwater harvesting systems and technologies in the UK

## A1.1 Introduction

Rainwater harvesting (RWH) systems and technologies offer a potential solution and are increasingly being considered at the building-level as a means for addressing water scarcity and stormwater attenuation. To date rainwater harvesting systems have been implemented with mixed experience in the UK. Technical concerns regarding water quality, potential cross connections and issues around the social acceptability of using recycled water have all been barriers to uptake. Further to this a 2011 Environment Agency (EA) report on the carbon implications of these systems suggested that due to pumping and treatment they are often more carbon intensive than the public water supply (Environment Agency, 2011). Additionally, the payback periods and return on investments can be obtrusive for some systems but may benefit from economies of scale if they are introduced at a development scale or centralised within an existing community.

While over the last decade there have been advances in RWH technologies, there remains a gap in research and accreditation for these systems compared with countries such as the USA and Australia, and in support to bring them to the market on a wider scale. There has also been a lack of coordinated and collated evidence across the country, especially on differing scales and for non-domestic properties. Information guides published by the Environment Agency (Environment Agency, 2010 and 2011) outlined the costs and benefits for domestic installations of RWH systems but these are now largely out of date.

This work aims to address this research gap. Drawing on case studies and industry examples the evidence base for rainwater has been developed and used to model the costs and benefits of existing the technologies in different contexts, scales, building types and new or retrofitted buildings.

## A1.2 Approach

A review of academic and industry research into RWH systems, designs and technologies including various retrofit installations and new build systems across a range of building types was undertaken. In parallel a series of stakeholder interviews were undertaken to address any potential gaps in information identified in the literature review and to widen the understanding beyond published work, gain greater sector insight and to identify further case studies and examples not in the public domain.

The approach combined a robust review of existing academic literature and industry research relating to RWH systems with a targeted stakeholder engagement programme to gather and collate the relevant data and information to inform the cost benefit analysis.

### A1.2.1 Literature review

The key objective of the literature review was to identify and collate academic and industry research into RWH systems, designs and technologies and gather information and data on the costs and performance of existing systems, including various retrofit installations and new build systems across a range of building types.

Targeted searches were undertaken to address the wide range of potentially relevant subject areas using keywords designed systematically to identify relevant studies. Platforms including GoogleScholar and ScienceDirect were used and all relevant data and information was collated into spreadsheet format to facilitate subsequent evaluation and review.

A four step process for identifying relevant literature and information was used as follows:

1. Development of a list of search themes and sub-divisions.
2. Agreement of search themes with the project steering group.
3. Preliminary high level search followed by adjustment and optimising of the search terms.

4. Capture all relevant titles in spreadsheet format and save electronic copies for easy access.

In addition, a similar search strategy was established to gather relevant grey literature (e.g. national and international government reports, studies published by industry and relevant trade associations, NGO's and academic theses) and other resources. A search of water retailer websites was undertaken to identify relevant services and incentives provided to business customers to encourage the uptake of RWH systems.

#### A1.2.1.1 Stakeholder engagement

From the outset it was anticipated that there would be gaps in data and literature available within the public domain such as those associated with the following:

- Establishing the actual capital and operational costs and data (including energy use etc).
- Validating the actual benefits (e.g. water savings, return on investments etc).
- Substantiating the technical barriers and challenges and identifying the reasons why some projects were not successful.
- Understanding how the technology is perceived in the market place.

Therefore to address these a series of stakeholder interviews were undertaken in parallel with the literature review. Using Ricardo's existing contacts together with the project steering group's knowledge and contacts, a comprehensive set of stakeholder organisations was identified. Further investigation was then carried out to establish relevant representatives within the organisations that responded and there were some difficulties in light of the ongoing COVID-19 pandemic due to staff being furloughed within some stakeholder organisations. Table A1-1 presents the list of stakeholder organisations that contributed to the study arranged by stakeholder and grouping.

Table A1-1 – Stakeholder engagement interviews

| Group | Stakeholder | Date |
|---|---|---|
| Equipment suppliers, installers and manufacturers | UKRMA | 31/03/2020 |
| | Aquality | 31/03/2020 |
| | Stormsaver | 15/04/2020 |
| | SDS Limited | 22/04/2020 |
| Water retailers | Castle Water | 16/04/2020 |
| | Affinity for Business | 16/04/2020 |
| | Waterscan | 30/04/2020 |
| Water industry / Retailers | UK Water Retailer Council | 22/04/2020 |
| Water Industry | Anglian Water | 24/04/2020 |
| | Affinity Water | 29/04/2020 |
| | Thames Water | 28/04/2020 |
| Academia | University of Exeter | 24/04/2020 |
| | University of Exeter | 27/04/2020 |
| Non-Government | GLA | 12/05/2020 |
| | CIRIA / Susdrain | 06/05/2020 |
| Developers | Redrow | 13/05/2020 |
| | Countryside Properties | 03/06/2020 |
| | Berkeley Group | 30/06/2020 |

In preparation for the interviews a tailored interview proforma was developed to provide structure to the discussion. Information, case studies and data attained as a result of the interviews fed in to the literature review and cost benefits analysis.

### A1.2.2 Scope

A list of search themes and sub-divisions was developed, the key areas of focus were as summarised below:

- Key drivers for uptake of rainwater harvesting systems;
- Types of system and their application (e.g. commercial, domestic, retrofit, new build, different building types etc);
- Operational performance of rainwater harvesting (including capital and operational costs, carbon, energy impacts across full lifecycle and any social/community / wider benefits);
- Benefits of rainwater harvesting (including water savings and wider benefits associated with flood prevention and urban water management)
- Barriers and challenges associated with installation of rainwater harvesting systems.
- Relevant case studies (UK and international).
- Potential pollutants such as microplastics.

As one of the key objectives of the review was to support the production of an updated version of the 2010 Environment Agency report, Harvesting Rainwater for Domestic Uses: An Information Guide (Environment Agency, 2010), data and information gathered through the review has been grouped accordingly as shown below:

- The types of system and their potential applications and limitations.
- Installation considerations for when / if a RWH system is / should be installed.
- Barriers and challenges associated with RWH systems. Including the long-term savings vs costs.
- The costs and performance considerations for RWH systems.
- Water quality considerations for RWH systems.
- The use of rainwater harvesting in countries other than the UK.

At the outset of the review a list of data requirements to inform the cost and benefit analysis element of the project was developed. This covered a range of building types including both domestic and commercial and both new and retrofit installations. The types of data that the study aimed to identify and collect is outlined in Table A1-2.

Table A1-2 – Data requirements for cost benefit analysis

| | |
|---|---|
| • Source & date of information<br>• New build / retrofit<br>• Building type (commercial, domestic)<br>• Project details (e.g. community project, residential block, detached house, public building, school etc)<br>• Scale (collection area $M^2$, tank size, $M^3$)<br>• Capital (£) and operational costs (£/annum)<br>• Yield ($M^3$/annum) | • Mains water cost (£/$M^3$)<br>• Energy type<br>• Energy use (kWh) and cost (£/annum)<br>• Anticipated lifespan of asset (years)<br>• Assessment of uncertainty / quality of source / data<br>• Interaction with other measures: e.g. Sustainable Urban Drainage (SUDs), Grey water recycling (GWR) etc |

In addition a summary of the findings from a separate review of the incentive schemes (e.g. discounts) that are currently in place in the water industry as well as policy options and interventions adopted in other countries to encourage the uptake of RWH is provided. In agreement with the project steering group this review focussed on several countries, due to their similarity to the UK in terms of climate and level of development. The countries selected were:

- Germany

- Australia
- Japan
- USA.

For the purposes of this study the review broadly follows the definition of rainwater harvesting as identified in the British Standard BS 8515:2009 + A1:2013 Rainwater harvesting systems – Code of Practice (British Standards Institute, 2013), i.e. systems which capture precipitated rainfall and store it for non-potable water uses in the home, workplace and garden. It also covers the benefits of RWH in the attenuation of surface water run-off.

The RWH systems included in the review are broadly commercially available systems for domestic and commercial uses of relevance to homeowners, house builders, planners, architects and building managers.

## A1.3 Background

In the face of significant pressure on water resources within the UK there is a distinct need to manage and use existing supplies as efficiently as possible. Our changing climate is causing more extreme weather conditions with extended periods of drought and more frequent, intense rainfall becoming the norm. This coupled with a rising population means that both water shortages and flooding is likely to become an increasing problem in a number of regions across the UK. With population in England set to increase by 8.7 million by 2050[1], the new homes and services required will place a significant additional demand on water and sewerage services and will severely exacerbate the risk of surface water flooding in many urban areas (Policy Connect, 2018)

The Water UK 'Water resources long-term planning framework (2015-2065)' (Water UK, 2016) stated that a 'twin-track' approach of increasing supply and reducing demand is needed in order to secure the resilience of water supplies over the next 50 years. The National Infrastructure Commission's report 'Preparing for a drier future: England's water infrastructure needs' (National Infrastructure Commission, 2018) supported the need for this approach suggesting that two thirds of the additional capacity required to maintain the current level of resilience should come from demand management measures. The report stated that increasing efficiency savings and near universal smart metering would reduce the average per capita consumption (PCC) from the current 141 litres/person/day to 118 litres by 2050. Further to this the Environment Agency's National Framework for Water Resources suggests a planning assumption of 110 l/p/d is adopted (Environment Agency, 2020).

RWH together with GWR technologies offer potential solutions and are increasingly being considered at the building-level as a means for addressing water scarcity and can also support stormwater attenuation. Over the past decade, there has been advances in the associated technologies but there has not necessarily been an increase in the take up of such systems in the UK.

The practice of RWH for supplying drinking water and irrigation in urban areas, particularly in semi-arid regions, can be traced back at least 4000 years BC (Memon and Ward, 2018**).** However in many countries it was all but replaced due to technological advances and the development of centralised water supply systems which allowed abstraction from groundwater aquifers, large transfer systems and large scale management networks to meet growing water demand (Yannopoulos et al., 2019). In more modern times RWH has primarily been used in the rural domain where the construction of centralised infrastructure was not feasible.

More recently RWH has received renewed attention in many countries (Yannopoulos et al., 2017) and is again penetrating into cities where the bulk of the world's population resides (Memon and Ward, 2018). Researchers and policymakers have also shown a renewed interest in RWH primarily driven by pressures on available water resources through rising water demand, an increased interest in conservation of water and energy, and increased regulatory emphasis on reducing stormwater runoff volumes and associated pollutant loads (Yannopoulos et al., 2019).

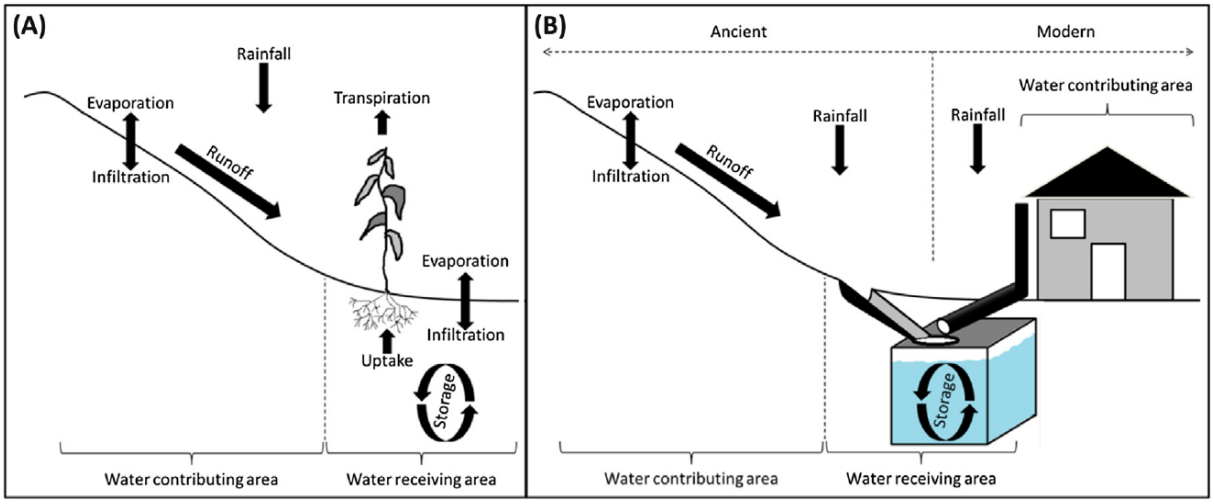
[1] England's population of 55.3 million people is projected to grow by 5.9% over the next 10 years, and to almost 64 million by 2050, an increase of nearly 15%

### A1.3.1 What is rainwater harvesting (RWH)?

A variety of terms are used to describe the various methods employed to collect and store rainwater to increase the availability of water for potable and non-potable use (Yannopoulos et al., 2019). RWH, as a general term is used in the literature to describe a breadth of methods to harvest water. These range from collecting rainwater from surfaces such as the ground or rooftops, runoff harvesting and rooftop harvesting respectively, to channel flow (flood water harvesting) and from various atmospheric sources (rain or dew) all of which can be used for various purposes, domestic, commercial or otherwise (Yannopoulos et al., 2017).

Figure A1-1 demonstrates how RWH systems have evolved of over time, moving from the capture of surface runoff for irrigation purposes to a more complex system including channel systems to deliver rain and surface runoff water towards underground storage (Nachshon et al., 2016). Panel (A) highlights a simple system where runoff and rainfall is routed towards lower ground where it can be collected and used directly for irrigation; and panel (B) shows a more complex system where rain and surface water from the land and buildings have historically been routed by systems of channels or more recently by pipes and tubes towards reservoirs, where the water can be used for domestic and agricultural purposes, based on quality and needs **(**Nachshon et al., 2016**).**

Figure A1-1: Comparison of the evolution of RWH systems design and functions over time (Nachshon et al., 2016)




The choice of which type of RWH system is utilised is a product of several factors including the intended application of the harvested rainwater and the materials available for the construction of the system. RWH systems can be as simple as a plastic sheet suspended between 4 wooden beams (Sendanayake, 2016) or more complex involving filtration and treatment of harvested rainwater.

For the purposes of this study RWH is considered as the collection of atmospheric precipitate, collected upon a catchment and routed to a storage facility for future usage, as potable or non-potable water in an industrial or domestic capacity.

### A1.3.2 Why consider a RWH system?

Developments to improve its efficiency has returned RWH to the forefront as a popular method to meet water resource demands (Campisano et al., 2017). In developed countries the applications for harvested rainwater are disparate, however it typically functions as a supplementary measure to conventional systems, more accurately to reduce the consumption of potable water from centrally supplied sources, for non-potable purposes such as irrigation, laundry, and toilet flushing (Campisano et al., 2017). This supplementary function is typically to meet increasing water demand, which cannot be satisfied without the development of new resources (Nachshon et al., 2016 and Fewkes, 2012), as well as providing a solution to the hydrological challenges imposed by the urban environment, specifically attenuating stormwater runoff exacerbated by urban expansion (Campisano et al., 2017, Amos et al., 2016 and Nachshon et al., 2016). In rural areas of some developed countries such as

Australia, the collected water is also used as a potable resource, supplementing conventional supply (Yannopoulos et al., 2019**).**

### A1.3.3 What are the benefits?

The primary function of RWH is to supplement existing water resources, through reducing demand (Amos et al., 2016, Nachshon et al., 2016 and Fewkes, 2012); as such the primary benefit to the end-user will be reduced mains water costs. This reduction in consumption of potable water reduces the water stress on existing water resources and reduces the necessity to over utilize existing resources, through abstraction from aquifers or rivers, the seeking out of new water resources to meet growing demand and to transport water to the area of demand (Fewkes, 2012 and Campisano et al., 2017). These activities can have a severely detrimental effect upon ground water sources causing a reduction in the water table and significantly altering ground water flows (Sendanayake, 2016)

Along with supplementing existing water resources RWH can provide a further environmental benefit through the detention and attenuation of surface water runoff during rainfall events. In the last 20 years RWH has become incorporated into a large family of detention-based low impact development (LID) or SuDS approaches that can be adopted as a complementary measure to reduce frequency, peaks and volumes of urban runoff (Wilcox et al., 2016**).** An increasing regulatory emphasis on reducing stormwater runoff volumes and the associated pollutant loads has also positioned RWH as a viable option (Yannopoulos et al., 2019).

The retention of water deposited upon the urban landscape by RWH systems helps to reduce the quantity of stormwater runoff, mitigates sewer overflows and decreases watershed pollution (Ghimire et al., 2014). By retaining water in decentralised systems RWH prevents the inundation of the centralised water management infrastructure, namely surface water drainage systems and treatment facilities (Schuetze, 2013). This has a positive effect upon local surface waters as these water bodies are therefore no longer the recipients of untreated discharges from inundated treatment infrastructure in times of excessive surface runoff (Schuetze, 2013).

In recent years research has also indicated a focus on the educational and prestige benefit of harvested rainwater. In Europe it has been suggested that engaging with the practise of RWH facilitates individuals to consciously connect their behaviour and the natural resources they consume, thereby engendering a feeling of responsibility towards their water use (Sendanayake, 2016). Similarly, an interest in RWH systems has been noted due to the increased drive in water self-sufficiency of large urban areas and cities, where they can help delay the need to construct new centralized water infrastructures (Campisano et al., 2017 and Schuetze, 2013). These combined with the growing interest in the conservation of water and the understanding of the importance of water resources could assist in the amelioration of increased demand due to climate change and or the accompanying variability in weather patterns (Yannopoulos et al., 2017).

### A1.3.4 What savings can be achieved?

A RWH system allows collected rainwater to be used as a substitute to potable water for non-potable applications, thus reducing overall potable water consumption and potable water costs to the customer **(**Amos et al., 2016, Fewkes, 2012 and Corvaro, 2019). Typically the level of savings that can be achieved using a RWH system will be dependent upon the price of potable water supplied and the quantity of potable water saved. However, these savings can only be truly realised by customers that are connected to a metered water supply which at present is around 50% of households in the UK[2]**.** In commercial/industrial buildings the savings that can be achieved are typically higher as these generally have larger roof areas and a greater demand for non-potable water than private dwellings.

It is important to note that research suggests that RWH is only economically viable, meaning has a realistic payback period or chance of creating a saving for the user, if the water resources in a country are priced to encourage efficiency measures (Schuetze, 2013). This is further expanded upon in Section A1.9.

[2] https://www.water.org.uk/advice-for-customers/water-meters accessed on 05/06/2020

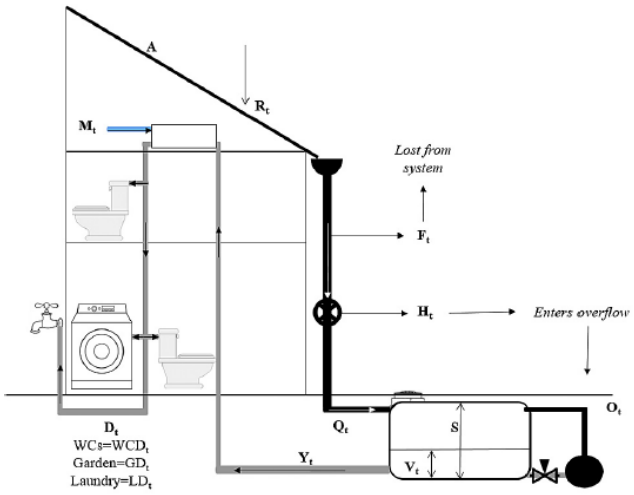
# A1.4 Characteristics of RWH systems

The term rainwater harvesting is employed to describe a variety of methods for the collection and storage of rainwater for potable and non-potable use (Yannopoulos et al., 2019). System design ranges from small scale (domestic) roof collection systems, through larger systems deployed in schools, stadiums, airports and so on, to community scale land surface catchment systems and dual purpose systems used for stormwater attenuation.

## A1.4.1 Conventional systems

Conventional or traditional RWH systems are relatively simple consisting primarily of a catchment area, typically a building roof, a conveyance system, a storage tank and interconnecting pipe work **(**Fewkes, 2012 and Sendanayake, 2016 and Alameddine et al., 2019). Additional features such as filtration and treatment units may also be required depending upon the intended end use for the harvested water (Alameddine et al., 2019). Depending on the end use, the system may, where possible, be also connected to the mains supply to provide a backup system in times of low flows (Vieira et al., 2014). Figure 2 shows the configuration of a typical system for on-site RWH and the interaction of its main components. Each of the key components are outlined further below.

Figure A1-2 Components of a typical rainwater systems. Arrows indicate water fluxes. (Reproduced from Campisano et al., 2017).




A [m²] = impermeable collection area; $R_t$ [m] = rainfall; $F_t$ [m³] = First flush losses; $H_t$ [m³] = diverted flow (filter losses); $Q_t$ [m³] = inflow to the tank; $O_t$ [m³] = overflow from the tank; $V_t$ [m³] = volume in store; S [m³] = functional tank capacity; $Y_t$ [m³] = rain water volume yielded from the tank; $M_t$ [m³] = water from mains; $D_t$ [m³] = water demand; Subscript $_t$ relates to the time step of the simulation.

### A1.4.1.1 Collection surface /catchment area

The most common collection surface for a RWH system is the rooftop, though other impermeable surfaces (e.g. paving or carparks) can also be connected to a storage tank (Campisano et al., 2017). The size of the roof area and its construction material can affect the efficiency of water collection and water quality (Sendanayake, 2016). The preferred surfaces are those which are chemically inert such as slate, though metal roofing is also acceptable although the acidic nature of rainwater can result in dissolution of metal ions from the roof surface (Fewkes, 2012). Green roof infrastructure is a viable addition to a rainwater harvesting system however while they filter some nutrients out of the deposited water they can also add heavy metals and various other contaminating elements to the harvested rainwater **(**Ghaffarianhoseini et al., 2015). Rainwater collected from impermeable surfaces around a building is also likely to be more heavily polluted than that collected from a roof surface (Fewkes, 2012).

### A1.4.1.2 Storage tank

A core component of the RWH system is the storage tank or cistern, which performs the function of storage and treatment of the collected rainwater.

The size of the storage tank is significant as this factor affects both the volume of water that is possible to store and the initial capital investment required (Fewkes, 2012). Typically storage tanks are sized based on the capacity to hold around 3 weeks' worth of rainfall (also see Section 1.7.3). A range of tank sizes are available from small 0.5m$^3$ capacity domestic tanks, through to large scale tanks which can hold around 100,000m$^3$. Where required further storage capacity can then also be provided through additional storage tanks.

A critical point of the design of domestic RWH systems is the type of tank to use for rainwater storage. Although non-potable use is expected in the large majority of cases, the demand type plays an important role in tank selection. Rainwater storage tanks can be formed of a variety of materials including, polyethylene (PE), glass reinforced plastic (GRP), steel or concrete (Fewkes, 2012). The British Standard (BS8515:2009 + A1:2013) states that the storage tank should be constructed from a waterproof material which will not impact the quality of the harvested water or encourage microbial growth (British Standards Institute, 2013). In the UK the use of GRP tanks is widespread with concrete tanks less common due to logistical challenges and economics. In contrast pre-cast concrete tanks or cisterns are most common in Europe.

#### A1.4.1.3 Pump

In several types of RWH systems one or more rainwater supply pumps are commonly (but not exclusively) adopted to ensure that the appropriate static head (pressure) is maintained for the various uses across the site or where it is necessary to distribute the collected rainwater from a ground level / underground storage point to an elevated position (British Standards Institute 2013).

Depending on the application the pump can either be located within the storage tank (submersible pump) or outside of the tank (suction pump). Typically submersible pumps are more powerful than suction pumps and their location within the tank reduces any associated noise. However, they are less easy to inspect, service and maintain than suction pumps located outside of the tank, and an electricity supply to the tank is not required. While the storage tank is often cited as the costliest component of a RWH system (Sendanayake, 2016) the cost of the pump, or pump set can also be significant. As such it important to make sure the pump(s) chosen are correctly sized for the application (Corvaro, 2019). Oversized pumps are not only less efficient they can also cause excessive noise and vibration of pipes which can lead to premature wear or failure.

There are two common pump types that are currently employed in RWH systems; single or fixed speed, and variable speed. Variable speed pumps are designed to vary output based on the flow-rate requirement, while fixed speed pumps operate at a single output level regardless of the requirements of an end-use event (Memon and Ward, 2018). As a result, fixed speed pumps are typically lower cost for the unit, however operational costs are typically higher than variable speed pumps as they are less energy efficient due to variable pressure requirements (Vieira et al., 2014).

#### A1.4.1.4 Filtration

Filtration of harvested rainwater is the generally the first step of treatment and prevents the ingress of solid debris and particulates (e.g. sediment and leaves etc) from entering the storage tank. The filter is typically placed in the collection pipework upstream of the tank and the level of filtration is dependent upon the end use requirement of the harvested water. Coarse filtration will remove gross pollutants that may deteriorate the water quality in the storage tanks, while fine filtration will allow removal of fine particles that may be associated with pathogens and improve the aesthetics of the harvested rainwater's (Vieira et al., 2014).

Filters with a maximum particle size between 0.2 to 1.00mm are widely reported in RWH systems intended for non-potable applications with little to no additional treatment required prior to entering the storage tank (Madara et al., 2016 and Fewkes, 2012). However, rainwater intended for potable use requires more stringent treatment to conform with water quality standards **(**Vieira et al., 2014 and Fewkes, 2012). The British Standard (BS8515:2009 + A1:2013) suggests that all filter systems have an

efficiency of at least 90%[3] and a maximum particle size of <1.25mm is specified (British Standards Institute, 2013).

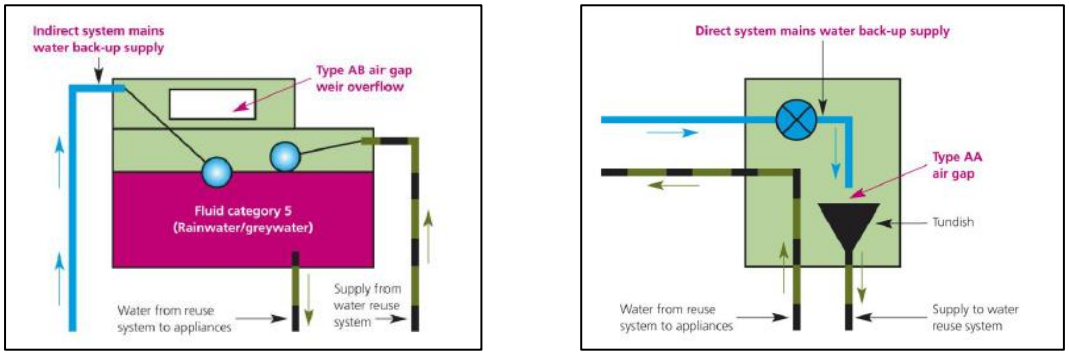
During periods of no rainfall roof areas can become polluted with various atmospheric particulates and bird droppings. The first flush of rainwater from the roof area is therefore usually more polluted than the subsequent runoff (Fewkes, 2012). While some research has suggested that initial separation of this contaminated water is unnecessary, measures are available that allow the initial flush of water to be syphoned off of to prevent contamination of the other harvested water (Fewkes, 2012). For example, the installation of devices such as first flush filters or diverters (also see Section 1.5.1.1) are often used to ameliorate the concentration of pollutants in harvested rainwater.

#### A1.4.1.5 Mains back up supply and backflow prevention

There are two commonly employed methods for supplementing the rainwater supply with mains water when demand cannot be met: trickle top-up systems and automatic switches. The former can operate both mechanically or electronically, whereas the latter works only electronically through the use of level sensors and solenoid valves. The mains back up supply system can feed directly into the storage tank or to the header tank although back flow prevention must be put in place to avoid the rainwater coming into contact with the mains water supply.

In either arrangement the Water Supply (Water Fittings) Regulations 1999[4] require that the mains water system is adequately protected from any potential contamination in the event of backflow occurring. The mains water back-up supply therefore needs to have suitable backflow protection provided at the point of supply into the RWH system. To meet the Water Fittings Regulations, fluid category 5 protection can only be achieved through the installation of either a Type AA, AB or AD air gap, or through the use of a Type DC pipe interrupter (a device that incorporates an air gap), to separate the mains water supply and a water reuse system. The most common methods are through a Type AA or AB air gap (Figure A1-3).

Figure A1-3 (a) Indirect RWH system with Type AB air gap, (b) Direct system with Type AA air gap




#### A1.4.1.6 Control unit

A variety of monitoring and control equipment is available for RWH systems ranging from a simple float switch, which is present within the storage vessel through to pump controllers, which combine the functions of a pressure switch and a flow switch to provide automatic control of the system.

A typical control unit monitors the water level in the storage tank and can display this information to the user. If levels drop too low, the system switches to the mains water supply and if it gets too high, an overflow trap allows excess water and floating material to be skimmed off to a soakaway or storm drain.

#### A1.4.1.7 Pipework

To reduce the risk of cross-connection and contamination of the potable water supply it is essential that the pipework associated with the RWH system is both readily distinguishable from other pipework and

[3] The efficiency of the filter also affects the amount of water that can be captured. Of the water that is collected in the gutters not all will reach the holding tank. Manufacturers usually advise that 90% of the water flowing into the filter is retained.
[4] Statutory Instrument 1999 No. 1148 (http://www.hmso.gov.uk/si/si1999/19991148.htm) and Statutory Instrument 1999 No. 1506 (http://www.opsi.gov.uk/si/si1999/19991506.htm).

instantly recognisable wherever it is located. In addition to colour coding all pipework should also be labelled so as to clearly identify what is being distributed and the direction of flow (Figure 4).

Insulated pipes should be labelled on the outer surface of the insulation, regardless of whether the pipe has been identified prior to insulation, and marking should be designed for the life of the system. In non-domestic properties labels specifying the nature of the supply should be applied, within 100mm, either side of the colour coding banding (Figure A1-4). In the case of domestic properties only one label need be applied. It is also recommended that all storage cisterns and point of use appliances supplied by a RWH system are also clearly identified through signage (Figure A1-5).

Figure A1-4 Examples of recommended marking and labelling for pipework within buildings (Reproduced from WRAS, 2015).

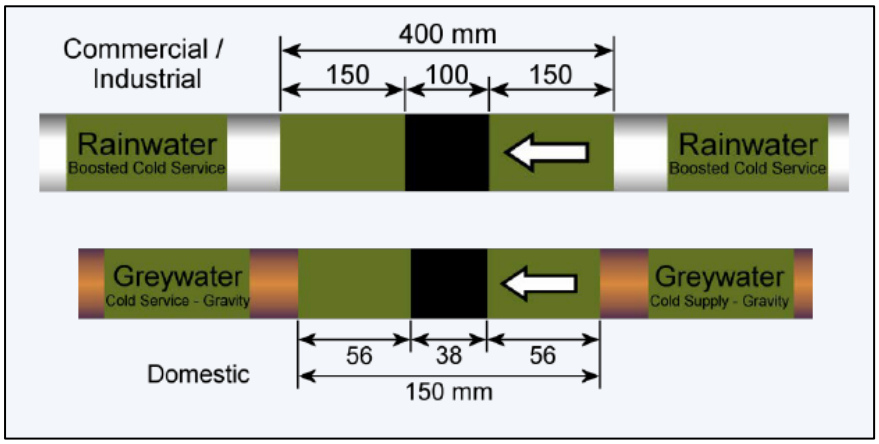
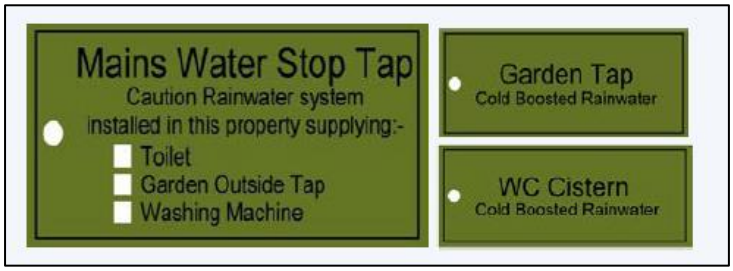



Figure A1-5 Examples of labels for use at the stop valve and other points of use (Reproduced from WRAS, 2015).



### A1.4.1.8 Treatment

Treatment of harvested rainwater is often an interconnected process, where the end usage of the water will decide the level of treatment. Typical systems for RWH treatment consist of a three stage process, firstly sediment removal followed by organic treatment (if required), and then disinfection (Medina, 2016). Ultraviolet light, chemical treatment and or membrane filtration are common methods to disinfect harvested rainwater (Campisano et al., 2017). and is covered further in Section A1.4.1.8 While no additional treatment is required for non-potable usage of harvested water it is advised that the conveyance system, gutters and pipping are cleaned regularly to prevent accumulation of detritus and animal waste, see Section A1.5.2 for more details.

## A1.5 Types of RWH systems

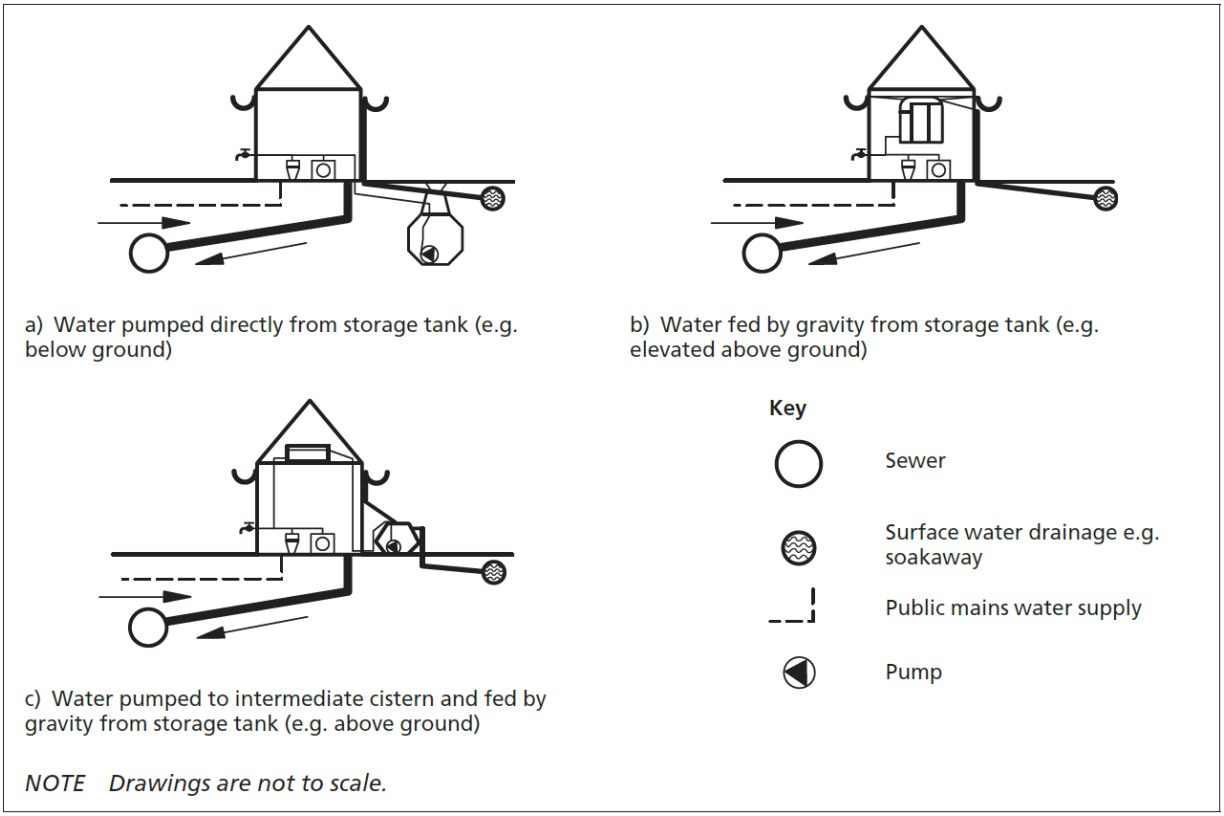
A RWH system can be as rudimentary as a plastic sheet and storage bottle, simply a collection area and storage facility **(**Sendanayake, 2016) or more complex involving multiple additional components to channel and convey harvested water through guttering and piping, pumps to convey the water to point of use and treatment systems to ensure the water is fit for use.

In the UK the most prevalent systems involve the capture of rainwater from a building roof area and storage within a rainwater tank which can either be located above or below ground (Yan et al., 2017 and Fewkes, 2012). A number of different system designs and configurations are available. These systems can be classified depending upon how the harvested rainwater is stored and distributed within the installation (Fewkes, 2012).

According to the British Standard (BS8515:2009 + A1:2013) there are three major groups of RWH systems as illustrated in Figure A1-6 (British Standards Institute, 2013, and Vieira et al., 2014):

- Direct or direct pumped system: Harvested water is collected in storage tank(s) and pumped directly to the points of use within the building (Figure A1-6a). The storage tank is generally located at ground or below ground level and the rainwater is typically distributed by a fixed speed pump to the points of use **(**Fewkes, 2012).
- Gravity or gravity only system: Harvested water is collected in storage tank(s) in an elevated position and fed by gravity to the points of use (Figure A1-6b).
- Indirect or combination system: Harvested water is collected in storage tank(s), pumped to an elevated cistern or header tank and fed by gravity to the points of use (Figure A1-6c).

Figure A1-6: Illustration of RWH system types from BS8515:2009 (British Standards Institute, 2013).




Typically, one or more pumps are adopted to assure appropriate pressure for the various uses, though the type and number of pumps is dependent upon the system type and location of the points of use or header tank, such as multiple stories above ground level. In all cases the storage tank is connected to the points of use within a building via a separate piping network (Campisano et al., 2017). Some overlap of terminology is also noted in the literature, where a system that supplies water directly to the point of use from the storage tank is referred to as a direct system, and does not necessarily have to perform this supply by pumping but can do so by gravity (Vieira et al., 2014).

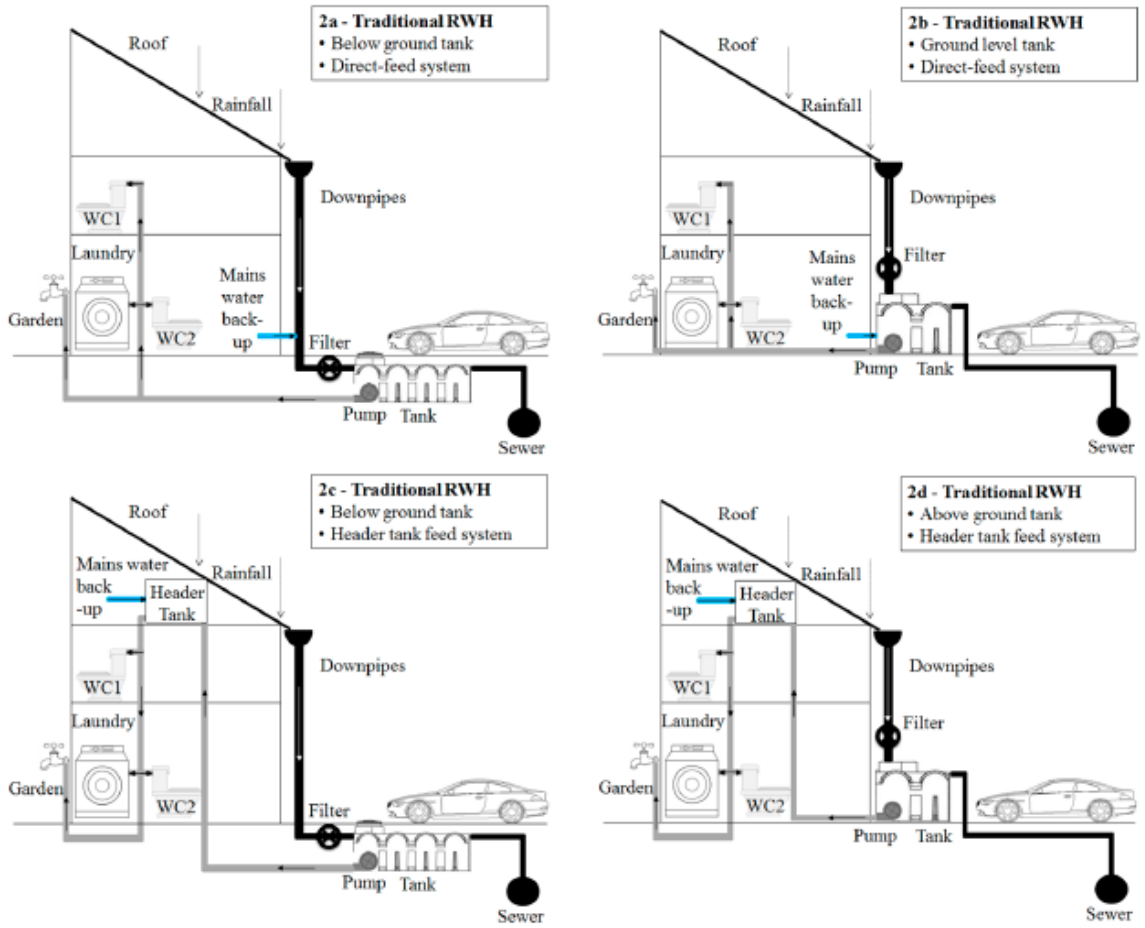
A comparison of the advantages and disadvantages of pumped flows delivered via direct-feed or header tank systems are provided in Table A1-3.

Table A1-3: Advantages and issues of direct feed and gravity fed systems (Source Environment Agency 2010)

| Direct feed systems | | Gravity fed (header tank) systems | |
|---|---|---|---|
| **Advantages** | **Disadvantages** | **Advantages** | **Disadvantages** |
| No header tank required | More energy intensive | Less pump maintenance. | A suitable elevated space is required to install the tank. |
| Adequately pressurised supply | Costly/regular pump maintenance | Greater energy efficiency | Tank can be difficult to install in elevated position. |

As a consequence, four traditional RWH system configurations have emerged in the UK as representing current best practice for household installations as described in Figure A1-7 (Melville-Shreeve et al., 2016).

Figure A1-7 Schematics illustrating four traditional RWH configurations used in the UK. (a) below ground, direct-feed; (b) above ground, direct-feed; (c) below ground, header tank feed; (d) above ground, header tank feed (Reproduced from Melville-Shreeve et al., 2016).




While these systems cover the broad types there are also additional variations. These relate to other components of the system including the location and number of storage tanks, if the tank is free standing, or whether there is a singular storage tank or multiple storage tanks supplying a single property or a communal tank supplying multiple properties (Vieira et al., 2014, Fewkes, 2012 and **167).**

There are also variations that bridge the gap between the various designs. The indirect pumped system for example provides a compromise between the combination / indirect gravity system and the direct

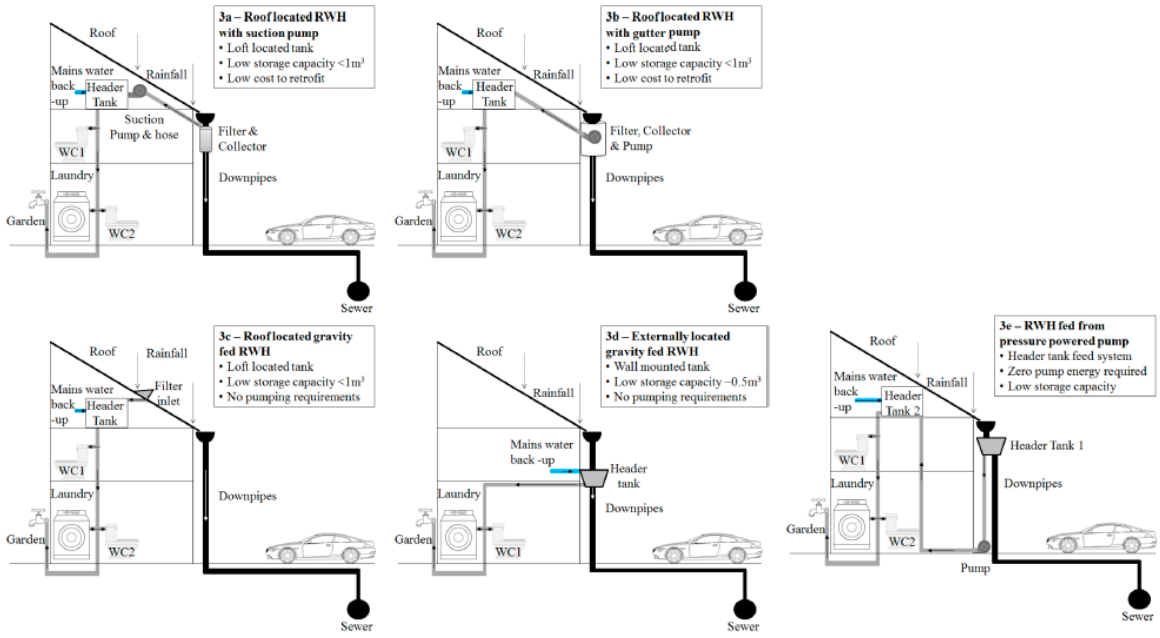
system. This follows the design of the combination system, in which harvested rainwater is pumped from a storage tank to an elevated cistern or header tank, however unlike the combination system the header tank of the indirect pumped system can be positioned at any level in the building, as it does not rely on gravity to supply outlets, instead employing a booster pump to provide a pressurised supply.

### A1.5.1 Innovative RWH designs and technologies

While RWH systems as a practise is ancient in origin the modern RWH system has seen many innovations, ranging from fractioning of storage by use of interrelated modular systems and collapsible tanks, gutter based collection and storage or other high-level, low-energy systems, each aiming to fit with the pressures of different contexts (Campisano et al., 2017).

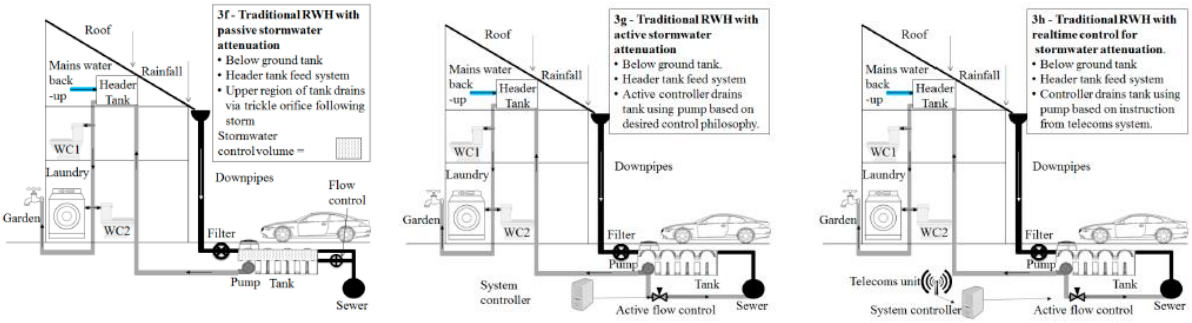
A number of innovations emerging in the UK market configured around a high-level roof-runoff inlet, which facilitates the replacement of the large ground-level tank with wall-mounted or internal header tanks. This enables rainwater to be propelled by low energy pumps or flow under gravity into header tanks, which in turn feed appliances by gravity (Figure A1-8; Melville-Shreeve et al., 2016).

Figure A1-8 Innovative RWH systems emerging in the UK market: High level roof runoff inlet (Reproduced from Melville-Shreeve et al., 2016).



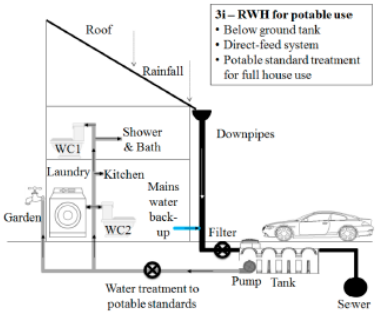

More recently RWH has also been combined to good effect within sustainable urban drainage systems as part of wider stormwater control and attenuation schemes (Campisano et al., 2017 and Melville-Shreeve et al., 2016). In these dual purpose systems separate tank units designated for both stormwater detention and retention storage objectives are incorporated. The retention storage volume is designed to meet user demands and the detention storage volume serves as a temporary holding space for runoff control. Flow is released from the storage tank either passively or actively through a release valve. These configurations also enable real time control of rainwater discharges to a sewer network based on predicted rainfall (Figure A1-9).

Figure A1-9 Innovative RWH systems emerging in the UK market: Dual purpose systems (Reproduced from Melville-Shreeve et al., 2016).




A further innovation to enable harvested rainwater to be treated to potable standards features the inclusion of a treatment train consisting of filtration, UV and ozonation (Figure A1-10; Melville-Shreeve et al., 2016).

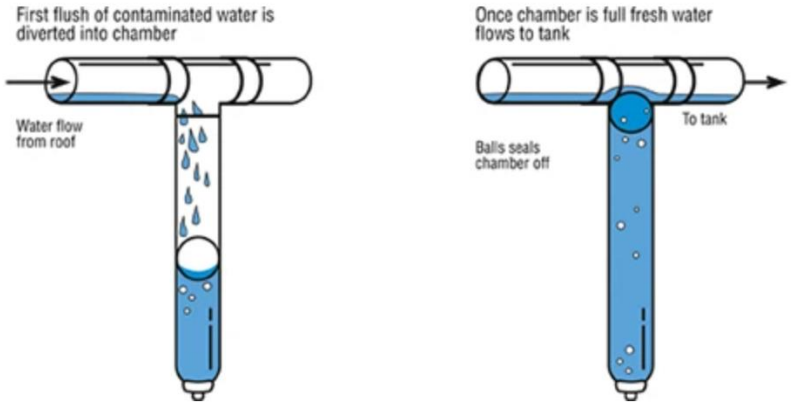
Figure A1-10 Innovative RWH systems emerging in the UK market: Treatment to potable standards (Reproduced from Melville-Shreeve et al., 2016).




### A1.5.1.1 Quality control devices

As previously stated, during periods of no rainfall roofs can become polluted with atmospheric particulates and bird droppings. The first flush of rainwater from the roof is therefore usually more polluted than subsequent runoff (Fewkes, 2012). As such recent designs of RWH systems have made use of first flush filters, or first flush diverters (Figure A1-11). These devices are not strictly filters, in that they do not filter water, instead water from the catchment area flows through the conveyance system into chambers installed in conjunction with, or subsequent to, downpipes. This system avoids the ingress of excessive concentrations of suspended solids, pathogens and organic matter in storage tanks, thereby preventing contamination of other harvested water (Vieira et al., 2014). Additionally, they may remove some of the suspended solids from the harvested water which is beneficial as increased water turbidity may influence the treatment strategies by shielding microorganisms from UV-radiation thereby reducing their effectiveness (Hamilton et al., 2019).

Figure A1-11: First Flush Filter / Diverter (Reproduced from Freeflush[5])




### A1.5.2 Maintenance

The maintenance requirements for RWH systems vary depending on the system type, complexity and scale of operation. Frequent cleaning of the system is recommended as this has been found to improve water quality (Campisano et al., 2017). This is perhaps unsurprising as the primary influences upon the quality of water is the deposition of atmospheric particles and animal waste upon the collection surfaces (Fewkes, 2012). Therefore, the maintenance of roofs used as collection areas and the cleaning of gutters must be conducted frequently (Campisano et al., 2017, Medina, 2016 and Ward et al., 2017). Similarly, due to their role in preventing the ingress of potential contaminants and debris, first flush diverters and debris screens / filters, must be cleaned regularly to prevent reduced efficiency or damage to the filters. The regularity of this cleaning will be dictated by the environment in which the system is placed, more regular debris clearing, and cleaning is suggested if the system is installed for example underneath trees.

## A1.6 Application of RWH systems

### A1.6.1 Retrofit

Given that most housing stock in the UK already exists with approximately 80% of the homes that will be standing in 2050 having already been built (Policy Connect, 2018), the retrofit of RWH systems could provide a significant opportunity to reduce per capita consumption. However, retrofitting of RWH systems to existing buildings has yet to see significant growth in the UK (Melville Shreeve et al., 2014). This is primarily due to the capital investment required and the long payback periods to achieve a return on investment for the consumer, and challenges associated with installation of such systems, in particular the siting of storage tanks and changes to pipework (also see Section A1.7**)**.

Many property owners are also reluctant to experience the disruption associated with retrofitting a RWH system. In a 2019 report on public perceptions Waterwise reported that people were "*concerned about the upheaval of installation, and the idea that getting either system installed would be complicated and disruptive"* (Waterwise, 2019).

To increase the resilience of water supplies in new buildings dual water distribution systems are now a requirement in a number of countries (e.g. Hong Kong and Germany). The dual pipe system provides one set of pipes for mains potable water and a second set for non-potable water. The provision of the

[5]. https://www.freeflush.co.uk/blogs/freeflush-rainwater-harvesting-blog/77827905-first-flush-filters-theory-and-application#:~:text=The%20first%20flush%20filters%20simply,is%20diverted%20to%20conventional%20storage. Accessed 06/06/2020

dual system during the development phase reduces the cost and disruption associated with retrofitting at a small additional capital cost.

Due to their large potential collection areas and high potential demand for non-potable water commercial and industrial buildings are better candidates for the retrofit of RWH systems (Doncaster et al., 2012 and UKRMA, 2020). Compared to domestic dwellings, such buildings are much more suitable for retrofitting as the added complication of pipework is usually carried in service-ducts, rather than behind plaster, as is the case in domestic properties (UKRMA, 2020).

### A1.6.2 New build residential installations

New build installations provide a range of opportunities for the uptake of RWH systems. Globally, RWH technologies are being more readily adopted, as the desire for buildings to become more adaptable and resilient to climate change and population growth increases (Lash et al., 2014). Generally speaking increasing water efficiency in new build homes is easier and cheaper than retrofit (Policy Connect, 2018). New build residential installations allow the necessary design and plumbing to be incorporated to allow for a wider range of RWH approaches. Alternatively architects, designers, builders, and developers can future proof buildings so that they are rainwater-ready. Where RWH is considered strategically involving planners, developers and water companies, significant benefits can be achieved and infrastructure costs avoided.

A recent Waterwise study investigated public perceptions of RWH and GWR for domestic use highlighted that the public tend to prefer the concept of new build instillations over retrofit, with residents being overwhelming in favour of RWH systems if they were already installed in a property that customers could move into (Waterwise, 2019). However, in the UK the current requirement of the Building Regulations (2010) for all new dwellings to achieve a water efficiency standard of 125 litres per person per day has failed to act as a driver for the installation of RWH systems.

A number of water companies in England, particularly those operating in water stressed regions, have offered discounts on infrastructure connection charges for new developments that go beyond the 125 l/p/day water consumption target set out in the Buildings Regulations. However, interest from developers has been limited.

Property developers cite a number of reasons for not including RWH systems into new developments including:

- Lack of willingness to invest as the capital cost (CAPEX) is not reflected in the selling price of the properties.
- Information on installation costs, potential savings and hence payback was not available and/or not considered robust.
- Requirement for the system to be maintained including:
    - The cost of maintenance.
    - Lack of ownership/business models for maintenance (developers tend to want to sell and move on rather than be saddled with legacy associated with ownership and maintenance requirements)[6,]
    - Lack of skills, expertise and knowledge base.

Some RWH system suppliers have noted that while developer decisions are driven primarily by costs, there is a growing importance being placed upon the environmental aspects of properties, meaning that in the future decisions regarding RWH and new properties may be driven less by cost and more by customer values. While the reasons for RWH system uptake may be changing, suppliers have noted that the UK market has been slow over the last decade, with potentially only around 5,000 systems installed across the country each year (Melville Shreeve et al., 2014). In comparison in Germany around 100,000 systems are installed annually (Melville Shreeve et al., 2014) while Belgium has around 20,000 new builds each year with RWH systems.

[6] Pers comms (GLA)

### A1.6.3 New build commercial installations

As a consequence of the issues described above within the UK market there has been a move away from small scale domestic installations and retrofits and there is now greater emphasis on larger scale projects at the development phase (e.g. community projects, commercial installations and multi-purpose developments) where the return on investment is often more favourable. The business case for the large commercial market is a lot stronger in terms of environmental and cost savings. It is noted that some UK suppliers focus exclusively on large commercial and new build developments and considered retrofitting of systems not to be commercially viable.

## A1.7 Considerations when installing a RWH system

The performance of a RWH system is dependent upon the interplay between the characteristic of the catchment area, potential rainfall, water demand and the storage tank capacity (GhaffarianHoseini., et al., 2015 and Imroatul et al., 2017). While the sizing of the storage tank is a key factor the amount of rainwater that is available for collection and use (effective rainfall volume) is primarily dependent on the amount of rainfall and the size of the catchment (roof / car park) area according to the following:

$$RWH\ potential = Px\ A\ x\ R\ x\ C$$

Where:

P = Local precipitation (mm/annum);

A = Size of the catchment area ($m^2$); and,

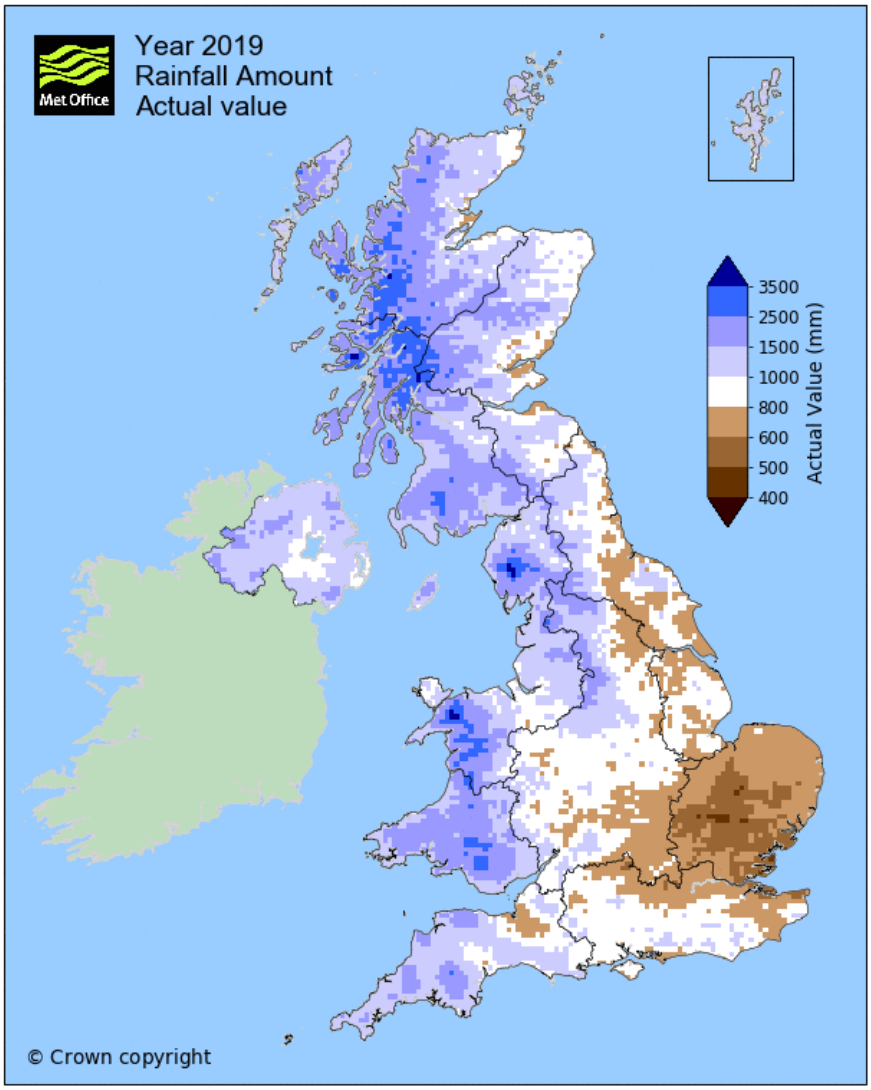
RC = Runoff coefficient **(**Farreny et al., 2011**)** - a measure of how efficiently water that is deposited upon a surface will be conveyed to storage.

Modelling tools and methodologies have been developed over the last 20 years to facilitate the evaluation (and design) of RWH systems. Key studies have focussed on objectives associated with matching water availability (e.g. rainfall) with water demand. As both rainfall and water demand are temporally variable, RWH evaluation models are frequently used as a design tool to calculate the volume of storage required to balance these inflows and outflows, such that the water demand is adequately met for a specific building or location (Melville-Shreeve et al., 2016, 232 and 233).

### A1.7.1 Annual rainfall

The patterns of rainfall are highly variable across different geographic regions and from season to season. Figure A1-12 illustrates the amount of precipitation across the UK in 2019 and highlights the regional variances. The South East of England in particular has low annual rainfall, with as little as 400mm annually in some areas, while the North West of the UK and Wales experienced large volumes of rainfall, ranging from 1000mm to 3500mm in some areas. The variance in Scotland and Northern Ireland is smaller in range, typically varying between 3500mm to 800mm annual.

Figure A1-12: Annual recorded rainfall of 2019[7]




The patterns of rainfall in the UK are projected to change under current climate models (Lash et al., 2014) with the possibility of more extreme weather events such as aridity, droughts, floods or storms rainfall increasingly likely (Struk-Sokołowska et al., 2020). Under the modelled scenarios from the UK Climate change projections report of 2018, UKCP18 (UK Government, 2019) precipitation patters in the UK are due to change with Winter and Summer Increases, and decreases respectively, in the range of +10 to +30% over most of the country (Figure A1-13 and Figure A1-14). The modelled increases are smaller than this in some parts of the country, though this is typically related to areas of high ground. In the summer, there is a general south to north gradient, from decreases of almost –30% in SW England to almost no change, or even increased rainfall in summer and decreased rainfall in winter in Northern Scotland (UK Government, 2019).

Under the 50% probability scenario rainfall is projected to be roughly 10-30% wetter in the winter, and 10-30% drier in the summer across the UK, though with a maximum possible decrease of 47% in some areas (UK Government, 2019). This variation will likely impact RWH systems in certain areas of the UK as reduced quantities of rainfall will reduce viability of RWH systems, increased rainfall may present issues regarding the sizing of already installed water storage tanks, see Section A1.7.3. Further to this there is a trend towards a higher frequency of warmer and wetter winters, while in the summer, the trend is towards a greater frequency of hotter and drier periods (UK Government, 2019).

[7] https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-actual-and-anomaly-maps

Figure A1-13: Changes in Summer precipitation (%) across 8.5 (top), 6.0 (second from top), 4.5 (second from the bottom) and 2.6 (bottom) watts per meter square scenarios at the 10, 50 and 90% probability levels, for the 2020 – 2039 (reproduced from UK Government, 2019).

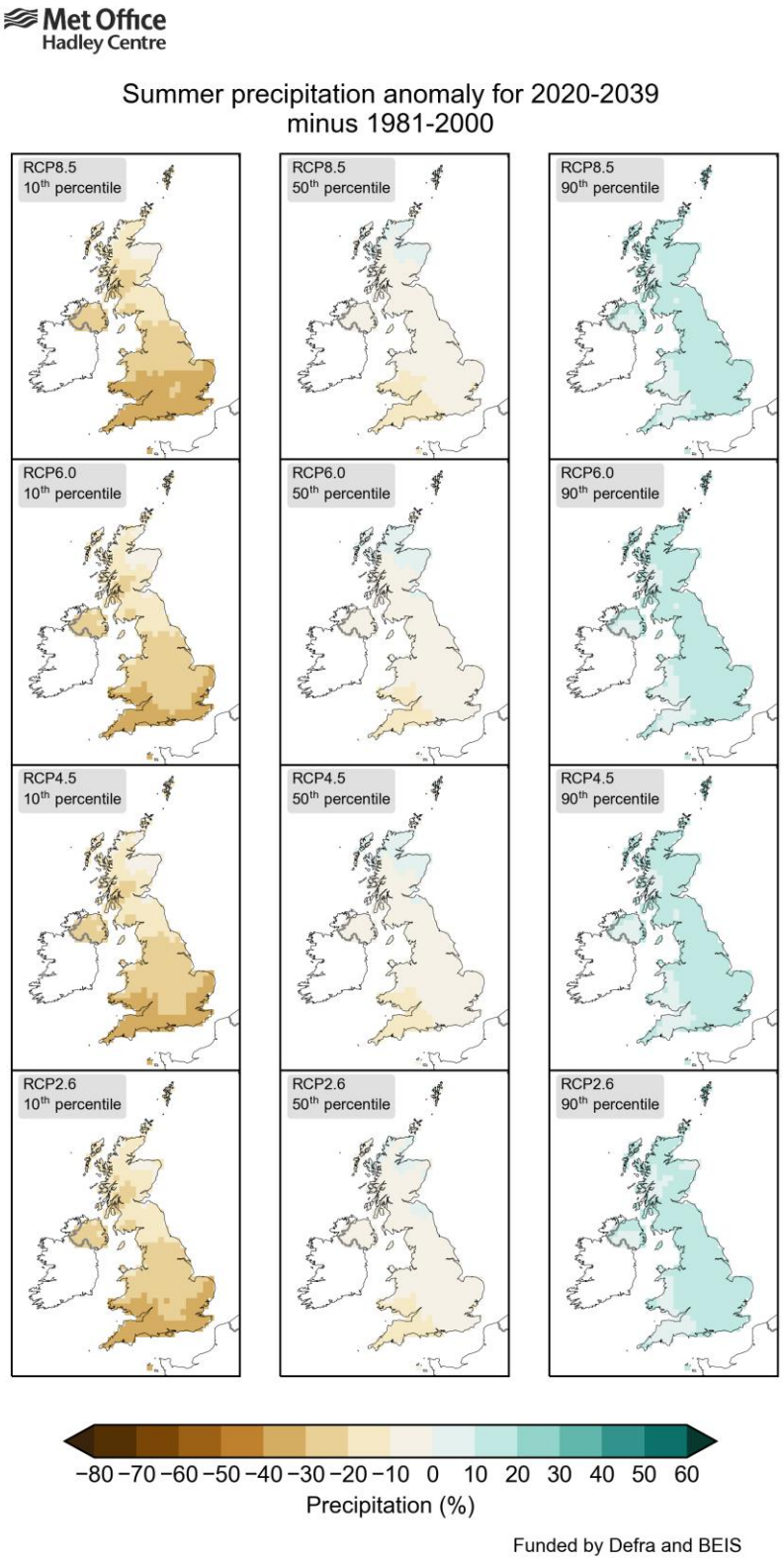
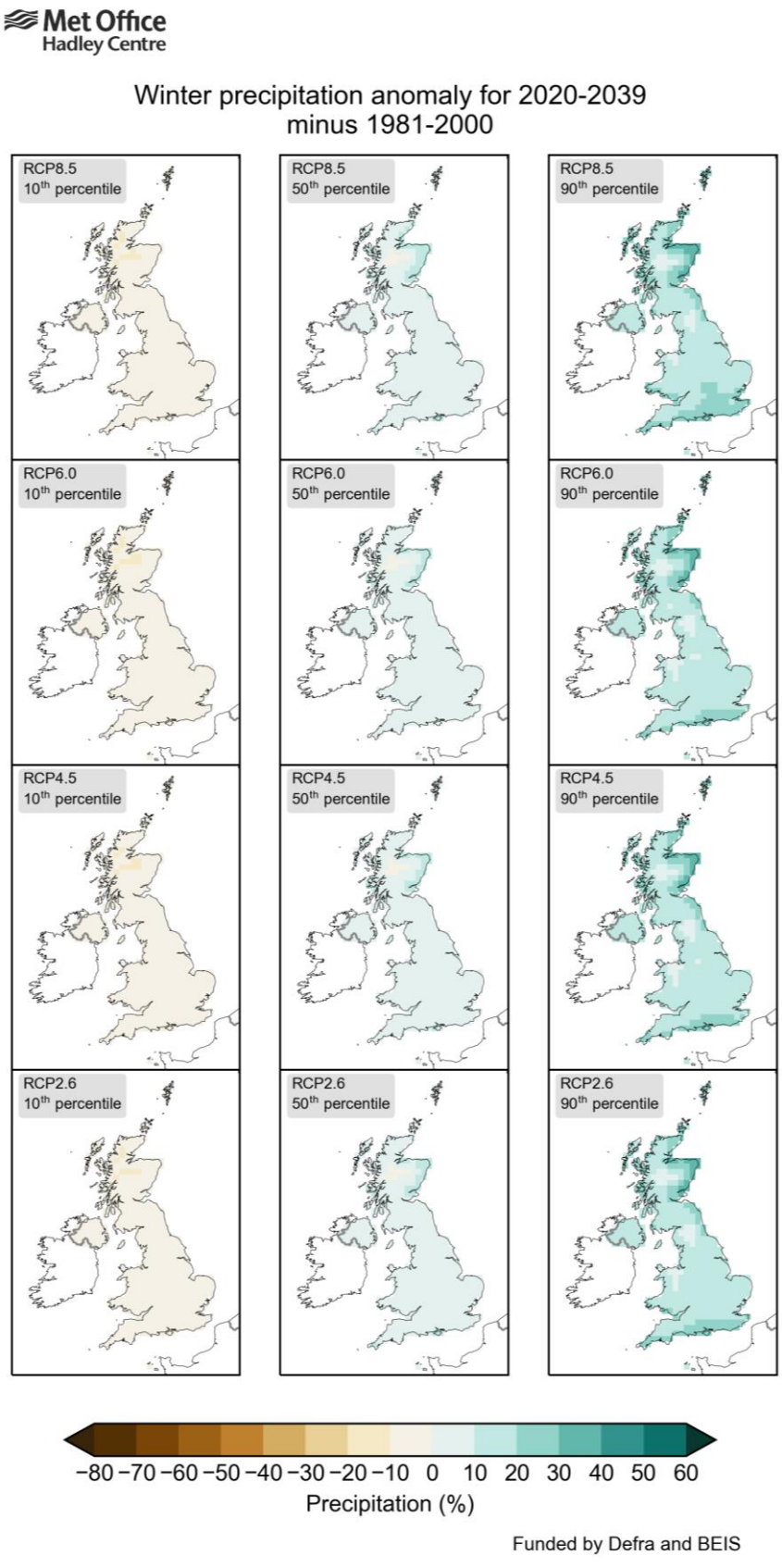


Figure A1-14: Changes in Summer precipitation (%) across 8.5 (top), 6.0 (second from top), 4.5 (second from the bottom) and 2.6 (bottom) watts per meter square scenarios at the 10, 50 and 90% probability levels, for the 2020 – 2039 (reproduced from UK Government, 2019).



### A1.7.2 Collection area and system performance

The collection area of a RWH system is the surface on which rainfall precipitate will land and collect before being transported to the storage area of the system. This area is typically either the roofing of a structure or mounted upon the roof of a structure though there are also infiltration-based systems of for RWH that make use of hardstanding areas around properties, or permeable surfaces such as green infrastructure or permeable pavements (Fewkes, 2012). The collection area determines the amount of rainwater that can be harvested in any given rain event (Sendanayake, 2016). For rooftop RWH systems either the entire roof, or a section of roof area, will serve as the catchment area, likely depending upon the capacity of the conveyance system, drainpipes, and the demand requirements of the building.

#### A1.7.2.1 Collection losses

Not all the rainfall that falls on the collection area will be captured. There are a range of factors that can influence collection losses including weather variability (e.g. the size and intensity of the rain event, prevailing winds or evaporation), and architectural parameters such as slope, roof material, surface depressions, leaks/infiltration, losses occurring in gutters and surface roughness (Farreny et al., 2011). These losses are generally accounted for by applying a runoff factor or coefficient which is based on the fact that some roof types and surfaces (i.e. pitched roofs) are more efficient than others at collecting rainwater as expressed in (Table A1-4).

Table A1-4 Runoff coefficients (reproduced from British Standards Institute, 2013).

| Surface type | Runoff coefficient |
|---|---|
| Pitched roof with profiled metal sheeting | 0.95 |
| Pitched roof with tiles | 0.9 |
| Flat roof without gravel | 0.8 |
| Flat roof with gravel | 0.6 |
| Green roof | 0.3-0.6 |
| Permeable pavement – granular media | 0.6 |
| Road / pavement – plastic crates or tanks | 0.75 |

### A1.7.3 Rainwater tank sizing

Design for optimum tank size is often based on the median annual rainfall of the location and yield calculated in conjunction with the roof area, tank size, installation method and demand profile. As a general rule the tank size should be around 5% of the annual rainwater supply, or 5% of the annual demand.

As one of the most expensive components within a RWH system the optimization of the rainwater tank size is a widely studied topic **(**Karim et al., 2015). In the UK the Rainwater Harvesting Systems – Code of practice recommends three methods for tank sizing as outlined in Table A1-5.

Table A1-5 Recommended methods for tank sizing (adapted from British Standards Institute, 2013 and Lash et al., 2014)

| Method | Typical application | Method summary |
|---|---|---|
| The Simple Approach | Approach for residential properties, where there is consistent daily demand, for which no calculations have to be carried out | Uses simple look-up charts, which relate average rainfall bands for the UK to building roof areas and occupancy rates for domestic buildings. |
| The Intermediate Approach | Approach which uses a formula to calculate a more accurate estimation of storage capacity. This is more accurate than the simplified approach | $YR=A \times e \times AAR \times h \times 0.05$<br>YR is 5% of the annual rainwater yield (L)<br>• A is the collecting area ($m^2$)<br>• e is the yield (runoff) coefficient (%)<br>• AAR is the depth of annual average rainfall for the location (mm)<br>• h is the hydraulic filter efficiency<br>$DN = Pd \times n \times 365 \times 0.05$<br>DN is 5% of the annual non-potable water demand (L);<br>• Pd is the daily requirement per person (L)<br>• n is the number of persons.<br>The lesser of these two results should be used to estimate the tank size |
| The Detailed Approach | Approach for use with non-standard systems, where there is variable demand through the year, variable rainfall or the system is very large and as such significant savings may be achieved | The detailed approach to sizing storage capacity recommends the development of a model of yield and demand to estimate tank sizing requirements. This model should be based on a continuous daily rainfall time series for a minimum of 3 years and preferably 5 years. |

It should be noted that there is potential vulnerability in tank sizing for the future. While annual rainfall in the UK is not predicted to change by more than a few per cent other aspects will affect tank sizing requirements. The distribution, seasonality and intensity of rainfall events are all expected to increase, meaning that a RWH system sized for the current UK climate could be poorly adapted for future climates suggesting a need to oversize tanks under current climatic conditions to provide resilience against projected climate change (Lash et al., 2014). To ensure it is 'likely' that the same non-potable demand could be met in 2080 as in the present, a tank 112% larger would be required. This increases to a 225% oversizing for a 'very likely' probability of meeting the same level of non-potable demand (Lash et al., 2014).

Such measures would however require a greater initial capital investment requirement on the part of the developer and customer, and possibly reduce the frequency with which the storage system overflowed, presenting a risk to long term harvested water quality. An additional issue with tank sizing for RWH systems is the balance between the competing uses for RWH systems. The need to address objectives that often mutually conflict, such as maximizing water saving and empty tank volume for runoff control with minimizing cost, requires customizing RWH systems in order to maximize their return on investment.

In addition to satisfying local water demand, RWH is increasingly being considered as an option for contributing to stormwater management. Consequently, RWH evaluation tools have been further extended to enable stormwater management metrics to be evaluated (Environment Agency 2018 and 2008). Some suppliers in the UK have begun to resolve this issue with smart RWH water storage systems. One 2014 study (Campisano et al., 2017), illustrated the opportunity for dual purpose "retention and throttle" RWH systems to be designed and evaluated within proprietary drainage software. These findings showed that RWH systems for UK houses could be developed that provide 95% of the user's non-potable water demand whilst also maintaining sufficient attenuation capacity to control stormwater runoff during the 1 in 100 year design storm.

## A1.8 Barriers and challenges to the technology

While RWH has seen something of a resurgence in recent years globally, uptake in the United Kingdom (UK) has to date been limited in comparison to some other European countries where legal and economic conditions have been created to support or enforce the use of RWH as part of climate, environmental and social policies (Struk-Sokołowska et al., 2020). As a result the technology has yet to become mainstream in the UK. This is largely due to the initial capital investment required to utilise RWH systems, the low unit price of mains water, and the variable payback periods which have been reported (Alameddine et al., 2019). As such the financial viability of RWH systems is often the main driver for investment decisions **(**Bashar et al., 2018).

The success of the RWH sector in other countries (e.g. Australia and Germany) is strongly associated with regulation and incentives aimed at promoting the adoption of RWH systems (Rahmana et al., 2012 and Corvaro, 2019**).** In both Japan and Australia this involved the provision of subsidies, low interest loans and tax benefits to encourage individuals to invest in the systems (Schuetze, 2013). In Germany there are special tariffs which ensure monetary savings for individuals who have adopted RWH systems, along with reductions in surface water charges which encourage the uptake of decentralised measures to store and utilise rainwater (Schuetze, 2013, Alameddine et al., 2019 Johnen, 2018). A 2016 report, highlighted that there was no conflict within UK standards or codes that presented barriers to the take up of RWH systems (Policy Consulting Network Ltd, 2016). However, they reported that there was no positive encouragement or incentive to specify or install RWH systems in new properties.

The issue of cost has been highlighted as a reason for the limited uptake of RWH systems in the UK in the past Environment Agency 2008). Customers have been found to be unwilling to endure the cost of retrofit to install RWH systems, though were overwhelmingly in favour of RWH systems already installed in new build residents (Waterwise, 2019).

The series of stakeholder interviews undertaken as part of this study included discussion around the barriers and challenges to the technology. The key points from these discussions have been summarised as follows:

- Capital cost:
  - The low unit price (£/m$^3$) of water in the UK and relatively high capital cost of installation lead to long payback periods particularly on small scale installations and retrofits thus investments are often not considered financially viable.
  - Developers are not willing to invest as the capital cost is not reflected in the selling price of the properties.
  - Information on installation costs, potential savings and hence payback was not available and/or not considered robust.
- Absence of specific policy and regulatory drivers. In particular the withdrawal of the Code for Sustainable Homes in 2015.
- Lack of customer demand / interest. This is in stark contrast to other measures that reduce $CO_2$ emissions such as solar panels[8].

[8] Pers Comm (Redrow)

- The actual performance of existing systems is poorly understood and the wider benefits are often not clear. There is currently a lack of monitoring of existing systems and general information and guidance.
- The technologies are not feasible in all applications and are dependent on the amount of rainwater or grey water that can be collected (yield) and demand within the building.
- Requirement for the system to be maintained including:
    - The cost of maintenance.
    - Lack of ownership/business models for maintenance (developers tend to want to sell and move on rather than be saddled with legacy associated with ownership and maintenance requirements)[9,8,13]
    - Lack of skills, expertise and knowledge base.
    - User behaviour e.g. switching to mains supply when there is an issue or fault.
- Public perceptions around water quality. In a recent Waterwise survey reported that *"People preferred the idea of a rainwater harvesting system to a grey water harvesting system. This is likely due to the perception of rainwater as being relatively 'clean' and 'pure' versus grey water, which was viewed as less clean, or sometimes as contaminated" (*Waterwise, 2019).

As a result, growth within the sectors has been stifled over the last decade with the RWH sector witnessing some consolidation. As a consequence there is now greater emphasis on larger scale projects at the development phase (e.g. community projects, commercial installations and multi-purpose developments) where the return on investment is often more favourable. There has also been a move away from small scale domestic installations and retrofits.

## A1.9 Costs and performance

Economic analysis plays a key role in the decision-making process of end users and developers when installing a RWH system (Bashar et al., 2018). In general, the installation of a system during property construction is more cost effective than retrofitting a system into an existing building, due to the costs of the changes required to the existing plumbing system, and any additional groundworks associated with the installation of the storage tank.

The economic viability of RWH systems has received a great deal of attention over the last decade with the different appraisal models producing varied outcomes. A financial appraisal of the viability of a RWH system can be achieved by simply evaluating the return on investment or payback period of the system, through setting the capital cost against the long-term savings generated from the reduced mains water supply consumption and the associated sewerage costs (Domènech and Saurí, 2011 and Melville-Shreeve et al., 2016).

### A1.9.1 Capital and operational costs

The costs of a RWH system can be divided into the capital expenditure (CAPEX) and operational expenditure (OPEX). The CAPEX being the initial cost of materials or components and the OPEX being the ongoing costs such as maintenance and energy requirements through the life of the system. The costs of RWH systems will depend greatly on requirements and site-specific factors. Typically, these include whether it is being installed in a new development or retrofitted to an existing building, the siting of the storage tank (above versus below ground) and scale - the greater number of components required, such as pipes, pumps and water treatment devices typically the higher the cost (Doncaster et al., 2012).

### A1.9.2 CAPEX

The capital investment required for a RWH system can vary significantly depending on scale, from a few £1,000 for a small scale domestic unit, to many tens of £1,000's in large scale developments. Storage tank size is usually the largest factor of the total installation cost hence its optimisation is

[9] Pers comms (GLA)

essential to the economic viability of the system (Matos et al., 2015). The cost of the other fixtures and components has been estimated as being around 30% of the price of the tank (Matos et al., 2015). A range of capital costs have been reported for small scale systems in a number of different countries;

A 2019 study in Italy estimated the cost of a storage unit alone in the range of (2 to 40m$^3$) as 1,200€ to 25,000€ with an additional cost of 400€ to 1,000€, for a pump and 800€ to 2,000€, for other devices, piping systems and a filter (Corvaro, 2019). In a similar study in Spain which compared RWH systems in single and multi-family buildings the cost of the storage tank increased with tank size ranging from 2,800€ and 12,500€ for a 5 to 40m$^3$ capacity tank respectively (Domènech and Saurí, 2011).

Conversely in Lebanon costs varied between $2,100 and $9,500 depending on the capacity of the storage tank (between 5 and 40 m$^3$), and in Australia the cost of a single 25 m$^3$ rainwater tank was estimated at around Aus$2,690 (Rahman et al., 2010).

An assessment of the capital costs of two innovative RWH systems for residential properties at prototype stage was undertaken (Melville Shreeve et al., 2014). These systems were design to provide low cost, simple technology with loft based storage (1m$^3$) and no underground tanks. The study highlighted a notable differential in price between the innovative systems and eight traditional RWH designs with overall capital costs estimated as £835 (31%) and £1,035 (40%) in comparison to the lowest cost traditional design (£2,653).

CAPEX information for larger scale applications is much more limited however, data provided by suppliers for commercial installations in the UK categorised by the size of the storage tank is summarised in Table A1-6.

Table A1-6 Range of capital costs for commercial RWH systems in the UK

| Tank size | Capital cost | Annual operational cost |
|---|---|---|
| 5 to 15m$^3$ | £8 - £15k | £400 - £1,400 |
| 15 to 30m$^3$ | £15 - £40k | £420 - £1,400 |
| 30 to 100m$^3$ | £40 - £70k | £420 - £2,200 |
| >100m$^3$ | >£80k | £500 - £1,800 |

### A1.9.3 OPEX

Operational costs for the running and planned maintenance (pump replacement and tank cleaning) of a RWH system also vary depending on the scale of the system and the efficiency of the components. However, information on the actual running costs for RWH systems is limited, and in several studies the annual maintenance and operation cost has been estimated at £250. Further to this a maintenance cost of 300 €/year was also assumed in multi-family building in Barcelona (Domènech and Saurí, 2012).

In many cases, differences in the way maintenance and operational costs have been taken into account including pump replacement, electricity charges and cleaning of the roof / catchment system has led to controversial conclusions (Campisano et al., 2017). For example, a 2011 study suggested that different evaluation methods can determine differences up to 60% for energy consumption costs (Ward et al., 2011).

The energy consumption associated with the operation of RWH systems has been comprehensively investigated. In a 2014 review of the energy intensity of RWH systems, it was highlighted that the median energy intensity of theoretical studies (0.20 kWh/m$^3$) was considerably lower than that described in empirical studies (1.40 kWh/m$^3$) and that in comparison to conventional town water supply systems, the reviewed empirical studies showed that RWH systems were three times more energy intensive, although optimised systems were more comparable (Vieira et al., 2014).

In the UK, a 2011 study., showed that electricity use for a traditional RWH system installed at an office building was more favourable (0.54 kWh/m$^3$) in comparison to the mean energy consumption for the municipal water supply (0.60 kWh/m$^3$) (Ward et al., 2011). European average municipal water supplies are also quoted at a similar level of 0.46 kWh/m$^3$ (Ward et al., 2011).

Data provided by suppliers for commercial installations in the UK highlighted actual operational costs varied across a range system sizes (Table A1-6), with the cost of electricity accounting for less than 10% of the overall annual running cost.

### A1.9.4 Economic appraisal of RWH systems

Due to the high deployment costs associated with installing a RWH system it is often evaluated as not yielding a financial return (Pacheco and Campos, 2019). As such a general pattern has emerged which suggests RWH systems are uneconomic in domestic scale properties but may be viable in larger types of building such as schools, supermarkets or commercial buildings depending on the available collection area and demand for non-potable water. However these observations are sensitive to water and supply disposal costs as illustrated by the experience of countries such as Germany and Belgium (Fewkes, 2012).

In a comparative appraisal of the use of rainwater in a single and multi-family buildings in Barcelona, a payback period of between 33 and 43 years (depending on the tank size), was reported for single family households (Domènech and Saurí, 2012), whereas in a multi-family building the payback period was longer than 60 years for a 20 m$^3$ tank (Domènech and Saurí, 2012). Further to this a life cycle costing approach in domestic properties found that domestic RWH systems generally resulted in financial losses approximately equal to their capital costs (Fewkes, 2012). Whereas, other studies in Australia reported that RWH systems were financially viable but only with the presence of the government rebates (Rahmana et al., 2012) and they provided water at a cost in excess of Australian potable water provision costs (Memon and Ward, 2018).

In larger installations a 2011 study showed that for large tanks connected to commercial roofs in Melbourne, the capital cost can be recovered within 15 - 21 years depending on the tank size and future water price increase rate (Campisano et al., 2017). Payback periods ranging from 2 to 6 years were reported for a number of RWH scenarios in Portugal if the rate at which costs and benefits are reduced over time, known as the discount rate or interest rate, was increased to 10%. In comparison when a discount rate of 5 % was applied the payback periods would be reduced by approximately 1 year (Matos et al., 2015). In another example, empirical monitoring data estimated capital payback periods of between 6 and 11 years for a commercial-scale office-based RWH system serving a building occupancy of 110 people (Ward et al., 2012).

While academic research modelling the payback periods of RWH systems frequently report that RWH is not financially viable it should be noted that the scale of analysis is important when assessing viability, as RWH becomes more economically efficient as more parameters are included in the analysis (Paper 7). Often research focuses simply on the benefits in terms of RWH for the provision of drinking water rather than considering the additional benefits. These include the reduced costs incurred for central water infrastructure, such as water treatment and associated energy costs, pumping costs associated with mains supply, disposal costs through less rainwater entering sewers and being unnecessarily treated in sewerage treatment works and costs associated with supply and sewer network infrastructure (Doncaster et al., 2012). The inclusion of these additional benefits could provide a more positive financial perspective of RWH if included in the analysis although this would require a more holistic approach to the costs and benefits of RWH system than is currently implemented.

The viability of a RWH system will also be dependent upon the potable water charges, as ultimately, the cost of water will directly affect the economic viability. However, the interplay between the principal parameters that affect operational efficiency must also be considered when determining the cost effectiveness of a RWH system. These parameters, namely the amount of rainfall, size of the catchment area, tank volume, water demand, and the efficiency of runoff collection area and the filter (Matos et al., 2015 and Corvaro, 2019) can all have considerable effects on the performance of RWH systems but are considered less often (Pacheco and Campos, 2019) As such there is a tendency to

underestimate system viability, suggesting using only economic indicators to assess the feasibility of RWH systems is unwise (Pacheco and Campos, 2019).

Improper consideration of maintenance and operational costs has also been reported to be responsible for many of the conflicting conclusions on the economic viability of a RWH system. Ongoing maintenance expenses have often been identified as a primary reason for RWH system costs outweighing the benefits, with the variation in yield, along with pump and tank life and maintenance, having the largest effect on cost-effectiveness (Amos et al., 2016). Others report that if the system owner is only responsible for the operational and maintenance costs, and not the capital costs, then any financial loss will be minimal and there is a chance of a financial benefit from a RWH system (Amos et al., 2016).

In addition, customers will need to consider which benefits to best to capitalise on where RWH benefits may conflict: harvesting rainwater to reduce potable water consumption, the use of harvested water, or benefits of reduced flooding risk through RWH runoff control (Corvaro, 2019).

While many previous evaluation studies have focused on analyses using a traditional set of criteria (including capital cost, water saving and energy consumption), the interception and use of rainwater where it falls can provide additional benefits which are often not considered. Controlling stormwater discharges to combined sewer networks can mitigate the risk of pollution events from sewage spills during intense rainfall. In a 2016 study, a number of traditional RWH systems were appraised against two stormwater-related criteria using a multi criteria analysis approach including: (1) a reduction in peak daily stormwater discharge volumes; and (2) a reduction in annual average stormwater discharge volumes to sewer (Melville-Shreeve et al., 2016). The study illustrated that RWH can reduce stormwater discharges successfully when the non-potable demand of a property exceeds the rainwater yield. Supporting this, a number of modelling studies on RWH systems have demonstrated their ability to reduce stormwater runoff volumes and rates (Campisano et al., 2013).

A further 2019 study, explored the potential benefits of RWH system on water supply augmentation and stormwater control in a three-bed rooms house in Newcastle-upon Tyne. Modelling results indicated that around 2/3 of WC demand could be supplemented by the RWH system and continuous simulation over the 30-year period (1984-2013) highlighted that the system could provide over 75% flood peak attenuation and over 85% reduction in stormwater runoff volume (Ahilan et al., 2018).

One possible way forward therefore is to adopt a more integrated approach and use RWH as both a water conservation measure and method of reducing stormwater runoff. Future proofing against greater storm events would however require increasing the storage capacity by a factor of 1.5 to 2.0, although any additional costs would be offset by reducing the capacity and construction costs of traditional stormwater retention devices which will in most cases still be required in the storm sewer system.

### A1.9.5 Carbon and energy implications

The energy requirements and carbon emissions of RWH systems will vary depending on system type, installation arrangements and water demand. The emissions from a RWH system can be divided into those resulting from manufacture, transportation and installation of system components (embodied) and those resulting from use of the system itself (operational). The size and material of the storage tank, the type and size of the pump used to convey the water (assuming a pump is required), the energy requirements for treatment, the type of energy used to power the system and the lifetime of the asset are all important factors. Life cycle analyses (LCAs) show the main operational energy contribution for rainwater-harvesting (RWH) systems are generated from pumping rainwater from the tank to the building and ultraviolet UV disinfection (Ward et al., 2011).

The 2011 Environment Agency report, Energy and Carbon Implications of Rainwater Harvesting and Grey water Recycling, (Environment Agency, 2011) and other previous research (Vieira et al., 2014 and Fewkes, 2012) observed that RWH systems emitted more carbon than water supplied by the centralized water network. The report suggested that the materials used to construct the RWH system can have an impact on the carbon implications of a RWH system, stating the operational energy and carbon intensities of the systems studied were higher than those for mains water by around 40%, for a typical rainwater application.

Previous studies in the academic literature have also provided evidence that RHS often has operational energy intensities that are far higher than centralised town water systems (Vieira et al., 2014), due to the relative efficiencies of pumping (Memon and Ward, 2018) with some sighting RWH as being 40% to 100% greater than water supplied from the mains (Fewkes, 2012). A 2011 study into the energy and carbon dioxide contribution of RWH systems suggested that an office based RWH system produced 0.56 kg $CO_2$-eq/$m^3$, making it more carbon intensive than the centralised water supply which requires only 0.44 kg $CO_2$-eq/$m^3$ (Ward et al., 2011).

However, other studies have shown the emissions associated with RWH to be much more favourable. For example; a 2012 life cycle study of domestic RWH systems for 3 different types of buildings at an urban scale in 16 cities in Spain, found that the use of fossil fuels to supply RWH systems produced a $CO_2$-eq/$m^3$ of 0.27 to 1.38 kg (Morals- Pinzón et al., 2012). A 2014 evaluation of domestic RWH systems for a watershed in Virginia, USA also suggested RWH water outperforms municipal water with life cycle emissions for domestic RWH water of 0.41 kg $CO_2$-eq/$m^3$, as opposed to 0.85 kg $CO_2$-eq/$m^3$ for municipal water (Water UK, 2016). A life cycle assessment of energy use, carbon emissions, and costs of RWH for high efficiency toilet flushing in a university building (considering only manufacturing and operational phases) indicated RWH was preferable to potable water flushing (Ghimire et al., 2014); and in 2017 a further analysis of a commercial RWH system in Washington, D.C. also found that the RWH system outperformed the municipal water system (Ghimire et al., 2017).

While the literature predominantly implies RWH systems are potentially less viable from a carbon and energy perspective it has also been observed that potential technological innovation in pump design and in low or no energy RWH systems may make the energy requirements of RWH systems less of an issue in the future (Campisano et al., 2017). Improvements, such as the use of variable speed pumps and pressure vessels could promote a reduction in the energy intensity of direct feed rainwater distribution systems due to their increased efficiency over single speed pumps which have a higher energy consumption (Vieira et al., 2014). While different designs of RWH systems using header tanks and gravity driven RWH systems could also provide fit-for-purpose supply at energy intensity levels below, or much closer to conventional town water supply systems (Vieira et al., 2014). Other studies have also suggested that tank location and demand distribution were the most important variables in the optimization of RWH systems from an environmental perspective (Yan et al., 2017).

A further consideration is that the carbon emissions figures quoted for mains water often only account for the treatment and distribution of the water supplied with the construction of new infrastructure required and the maintenance of supply distribution systems not considered in the same way as RWH installations. Further to this the energy source is also an important factor for operational emissions particularly when comparing fossil fuel and renewable sources of energy.

Stakeholders interviewed as part of this study noted that both the use of renewable energy along with the usage of less carbon intensive components such as GRP tanks, would facilitate a reduction in operational and embedded carbon. For example, a number of suppliers reported the use of pea gravel rather than concrete for the tank surround. Furthermore, data provided by one UK supplier has suggested that the embodied carbon emissions for GRP tanks is significantly lower than those stated in the 2011 Environment Agency report (Environment Agency 2011).

### A1.9.6 Wider benefits

While RWH systems are primarily adopted to reduce potable water consumption from the centralised water distribution network (Doncaster et al., 2012) they can also be used to reduce frequency, peaks and volumes of urban runoff (Wilcox et al., 2016). By their design RWH systems reduce the quantity of rainwater that is conveyed to centralised drainage systems through retention and use within the boundary of properties where the system is installed. This reduction in runoff provides benefits to the overall central water infrastructure and the environment.

The retention of water deposited upon the urban landscape by RWH systems reduces the quantity of stormwater runoff thus preventing the inundation of the surface water drainage systems and treatment facilities (Schuetze, 2013). As a consequence load reduction mitigates sewer overflows and decreases watershed pollution in storm events (Ghimire et al., 2014) while RWH systems also reduce the runoff and the transport of pollutants directly into water bodies (Severis et al., 2019). An increased regulatory

emphasis on reducing stormwater runoff volumes and associated pollutant loads will further support the case for RWH in the UK (Yannopoulos et al., 2019).

Finally, RWH provides a benefit to both central infrastructure providers and the environment as the adoption of a decentralised approach reduces water abstraction (Struk-Sokołowska et al., 2020) and can be efficient as a complementary and viable alternative to large-scale water withdrawals thus reducing negative impacts on ecosystems (Madara et al., 2016).

# A1.10 Water quality and contamination

## A1.10.1 Water quality

The harvesting of rainwater can be performed either directly from the atmosphere or via runoff, and as such the quality can be impacted by a number of different factors. In the former rainwater quality is influenced by the atmospheric conditions (Yannopoulos et al., 2019), while the quality of water harvested from runoff from catchment surfaces is affected by the materials used to construct the RWH system and the environment in which it is located (Campisano et al., 2017).

In general rooftop collection surfaces are comparatively cleaner than the impermeable surfaces around a building such as paving or car parks, however, roof top run off can contain varying amounts of heavy metals and nutrients. A number of contributory factors have been reported, including:

- Acid rain is a prominent issue which can result in low pH levels in areas characterized by high vehicle traffic volumes, high-density residential development and industry.
- Wash off of the particulates that have accumulated on the roof surfaces.
- Roof materials can contribute dissolved and particulate matter to roof runoff due to weathering processes and chemical and physical reactions occurring between the rainwater and the materials.
- Gutters and downpipes (i.e. drainage system) have also been identified as major contributors of heavy metals to roof runoff, especially Zn and Al. Protective coatings are often applied to the outside of metal downspouts to protect the material from corrosion; however, runoff water comes into contact with the unprotected inside.

In addition, the design of the roof and the rainwater harvesting system, as well as material selection also appear to affect the microbial quality of the harvested rainwater. As such, RWH system components should be constructed from non-toxic, and or inert, materials, particularly the catchment area and the conveyance systems as the cleanliness and nonreactive nature of these components will reduce the effect upon both the amount of run-off that is harvested and its chemical, physical and possibly biological quality (Nachshon et al., 2016 and Fewkes, 2012).

In the UK there are currently no specific regulatory requirements for water quality that apply to systems which re-use rainwater for non-potable water use. Although harvested rainwater generally has quality parameters (i.e. pH, total chlorine concentration, electric conductivity, total dissolved solids, oxygen saturation and total hardness), within World Health Organisation (WHO) standards the total coliform count (measure of microbial quality) is often moderate to high based on maintenance of the collector surface (Sendanayake, 2016). As such once the water is harvested and stored the quality may deteriorate from a microbiological perspective which can present potential health risks (Ward et al., 2017). Guidelines for bacteriological and general systems monitoring are provided in the British Standard BS 8515:2009 + A1:2013 ((British Standards Institute, 2013).

### A1.10.1.1 Treatment of harvested rainwater

Any specific treatment requirements are dependent on the intended end use of the harvested rainwater, be this potable or non-potable. Water harvested for non-potable applications requires only filtration to be fit for purpose (Fewkes, 2012 and British Standards Institute 2013). Filtration can be performed using a variety of screens and filters to intercept solids (sediment, debris, leaves, etc.) and particulate matter, which should occur prior to water entering the storage tank, thereby preventing the build-up of debris in the storage tank (Fewkes, 2012 and British Standards Institute 2013). Water intended for potable use requires more stringent treatment to ensure it is fit for consumption.

The treatment chain of harvested water begins at the harvesting catchment. The frequency with which the catchment experiences rainfall contributes to the quality of the water harvested, meaning that during periods of no rainfall roofs become polluted with atmospheric particulates and bird droppings. The first flush of rainwater from the roof is there usually more polluted than subsequent runoff (Fewkes, 2012 and Farreny et al., 2011). The installation of first flush filters or diverters can negate this initial runoff from entering the storage tank by diverting the first few millimetres of rainfall harvested away to sewer (see Section 1.5.1.1).

Although first flush diversion and pre-storage filtration can substantially improve the quality of water stored in a rainwater harvesting system, frequent maintenance of these systems is required (Campisano et al., 2017). Once water has been conveyed to the tank, additional treatment can then occur. Through the addition of chemicals such as aluminium or calcium hydroxide it is possible to promote flocculation within the storage tank and the settling of any suspended fine particulate matter (Ward et al., 2017).

While filtration and flocculation can remove physical particles they have no impact on microbial quality. As such, more advanced treatments such as ultra violet (UV) or chemical treatment are beneficial in situations where there is potential for increased human exposure or for applications within public buildings. This may be prudent as concerns regarding harvested rainwater of poor-quality contacting with end users (or being accidentally ingested), for example by aerosols from toilet flushing, is regarded as one of a number of barriers to RWH in many countries, including in the UK. (Ward et al., 2017).

The choice of which method of advanced water treatment to use will depend on the consumer preference, as each has benefits and drawbacks. UV disinfection is becoming an increasingly popular in comparison to other chemical methods due to its high disinfection efficiency no handling and storing of chemical products, minimum maintenance and minimum health risks **(**Vieira et al., 2014). However, it is important to note that UV disinfection can be highly consumptive of energy, and as mentioned before the efficacy of UV treatment is depended upon effective removal of suspended solids by filtration, prior to UV treatment (Vieira et al., 2014 and Hamilton et al., 2019).

Chemical disinfection of rainwater can be performed using bleaching powder, potassium permanganate, iodine or chlorine (Campisano et al., 2017). Chemical disinfection has been found to be more effective in the removal of certain bacteria from harvested rainwater. However, effective chemical disinfection suffers from requiring continuous manual operation, by-products in the treated water and may also cause odour nuisance and Intoxication (Vieira et al., 2014).

Combined methods of treatment have also been reported. A study from the UK, in 2017 investigated the use of a novel treatment system combining filtration, UV and ozonation in a compact point-of-use device to successfully treat harvested rainwater to potable standard (Ward et al., 2017).

## A1.11 Regulation and guidance

A summary of the main regulatory and policy drivers which cover water consumption and sustainable urban drainage in new buildings and provide the legislative framework for the installation of RWH systems in the UK are outlined below:

### A1.11.1 Code for Sustainable Homes

An initial key driver for the installation of RWH systems was the Code for Sustainable Homes (the Code) which provided a voluntary national standard for the sustainable design and construction of all new homes. Introduced in England in April 2007, the Code provided performance targets which were more demanding than the minimum standards specified in Buildings Regulations and other legislation. Mandatory minimum standards were also set for specific areas, including indoor water use (Table A1-7).

Table A1-7. Assessment criteria for indoor water use in Code for Sustainable Homes (DCLG, 2010)

| Water consumption (litres/person/day) | Credits | Mandatory levels |
|---|---|---|
| ≤120 l/p/day | 1 | Levels 1 and 2 |
| ≤110 l/p/day | 2 | |
| ≤105 l/p/day | 3 | Levels 3 and 4 |
| ≤90 l/p/day | 4 | |
| ≤80 l/p/day | 5 | Level 5 |

While the lower levels of the Code could typically be met through the installation of water efficient fixtures and fittings, developers were required to consider water reuse (i.e. RWH and GWR) systems to achieve the higher levels (<100 l/p/day). Between 2008 and 2010 the Code became mandatory as house sellers were required to provide buyers with Home Information Packs which detailed the sustainability rating of the building. After this point and up until March 2015, the Code remained mandatory in England, Wales and Northern Ireland if it was a requirement of a Local Authority's Local Plan[10] or where affordable housing was funded by the Homes and Communities Agency[11]. However, following the technical housing standards review the policy was withdrawn and a new set of streamlined national technical standards, driven by Buildings Regulations was introduced.

### A1.11.2 Buildings Regulations 2010 (amended 2015)

The Building Regulations is a statutory instrument that seeks to ensure that the policies set out in the relevant legislation are carried out. They cover the construction and extension of buildings and are supported by Approved Documents which set out detailed practical guidance on compliance with the regulations. In England and Wales, Approved Document G (Part G: Sanitation, hot water safety and water efficiency) sets out a minimum standard for water consumption in new dwellings of 125 l/p/day with an optional target of 110 l/p/day where specified (HM Government 2016). Approved Document H (Part H: Drainage and waste disposal) also covers rainwater and grey water tanks and stormwater drainage (HM Government 2015). In Scotland[12] and Northern Ireland[13] specific water consumption targets are not currently specified in the technical guidance.

The Building Regulations define 'wholesome water' as: "*Water supplied to the building by a statutory water undertaker or a licensed water supplier through an installation complying with the requirements of the Water Supply (Water Fittings) Regulations 1999 (SI 1999/1148 as amended) may be assumed to be wholesome water".* It also states that *"Water treated to the high standards of wholesome water is not essential for all of the uses that water is put to in and about buildings, e.g. toilet flushing, irrigation".* It includes under 'alternative sources of water' both harvested rainwater and reclaimed grey water, together with water from wells and boreholes.

With respect to alternative sources of water' the Building Regulations state: "*Water from alternative sources may be used in dwellings for sanitary conveniences, washing machines and irrigation, provided the appropriate risk assessment has been carried out. A risk assessment should ensure that the supply is appropriate to the situation in respect of the source of the water and the treatment of it, and not likely to cause waste, misuse, undue consumption or contamination of wholesome water"*. And that "*Any system/unit used to supply dwellings with water from alternative sources should be subject to a risk assessment by the system designer and manufacturer, and appropriate testing carried out to*

[10] https://www.gov.uk/guidance/local-plans
[11] https://data.gov.uk/dataset/4fef1dc8-4056-4f5e-84a3-22f2d0e928cf/affordable-housing-starts-and-completions-funded-by-the-homes-and-communities-agency-and-the-greater-london-authority
[12] In Scotland, Section 3 (Environment) of the Buildings Standards Technical handbook 2017 covers water efficiency and surface water drainage. See https://www.gov.scot/publications/building-standards-2017-domestic/0-general/01-application/
[13] In Northern Ireland water and drainage are covered in Technical Booklets P and N. See http://www.buildingcontrol-ni.com/regulations/technical-booklets

*demonstrate that any risks have been suitably addressed. A risk assessment should include consideration of the effect on water quality of system failure and failure to carry out necessary maintenance".*

Approved Document G - Part G1 – Cold water supply signposts relevant information and guidance documentation which includes:

- *Guidance on the marking of pipework conveying water from alternative sources can be found in* BS 8515:2009 *Rainwater harvesting systems –Code of Practice.*
- *Guidance on installing, modifying and maintaining reclaimed water systems can be found in the WRAS Information and Guidance Note No. 9-02-04 Reclaimed water systems and in BS 8515:2009 Rainwater harvesting systems - Code of practice.*
- *Information on the technical and economic feasibility of rainwater and grey water can found in MTP (2007) Rainwater and grey water: technical and economic feasibility.*
- *Information on the specification of rainwater and grey water systems can be found in MTP (2007) Rainwater and grey water: a guide for specifiers.*
- *Guidelines for rainwater and grey water systems, in relation to water quality standards, can be found in MTP (2007) Rainwater and grey water: review of water quality standards alternative and recommendations for the UK.*

Approved Document – Part G2 covers water efficiency of new dwellings. It also mentions RWH: "*In some cases rainwater harvesting and grey water recycling may be used as a means of reducing water consumption to achieve higher water efficiency performance levels".* It identifies that for RWH (in accordance with BS8515) the water efficiency calculation methodology set out in Appendix A of Approved Document G must be followed.

### A1.11.3 SuDs and the National Planning Policy Framework 2019

SuDs are a natural approach to managing drainage in and around properties and other developments. As well as helping to reduce the causes and impacts of flooding by holding back the water that runs off from a site, SuDS can also provide additional benefits such as removing pollutants from urban run-off and combining water management with green space that offers scope for recreation and wildlife.

Through the implementation of the Flood and Water Management Act 2010[14], SuDs were intended to be mandatory for all major development throughout England and Wales. Schedule 3 of the Act proposed to establish a SuDs approval body (SAB) at the county council and unitary authority level. However, this was only enacted in Wales, where SuDs are now a requirement for all new developments of more than one dwelling house or where the construction area is 100 square meters or more (Paper 185).

In England, Schedule 3 of the Act was not enacted and the National Planning Policy Framework (NPPF) was amended to require the delivery of SuDs for major developments (10 dwellings, or equivalent non-residential developments) unless there is clear evidence that this would be inappropriate (Paper164). The NPPF sets out the policy approach for preventing inappropriate development in areas at risk of flooding. When determining planning applications the NPPF expects local planning authorities in England to ensure (through its local plans) that sustainable drainage is prioritised in areas at risk of flooding. The planning guidance supports the NPPF, setting out the types of sustainable drainage systems that should be considered according to a hierarchy of drainage options. In April 2015, Defra published Non-Statutory Technical Standards (NSTS) for Sustainable Drainage Systems, covering their design, maintenance and operation (Defra, 2015).

In Scotland SuDs are a legal requirement for all developments except single dwellings that drain to the water environment unless they discharge to coastal waters[15] and in Northern Ireland SUDs are a requirement under Section 4 of the Water and Sewerage Services Act (2016)[16].

[14] http://www.legislation.gov.uk/ukpga/2010/29/contents
[15] https://www.susdrain.org/delivering-suds/using-suds/legislation-and-regulation/scotland.html
[16] https://www.infrastructure-ni.gov.uk/sites/default/files/publications/infrastructure/water-and-sewerage-services-act-ni-2016.PDF

### A1.11.4 The Water Supply (Water Fittings) Regulations 1999

The Water Supply (Water Fittings) Regulations 1999[17] govern the efficient use and protection of drinking water in England and Wales. The purpose of the regulations is to prevent waste, misuse, undue consumption, erroneous measurement and most importantly contamination of drinking water. They apply to all plumbing systems, water fittings and equipment supplied from the public water supply. These Regulations require that the correct level of backflow prevention is provided to prevent contamination of the public mains water supply. For rainwater systems this is usually in the form of an air gap, which will prevent non-potable water entering the mains water supply. Backflow prevention for specific appliances needs to be reviewed with the manufacturer to ensure that a suitable fluid category 5 (air gap) backflow prevention has been incorporated into the appliance.

Under Regulation 5 of the Water Fittings Regulations anyone who proposes to install a water reuse system that incorporates a back-up supply from the public mains must notify the water supplier and not begin work without consent. Some water companies, such as Anglian Water, highlight that all water reuse systems will be inspected recorded and registered.

### A1.11.5 British Standards and other guidance

A review of the relevant standards other codes and guidance for RWH applicable to the UK was undertaken by the UK Rain Management Association (Paper 150) and highlighted the following:

- BS 8515:2009 + A1:2013 Rainwater harvesting systems - Code of Practice.
- BS 8595:2013 Code of practice for the selection of water re-use systems.
- Alternative Water Systems Information Leaflet and Guide. WRAS.
- Water re-use systems, guidance and advice. Water UK.
- Reclaimed water. CIBSE Knowledge Series 2005.

#### A1.11.5.1 BS 8515:2009 + A1:2013 Rainwater harvesting systems - Code of Practice

Originally published in 2009, then subsequently updated in 2013, BS 8515:2009 provides clear guidance on the minimum acceptable standards for RWH systems in the UK (British Standards Institute, 2013). The Standard covers the design, installation, water quality, maintenance, and risk management of RWH systems and applies equally to new build and retrofit projects.

#### A1.11.5.2 BS 8595:2013 Code of practice for the selection of water re-use systems.

This British Standard (BS 8595:2013) covers the following water reuse systems: rainwater harvesting, stormwater harvesting and grey water reuse. It covers the supply of water for domestic water uses that do not require potable water quality, such as laundry, toilet flushing and garden watering. It does not cover systems supplying potable water for drinking, food preparation and cooking, dishwashing and personal hygiene. The Standard provides recommendations on how to select water reuse system(s), taking into account water resources, surface water management, water supply and sewage infrastructure. It applies to both new and existing developments in residential and non-residential premises.

#### A1.11.5.3 Water Regulations Advisory Scheme (WRAS)

The purpose of WRAS is to contribute to the protection of public health by preventing contamination of public water supplies and encouraging the efficient use of water by promoting and facilitating compliance with the Water Supply (Water Fittings) Regulations. As identified in the Buildings Regulations 2010: Approved Document G guidance on the marking of pipework conveying water from alternative sources can be found in the WRAS Information and Guidance Note Marking and identification of pipework for water reuse systems (No. 9-02-05; WRAS, 2015).

The Guidance Note states that:

[17] Statutory Instrument 1999 No. 1148 (http://www.hmso.gov.uk/si/si1999/19991148.htm) and Statutory Instrument 1999 No. 1506 (http://www.opsi.gov.uk/si/si1999/19991506.htm).

- It is important that all pipework supplying reused water is readily identifiable to those who come across it for the first time.
- Pipework should be both recognisable and distinguishable from that supplying mains water.
- Pipes must be marked and labelled.

The WRAS Guidance Note should always be referred for full details and distinctions between different settings (e.g. the difference between domestic and commercial pipework).

### A1.11.6 Existing services and incentives to encourage uptake of the technology

A number of water companies in England, particularly those operating in water stressed regions, have offered discounts on infrastructure connection charges for new developments that go beyond the 125 l/p/day water consumption target set out in the Buildings Regulations (see Table A1-8).

Table A1-8 – Examples of water company incentives offered on infrastructure connection charges

| Water company | Charges / property | Incentive / discount | Water efficiency target | Outcome / comments |
|---|---|---|---|---|
| Anglian Water | £740 per plot | 100% | 100l/p/day | The water efficiency incentive aimed to help reduce water use in new homes across the region. Where premises were built to a water efficiency standard of 100 litres per person per day, the fixed element of the zonal charge could be refunded. The water efficiency incentive was available in 2018-2019 and 2019-2020. |
| Southern Water | £790 dual services | £565 | 110 l/p/day | Part of Southern Water's Target 100 programme[18]. |
| Severn Trent Water | £382 (clean water only) | 100% | 110 l/p/day | Further discount of £124 if no surface water connection is made to a public sewer, or £93 if the surface water connects to a public sewer via a sustainable drainage system (SuDS)[19]. |
| Essex and Suffolk Water (Northumbrian Water Limited) | Not specified | 100%[20] | 105 l/p/day | Take up has been low due to lack of developer awareness[21]. |

While these types of incentive are likely to have encouraged developers to consider RWH as a potential option to reduce water consumption in new buildings anecdotal evidence suggests take up has been limited as the water efficiency targets can generally be met via the installation of water efficient fixtures and fittings. In addition, the level of incentive only offsets a small proportion of the additional capital costs associated with RWH systems, which also require maintenance throughout the lifespan of the asset. This was highlighted by other water companies where infrastructure charges are low. For

[18] https://www.southernwater.co.uk/media/2227/t100_acttoday.pdf
[19] https://www.stwater.co.uk/building-and-developing/regulations-and-forms/application-forms-and-guidance/infrastructure-charges/
[20] https://www.eswater.co.uk/globalassets/customer-pdfs/developer-pdfs/esw/infrastructure_charges_guidance_v1_october_2018_south.pdf
[21] Pers comm (Thomas Andrewartha)

example, Thames Water whose charges are around £350/dwelling suggest that "….*discounts offer little incentive to drive uptake of these technologies'*.

## A1.12 Use of RWH systems in other countries

The practise of RWH is more prevalent in many countries than in the UK. The findings of a targeted review of the policy options and interventions adopted to encourage the uptake of RWH systems in Germany, Australia, Japan and United States was undertaken and is presented below.

### A1.12.1 Germany

Germany is often the country seen as leading the way in the production and implementation of RWH systems in Europe, and alongside Japan and Australia in a global context (Schuetze, 2013). As of 2017 almost one third of new buildings built in Germany were equipped with a rainwater collection system for non-potable uses (mainly for irrigation, toilet flushing, and laundry use) (Campisano et al., 2017). While the uptake of RWH systems is often driven by concerns around water scarcity and the need to augment mains water supply, the drivers behind the market in Germany are more focused upon the retention of rainwater to control the frequency, peaks and volumes of urban runoff to alleviate stresses upon the central wastewater infrastructure and the knock-on impacts on the environment (Schuetze, 2013). Specific policies and regulations supporting the decentralized management of rainwater harvesting and utilization of rainwater, have been increasingly applied during the last few decades and have contributed significantly to the increasing application and development of the sector (Yannopoulos et al., 2019).

A major element in the support of decentralized RWH systems is to provide certainty to all stakeholders, including the users, the installers and the operators of both the decentralized as well as the centralized drinking water supply and sewage discharge systems, with which the decentralized technologies have to be combined. Germany's implemented regulations, which provide clear rules, have been very effective in supporting the installation of decentralized systems. In addition the implementation of a "rainwater tax", a tax based on the impervious surface of a property which drains water into the public sewage system, encourages the uptake of RWH to reduce sewage costs, and also improve the functioning and effectiveness of wastewater treatment network in case of storm (Schuetze, 2013 and OECD, 2012).

### A1.12.2 Australia

Australia has one of the highest degrees of the implementation of RWH systems in the world, with about 1.7 million households having fitted rainwater tanks to their households, according to the results of a survey by the Australian Bureau of Statistics in 2015 (Campisano et al., 2017). Rainwater tanks are commonly connected internally to non-potable end-uses such as toilet cisterns and cold-water taps supplying washing machines and are also often fitted to outdoor irrigation (garden) taps (Umapathi et al., 2019).

The widespread adoption of RWH systems in Australia is likely a result of the provision of rebates by the government to cover the capital costs of RWH systems (Amos et al., 2016). Between 2009 and 2011, under the Water for Future Initiative (WFI), the Australian Federal Government introduced a rebate scheme for the purchase and installation of new rainwater harvesting or grey water systems for non-potable purpose. The National Rainwater and Grey water Initiative provided households with a rebate of up to $500 per installation and during the period 14,625 rebates, equivalent of $7 million, were offered through the scheme (Australian Government, 2009). In addition to the Federal Government rebate scheme, many Australian State governments have developed regulatory mechanisms to promote RWH or GWR systems. Schemes such as the South Australia Water's Stand-Alone Rainwater Tank Rebate Scheme, which between 2011 and 2014 was utilised by more than 30,000 existing households providing rebates of up to $200 to residents purchasing a rainwater tank of 1000 L or greater (Umapathi et al., 2019).

### A1.12.3 USA

The level of application of RWH in the USA varies depending on the State, though in 2002 more than 100,000 residential RWH systems were in use in the form of simple rain barrels for garden irrigation at

the end of roof downspouts, or complex large-scale multiple end-use systems including potable use (Campisano et al., 2017).

The varied level of uptake across states is due to the fact that rainwater harvesting is not currently regulated by the Federal government and it is up to the individual states to regulate the collection and use of rainwater (US Department of Energy, 2015). While State level regulations and policies vary considerably, and while the majority of states have no rainwater harvesting regulations in place, some states provide specific incentives to encourage the collection of rainwater (US Department of Energy, 2015). Texas is probably the state with the highest level of implementation, with harvested rainwater aiding a number of water-scarce communities to reduce the gap between supply and demand. The State of Texas also offers financial incentives for RWH systems exempting RWH equipment from sales tax (Campisano et al., 2017).

### A1.12.4 Japan

In Japan, there is widespread support for the utilisation of rainwater or recycled water as there is high awareness of the need to conserve water, along with relatively high water costs in urban areas (Yi-Kai Juan et al., 2016). From the early 1980s, much work has been done in Japan by local governments promoting the introduction of water recycling systems as an effective mitigation countermeasure for large cities facing both water scarcity and urban flood problems (Campisano et al., 2017).

Following the drought in 1994 and Great Hanshin-Awaji earthquake in 1995, a large number of municipalities re-evaluated RWH and tried to identify alternative water resources as a means to prevent urban flooding and to secure emergency water for disaster responses. The issue was regulated by ordinance and guidelines according to the local conditions (Yannopoulos et al., 2019).

In 2015, an Act to Advance the Utilization of Rainwater was introduced. Under this act, municipalities are obliged to make their best effort to define and work toward rainwater utilization targets, while the national government is required to grant financial support for subsidy programs. These arrangements are expected to provide a nationwide move to promote rainwater use (Japan for Sustainability, 2014 and 2015). On 10 March 2015, based on the above act, the Japanese government approved the wider usage of RWH systems in newly constructed buildings by the state government or incorporated administrative agencies, aiming for a 100% installation rate (Yannopoulos et al., 2019).

## A1.13 Conclusions

This report brings together the findings from a review of academic and industry research into RWH systems, designs and technologies in the UK. The review also supported an assessment of the costs and performance of existing systems, including various retrofit installations and new build systems across a range of building types.

Based on the information presented, the following conclusions are made regarding the current approaches to RWH in the UK and the associated costs and benefits.

- RWH systems provide a viable alternative source of water supply and therefore have the potential to reduce demand for mains water.
- RHW systems go beyond traditional water efficiency measures such as low flush toilets and low flow showers and can contribute to driving PCC below 100 l/p/d.
- Rainwater harvesting is increasingly being considered at the building-level, as a means for addressing water scarcity and stormwater attenuation.
- A variety of RWH system designs and configurations are available and can be applied in a range of building types.
- A number of innovations have emerged in the UK market configured around a high-level roof-runoff inlet, which facilitates the replacement of the large ground-level tank with wall-mounted or internal header tanks.

- In general installing RWH systems in new buildings is easier and cheaper than retrofitting into existing buildings. However, due to their large potential collection areas and high potential demand for non-potable water commercial and industrial buildings are better candidates than domestic dwellings for the retrofit of RWH systems.

- RWH systems need to be regularly maintained to ensure they continue to operate efficiently.

- The capital investment required for a RWH system can vary significantly depending on scale, from a few £1,000 for a small scale domestic unit, to many tens of £1,000's in large scale developments.

- The cost effectiveness of a RWH system improves with the scale of the project, meaning that larger buildings with larger collection areas are generally more cost-effective.

- Typically the level of savings that can be achieved using a RWH system will be dependent upon the price of potable water supplied and the quantity of potable water saved.

- The financial viability of a RWH system is directly linked to the cost of potable water, as the cost for potable water increases the viability of RWH systems also increases.

- A range of operational energy intensities for RWH systems have been reported which depending on the system design and scale, are either more or less favourable than the centralised town water systems.

- Along with supplementing existing water resources RWH can provide further environmental benefits (i.e. reduced surface runoff and flood risk) through the detention and attenuation of surface water runoff during rainfall events.

- RWH has recently been combined to good effect within sustainable urban drainage systems as part of wider stormwater control and attenuation schemes.

- Increasing awareness of the benefits of rainwater harvesting systems and the combination of these systems with SUDS will likely lead to wider uptake.

- There is now a greater emphasis on larger scale projects at the development phase (e.g. community projects, commercial installations and multi-purpose developments) where the return on investment is often more favourable. There has also been a move away from small scale domestic installations and retrofits.

- Uptake in the United Kingdom (UK) has to date been limited in comparison to some other European countries where legal and economic conditions have been created to support or enforce the use of RWH as part of climate, environmental and social policies.

- The success of the RWH sector in other countries (e.g. Australia and Germany) is strongly associated with regulation and incentives aimed at promoting the adoption of RWH systems.

- The distribution, seasonality and intensity of rainfall events are all expected to increase, meaning that a RWH system sized for the current UK climate could be poorly adapted for future climates suggesting a need to oversize tanks for the current climate in order to provide resilience against projected climate change.

## A1.14 References

Ahilan, S., Melville-Shreeve, P., Kapelan, Z., and Butler, D. The influence of household rainwater harvesting system design on water supply and stormwater management efficiency. 11th International Conference on Urban Drainage Modelling, Italy, 2018.

Alameddine, I., Majzoub, I., Najm, M. A. and El-Fadel, M. WIT Transactions on Ecology and the Environment, Vol 229, 2019.

Amos, C.C., Rahman, A. and Gathenya, J.M., Economic Analysis and Feasibility of Rainwater Harvesting Systems in Urban and Peri-Urban Environments: A Review of the Global Situation with a Special Focus on Australia and Kenya, Water, 8, 2016.

Australian Government. National Rainwater and Grey water Initiative: Household Rebate Guidelines, 2009.

Bashar, Md. Z. I. Karim, Md. R. K., and Imteaz, M. A. Reliability and economic analysis of urban rainwater harvesting: A comparative study within six major cities of Bangladesh. Resources, Conservation and Recycling, 133, 2018.

British Standards Institute, BS 8515:2009+A1:2013 Rainwater harvesting systems – Code of practice, 2013.

Campisano, A., Cutore, P., Modica, C and Nie, L. Reducing inflow to stormwater sewers by the use of domestic rainwater harvesting tanks. InProceedings of the Novatech 2013, Lyon, France, 23–27 June 2013.

Campisano, A., Butler, D., Ward, S., Burns, M. J., Friedler, F., DeBusk, K., Fisher-Jeffes, L. N., Ghisi, E., Rahman, A., Furumai, H., and Han, M. Urban rainwater harvesting systems: research, implementation and future perspectives. Water Research, 115, 2017.

Corvaro, S. Water efficiency and economic assessment of domestic rainwater harvesting systems in buildings with one- to three-floor elevations. Water Science & Technology Water Supply, 2019.

DCLG, Code for Sustainable Homes Technical Guide 2010.

Defra, Sustainable Drainage Systems Non-statutory technical standards for sustainable drainage systems, 2015.

Domènech, L and Saurí, D. A comparative appraisal of the use of rainwater harvesting in single and multifamily buildings of the Metropolitan Area of Barcelona (Spain): social experience, drinking water savings and economic costs. Journal of Cleaner Production, 19, 2011

Doncaster, S., Blanks, J., and Shepherd, W. Pennine Water Group, University of Sheffield. Rainwater harvesting: An investigation into the potential for rainwater harvesting in Bradford. 2012.

Environment Agency. Greenhouse gas emissions of water supply and demand management options, 2008

Environment Agency. Harvesting rainwater for domestic uses: an information guide, 2010.

Environment Agency, Energy and carbon implications of rainwater harvesting and grey water recycling, 2011.

Environment Agency. Preliminary Flood Risk Assessment for England, 2018.

Farreny, R., Morales-Pinzo´n, T., Guisasola, A., Taya`, C., Rieradevall, J., and Gabarrell, X. Roof selection for rainwater harvesting: Quantity and quality assessments in Spain. Water Research, 45 (10), 2011.

Fewkes, A. A review of rainwater harvesting in the UK. Structural Survey, 30 (2), 2012.

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Yusoff, S. M., and Hassan, N., B. State of the art of rainwater harvesting systems towards promoting green built environments: a review. Desalination and Water Treatment, 57 (1), 2015.

Ghimire, S.R., Johnston, J. M., Ingwersen, W., and Hawkins, T. R. Life cycle assessment of domestic and agricultural rainwater harvesting systems. Environmental Science and Technology, 2014.

Ghimire, S.R., Johnston, J.M., Ingwersen, W., and Sojka, S. Life cycle assessment of a commercial rainwater harvesting system compared with a municipal water supply system. Journal of Cleaner Production, 151, 2017.

Hamilton, K., Reyneke, B., Waso, M., Clements, T., Ndlovu, T., Khan, W., DiGiovanni, K., Rakestraw, E., Montalto, F., Haas, C. N., and Ahmed, W. A global review of the microbiological quality and potential health risks associated with roof-harvested rainwater tanks. Clean Water, 2, 2019.

HM Government. The Building Regulations 2010 – Drainage and waste disposal - 2015 edition: Approved Document H, 2015.

HM Government. The Building Regulations 2010 - Sanitation, hot water safety and water efficiency - 2015 edition with 2016 amendments: Approved Document G, 2016.

HM Government. A Green Future: Our 25 Year Plan to Improve the Environment, 2018.

Imroatul C. J., Kusuma, M. S. B., Cahyono, M., Kardhana, H., and Martokusumo, W., Performance of rainwater harvesting system based on roof. Matec Web of Conferences, 101, 2017.

Japan for Sustainability. Let's Use Rainwater! Recent Trends in Rainwater Use in Japan.2014 https://www.japanfs.org/en/news/archives/news_id035023.html

Japan for Sustainability. Cabinet of Japan Decide to Make Full Use of Rainwater in Newly Constructed Buildings, 2015 https://www.japanfs.org/en/news/archives/news_id035257.html

Johnen, L. Unfair charging in the UK? ...Or why Germany is ahead in SuDS. Watef Conference 2018.

Karim, Md. R., Bashar, M. Z., and Imteaz, M. A. Reliability and economic analysis of urban rainwater harvesting in a megacity in Bangladesh. Resources, Conservation and Recycling, 104, 2015.

Lash, D., Ward, S., Kershaw, T., Butler, D., and Eames, M. Robust rainwater harvesting: probabilistic tank sizing for climate change adaptation. Journal of Water and Climate Change. 05.4, 2014.

Madara, S. D., Namango, S. and Katana, H. Potential of roof rain water harvesting at an industrial setup. Journal of Environment and Earth Science. Vol 6 (7), 2016.

Matos, C., Bentes, I., Santos, C., Imteaz, M., and Pereira, S. Economic Analysis of a Rainwater Harvesting System in a Commercial Building. Water Resource Management, 29, 2015.

Medina, V.F. Rainwater Harvesting Technical Report, 2016.

Melville Shreeve, P., Ward, S., and Butler, D. A preliminary sustainability assessment of innovative rainwater harvesting for residential properties in the UK. Journal of Southeast University, 30 (2), 2014.

Melville-Shreeve, P., Ward, S., and Butler, D. Rainwater harvesting typologies for UK houses: A multi criteria analysis of system configurations. Water, 8 (129), 2016.

Memon, F. A., and Ward, S. Alternative water supply systems, IWA, 2018.

Morales-Pinzón, T., Lurueña, R., Rieradevall, J., Gasol, C. A., and Gabarrell, X. Financial feasibility and environmental analysis of potential rainwater harvesting systems: A case study in Spain. Resources, Conservation and Recycling, 69, 2012.

Nachshon, U., Netzerb, L., and Livshitz, Y. Land cover properties and rain water harvesting in urban environments. Sustainable Cities and Society, 2016.

National Infrastructure Commission, Preparing for a drier future: England's water infrastructure needs, 2018.

OECD Environmental Performance Reviews: Germany 2012.

Pacheco, G. C. R., and Campos, M. A S. Real options analysis as an economic evaluation method for rainwater harvesting systems. Water Resources management, 2019.

Policy Connect. Bricks and Water, 2018.

Rahman, A., Dbais, J., and Imteaz, M. Sustainability of rainwater harvesting systems in multi-storey residential buildings. American Journal of Engineering and Applied Sciences 3 (1), 2010.

Rahmana, A., Keanea, J., and Imteaz, M. A. Rainwater harvesting in Greater Sydney: Water savings, reliability and economic benefits. Resources, Conservation and Recycling 61, 2012.

Schuetze, T. Rainwater harvesting and management – policy and regulations in Germany. Water, Science and technology: water supply, 13.2, 2013.

Sendanayake, S. Rainwater harvesting for urban living, 2016.

Severisa, R. M., Arcari da Silvaa, F., Wahrlicha, J., Skoronskib, E., and Simionia, F. J. ,Economic analysis and risk-based assessment of the financial losses of domestic rainwater harvesting systems. Resources, Conservation and Recycling, 146, 2019.

Struk-Sokołowska, J., Gwo´zdziej-Mazur, J., Jadwiszczak, P., Butarewicz, A., Ofman, P., Dowikowski, D., and Ka´zmierczak, B. The Quality of Stored Rainwater for washing purposes. Water, 12, 2020.

UK Government. UKCP18 Science Overview Report. November 2018 (Updated March 2019).

UKRMA. Helping to avoid future floods and droughts: Overview of the water re-use sector in the UK, 2020.

Umapathi, S., Pezzaniti, D., Beecham, S., Whaley, D and Sharma, A. Sizing of domestic rainwater harvesting systems using economic performance indicators to support water supply systems, Water, 11, 2019.

US Department of Energy. Rainwater Harvesting State Regulations and Technical Resources, 2015.

Vieira, A. S., Beal, C. D., Ghisi, E., Stewart, R. A. Energy intensity of rainwater harvesting systems: A review. Renewable and Sustainable Energy Reviews, 2014.

Ward, S., Butler, D., and Fayyaz, M. Benchmarking energy consumption and CO2 emissions from rainwater harvesting systems: an improved method by proxy. Water and Environment Journal, 2011.

Ward, S., Memon, F., and Butler, D. Performance of a large building rainwater harvesting system. Water Research, 46 (16), 2012.

Ward S., Butler, D., Daly, B., Deegan, A., Maganha De Almeida, A., and Lennox, I. Alleviating health risks associated with rainwater harvesting. Journal of Environmental Engineering and Science 12(1), 2017.

Water Regulations Advisory Scheme (WRAS). Marking and identification of pipework for water reuse systems, No 9-02-05, 2015.

Waterwise, How Do People Feel About Domestic Water Recycling Systems?, 2019.

Water UK, Water resources long term planning framework (2015-2065), 2016.

Wilcox, J., Nasiri, F., Bell, S., Rahamanb, M. S. Urban water reuse: A triple bottom line assessment framework and review. Sustainable Cities and Society, 27, 2016.

Yan, X., Ward, S., Butler, D., and Daly, B. Performance assessment and life cycle analysis of potable water production from harvested rainwater by a decentralized system. Journal of Cleaner Production, 2017.

Yannopoulos, S., Antoniou, G., Kaiafa-Saropoulou, M., and Angelakis, A.N. Historical development of rainwater harvesting and use in Hellas: a preliminary review. Water, Science and technology: Water Supply, 17 (4), 2017.

Yannopoulos, S., Giannopoulou, I., and Kaiafa-Saropoulou, M. Investigation of the Current Situation and Prospects for the Development of Rainwater Harvesting as a tool to Confront Water Scarcity Worldwide. Water, 11, 2019.

Yi-Kai, J., Chen, Y and Jing-Ming, L. Grey water Reuse System Design and Economic Analysis for Residential Buildings in Taiwan. Water, 8, 2016.

# A2 Review of grey water recycling systems and technologies in the UK

## A2.1 Introduction

Grey water recycling (GWR) systems and technologies offer a potential solution and are increasingly being considered at the building-level as a means for addressing water scarcity and development sites with wastewater infrastructure constraints. To date GWR systems have been implemented with mixed experience in the UK. Technical concerns regarding water quality, potential cross connections and issues around the social acceptability of using recycled water have all been barriers to uptake. Further to this a 2011 Environment Agency report on the carbon implications of these systems suggested that they are often more carbon intensive than the public water supply. Additionally, the payback periods and return on investments can be obtrusive for some systems but may benefit from economies of scale if they are introduced at a development scale or centralised within an existing community.

While over the last decade there have been advances in GWR technologies, there remains a gap in research and accreditation for these systems compared with countries such as Germany, USA and Australia, and in support to bring them to the market on a wider scale. There has also been a lack of coordinated and collated evidence across the country, especially on differing scales and for non-domestic properties. An information guide published by the Environment Agency in 2011, outlined the costs and benefits for domestic installations of GWR, but these are now largely out of date.

This work aims to address this research gap. Drawing on case studies and industry examples the evidence base for rainwater has been developed and used to model the costs and benefits of existing the technologies in different contexts, scales, building types and new or retrofitted buildings.

## A2.2 Approach

A review of academic and industry research into GWR systems, designs and technologies across a range of building types was undertaken. In parallel a series of stakeholder interviews were undertaken to address any potential gaps in information identified in the literature review and to widen the understanding beyond published work, gain greater sector insight and to identify further case studies and examples not in the public domain.

The approach combined a robust review of existing academic literature and industry research relating to GWR systems with a targeted stakeholder engagement programme to gather and collate the relevant data and information to inform the cost benefit analysis.

### A2.2.1 Literature review

The literature review for GWR was conducted in unison with the Rainwater Harvesting (RWH) literature review (see Appendix A1). The key objective of the literature review was to identify and collate academic and industry research into GWR systems, designs and technologies.

Targeted searches were undertaken to address the wide range of potentially relevant subject areas using keywords designed systematically to identify relevant studies. Platforms including GoogleScholar and ScienceDirect were used and all relevant data and information was collated into spreadsheet format to facilitate subsequent evaluation and review.

A four step process for identifying relevant literature and information was used as follows:

5. Development of a list of search themes and sub-divisions.
6. Agreement of search themes with the project steering group.
7. Preliminary high level search followed by adjustment and optimising of the search terms.
8. Capture all relevant titles in spreadsheet format and save electronic copies for easy access.

In addition, a similar search strategy was established to gather relevant grey literature (e.g. national and international government reports, studies published by industry and relevant trade associations, NGO's and academic theses) and other resources. A search of water retailer websites was undertaken to identify relevant services and incentives provided to business customers to encourage the uptake of GWR systems.

#### A2.2.1.1 Stakeholder engagement

From the outset it was anticipated that there would be gaps in data and literature available within the public domain such as those associated with the following:

- Establishing the actual capital and operational costs and data (including energy use etc).
- Validating the actual benefits (e.g. water savings, return on investments etc).
- Substantiating the technical barriers and challenges and identifying the reasons why some projects were not successful.
- Understanding how the technology is perceived in the market place.

Therefore to address these a series of stakeholder interviews were undertaken in parallel with the literature review. Using Ricardo's existing contacts together with the project steering group's knowledge and contacts, a comprehensive set of stakeholder organisations was identified. Full details of the stakeholder engagement exercise is provided in Appendix A1.1.

### A2.2.2 Scope

A list of search themes and sub-divisions was developed, the key areas of focus were as summarised below:

- Key drivers for uptake of GWR;
- Types of system and their application (e.g. commercial, domestic, retrofit, new build, different building types etc);
- Operational performance of GWR (including capital and operational costs, carbon, energy impacts across full lifecycle and any social/community / wider benefits);
- Benefits of GWR (including water savings and wider benefits associated with urban water management)
- Barriers and challenges associated with installation of GWR systems.
- Relevant case studies (UK and international).
- Potential pollutants such as microplastics.

As one of the key objectives of the literature review was to supersede, or support the production of an updated version of, the 2011 Environment Agency report, data and information gathered through the literature review has been grouped according the below:

- Water supply, grey water demand and social acceptability of recycled water
- The types of GWR systems, designs and technologies.
- Barriers and challenges associated with GWR systems
- Costs and performance including capital and operational costs, carbon and energy impacts and wider benefits.
- Water quality and contamination considerations
- Regulation and guidance
- The use of GWR in countries other than the UK .

At the outset of the review a list of data requirements to inform the cost and benefit analysis element of the project was developed. Further information regarding this and the types of data the study aimed to identify are provided in Appendix A1.

In addition a summary of the findings from a separate review of the incentive schemes (e.g. discounts) that are currently in place in the water industry as well as policy options and interventions adopted in other countries to encourage the uptake of RWH is provided. In agreement with the project steering

group this review focussed on several countries, due to their similarity to the UK in terms of climate and level of development. The countries selected were:

- Germany
- Australia
- Japan
- USA.

For the purpose of this study the review broadly follows the definition of grey water as identified for the purpose of the British Standard (BS) 8525 i.e. bathroom grey water, that from domestic baths, wash and hand basins, showers and clothes washing machines characterised by its cloudy appearance. However, in line with the 2011 Environment Agency guide, it does not focus on the more contaminated water from washing machines or that from kitchen sinks.

The GWR systems included in the review are broadly commercially available systems for domestic and commercial uses of relevance to homeowners, house builders, planners, architects and building managers (in line with the 2011 Environment Agency guide). These can vary significantly in their complexity and size from small systems with very simple treatment to large systems with complex treatment processes. It is noted that larger reuse plants that process inputs from industrial processes or a network of wastewater/grey water sources (e.g. decentralised community recycling systems at the cluster level) are not considered within the scope of this study.

## A2.3 Background

The reuse of grey water is an old practice especially in historically water stressed regions of the world where it has been considered as a reliable method of ensuring water security as compared to other methods of water capture such as RWH which is dependent on hydrological conditions (Oteng-Peprah et al,. 2018). It is now recognised that some river basin districts in the UK are classified as being severely water stressed (Water Reuse Europe Review, 2018) and the risk of droughts that are more severe than those in the historic record is already significant. Whilst there are major uncertainties in the drivers of future risk of water shortage (population, uncertainty on levels of demand, climate, reductions in abstraction limits), these factors are all likely to increase the risk of water shortage in future (Water UK 2020). This and similar situations globally, especially in cities, has led to the current international focus on water saving measures (Toifl et al, 2016). Together with wastewater reuse (mainly by the water sector), rainwater and stormwater, grey water is often proposed as a potential alternative water source in the domestic setting, both for individual houses and low and high rise multiple occupancy dwellings (Toifl et. al, 2016). It is also being applied in commercial settings and built into the design of mixed use developments.

Early development and application of GWR started in Germany in the late 1980's and 1990's and is often seen as leading the way in Europe in the use of GWR (Grant, 2016). In the UK water saving measures associated with domestic or commercial buildings has traditionally focused on water efficiency measures such as low flush toilets and low flow showers. However, the application of GWR has been growing in the UK and since 2010 there has been the British Standards for GWR systems. There are now several specialist suppliers some of whom have brought over the experience from Germany and other places where the technologies are more established (Grant, 2016). Over the past decade, there has been advances in the associated technologies but there has not necessarily been an increase in the take up of such systems in the UK.

### A2.3.1 What is GWR?

Grey water, especially where this is limited to that derived from baths, showers and washbasins (sometimes termed 'light grey water') can be considered high volume, low strength wastewater with high potential for reuse and application (Oteng-Peprah et al. 2018). In traditional and existing drainage systems in the built environment all untreated grey water is combined and mixed with more polluted wastewaters (e.g. sewage and faecal matter from toilets, often termed black water) flowing into the sewer (Hyde et al 2018). Interventions that separate grey water offer subsequent use for non-potable (generally sanitary) purposes which in turn reduces the quantity of mains water used. There is some

mixed use of terminology in the literature. For example, a manufacturer of GWR systems considers the term 'grey water reuse' to apply to the use of untreated grey water and the term 'grey water recycling' the use of treated grey water. If this distinction is applied, the majority of systems and subsequent application discussed in this review are considered to be 'grey water recycling' (GWR). Generally, GWR can supply water for:

- Toilet flushing;
- Irrigation/outside water use (including that for Green Infrastructure); and
- Laundry.

The review does cover direct systems to some extent which use simple devices to collect grey water from appliances and deliver it directly to the points of use (generally irrigation), with no treatment and minimal, or no, storage. It is possible to reuse grey water without any treatment, provided that extended storage is not required. As untreated grey water quality deteriorates rapidly, the collected grey water ideally needs to be reused as soon as it has cooled. Where no treatment is included in the grey water system, applications are more restricted (British Standards Institute, 2010).

More modern, large scale and complex systems are capable of treating, what can be termed 'heavy' grey water, which includes that derived from washing machines, dishwashers and kitchen sinks. This has a higher pollutant loading and requires a greater level of treatment.

### A2.3.2 Why consider a GWR system?

From a homeowner's perspective a modern GWR system may bring cost savings (this is discussed further in Section A2.8). In addition, awareness around climate and environmental issues is gaining momentum, people are wanting more from their homes[22]. As such the demand for greater sustainability in homes is growing although it is noted that some developers are not seeing the same interest in GWR systems compared to those associated with $CO_2$ reduction technology which has recently risen sharply[23]. In this context it is noted that there isn't the same level of backing or support for sustainable water use compared for example to solar panel schemes to reduce environmentally unsustainable: energy use [24]. The inclusion of GWR systems may improve people's autonomy by reducing their reliance on central water infrastructure, particularly valuable during droughts and 'hosepipe bans' when there would still be water available for watering gardens or washing cars ((Policy Connect, 2018).

From a commercial perspective, there is the potential for costs savings for new developments associated with the reduction in mains supply charges as well as other savings such as reductions in connection charges (discussed further in Sections A2.8). However, there are also numerous barriers and concerns regarding the installation and operation of GWR, which are described in Section A2.7. In response to the increasing awareness around climate and environmental issues some businesses have strived for sustainably high performing buildings and there are some very high profile case studies especially in the UK capital notably; Bloomberg's new European headquarters. This is one of the world's highest BREEAM-rated major office buildings and it includes GWR systems which serve vacuum flush toilets. Developers also recognise the need to strive for high performing buildings but as Barratt developments highlight "*Meeting the challenge of water scarcity in future years requires a coordinated effort: between infrastructure and housing organisations, government, and both domestic and business water consumers"* and states that they are in discussions with other water companies around GWR innovations (Barrat Developments Plc , 2019). Taylor Wimpey also has a webpage[25] dedicated to GWR both as general information for existing homeowners as well as regarding new developments and case studies.

### A2.3.3 What savings can be achieved?

Domestic water demand in industrialised countries approximates to 100-150l/p/d (litres per person per day), of which 60-75% is transformed to grey water (Friedler and Gross 2016; and Boano et al, 2020).

[22] https://www.bregroup.com/news/bre-welcomes-green-housing-revolution/
[23] Pers Comm (Redrow)
[24] https://www.gov.uk/government/news/new-laws-to-guarantee-payment-for-solar-homes-providing-excess-electricity
[25] https://www.taylorwimpey.co.uk/inspire-me/sustainable-living/the-difference-you-can-make-with-greywater-recycling

The quantity of grey water that can be recycled and used depends on the demand in the home or building and the system employed. If used just for toilet flushing a well-designed a fully functional GWR system could potentially save a quarter of mains water used in a home. Greater savings would be achieved if the GWR systems also supplied other applications such as those associated with irrigation/outdoor use. As more grey water is treated, recycled, and reused, the volume of mains water required for basic functions such as toilet flushing and garden watering is reduced (Hyde et al, 2018). Reusing grey water not only reduces the consumption of mains water, it also reduces the volume of water discharged into the sewerage system. Consumers with water meters could therefore save money on both their water supply and wastewater bills.

### A2.3.4 What are the benefits?

From a homeowner's perspective there are potential cost savings described above. In addition, some of the modern GWR systems also have the capability of recovering the heat in grey water, feeding the heat back into the central heating system and consequently reducing energy bills. From a commercial/developers perspective there may be cost savings and the potential for greater appeal for developments that are sustainability led as described above. Water companies may also present benefits to developers e.g. incentives or through strategic agreements regarding infrastructure connections. These are described further in Section A2.8.6.

The source separation of grey water can reduce the volume sent to wastewater treatment plants treatment plants (reducing pressure on the sewer network) and reduce the energy required for treatment because only the more polluted fraction of wastewater is sent to the treatment plant. The recycled grey water reduces the requirement for mains water and the costs and energy associated with its treatment and supply in this way, a circular economy is promoted (Boano et al, 2020). Although, if this reduction is significant there is the potential for this to result in disbenefits where the domestic volume of (less polluted) wastewater is used to offset industrial load on the wastewater treatment plants.

From a community, societal and environmental perspective GWR (and reuse more generally) if embraced and enforced can lead to a decline in over-reliance and pressure on existing freshwater sources wither numerous wider benefits. Section A2.8.4 describes potential benefits in more detail.

## A2.4 Household and non-household water demand

### A2.4.1 Household water use

Household consumption can be reported in two ways:

- PHC or per household consumption in litres/property/day
- PCC or per capita consumption in litres/head/day.

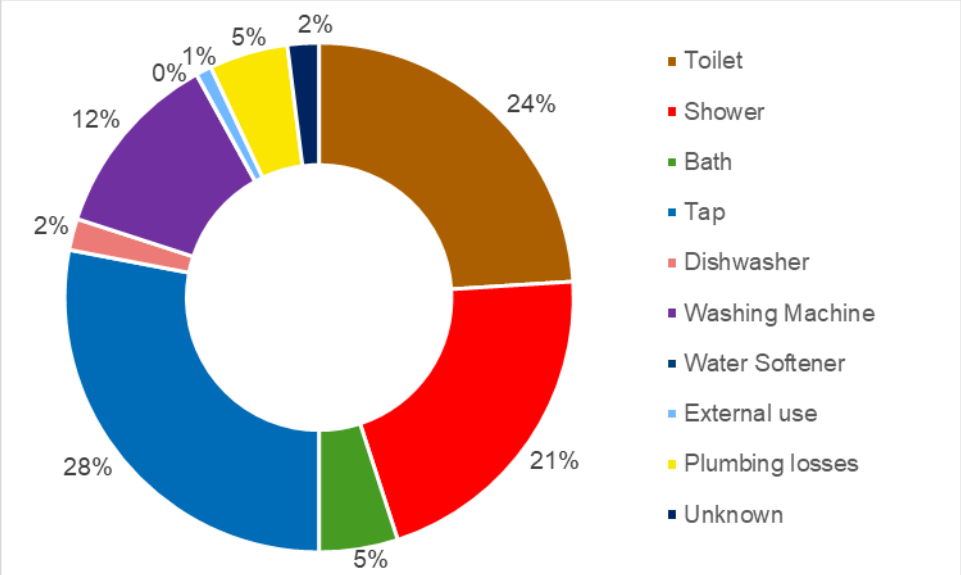
Both PHC and PCC vary from house to house and region to region. Variations in consumption can be influenced by: household occupancy, property type and age, age of occupants, socio-demographic factors (social status, levels of affluence, culture, religion, lifestyles, and household or individual values towards water use), whether households pay via a water meter, the weather, and the methods used to measure and estimate household consumption (Artesia, 2018) .

The latest reported average PCC for England and Wales is 143 l/p/d[26]. The average household consumption is around 349 l/h/day. Less water is used in households with a water meter (133 l/p/d) compared to ones without (166 l/p/d). The PCC is higher than some other western European countries (e.g. Germany 121 l/p/d).

Figure A2.1 shows the different types ('micro-components') of water use in the home, noting that these are average values and in reality the way in which water is used in households can vary significantly. The data was sourced from a group of 62 metered properties, spread across England and Wales, monitored in 2015/16 (Artesia, 2018).

[26] https://www.discoverwater.co.uk/amount-we-use

Figure A2.1 – Average micro-components of water use (Source Artesia, 2018)



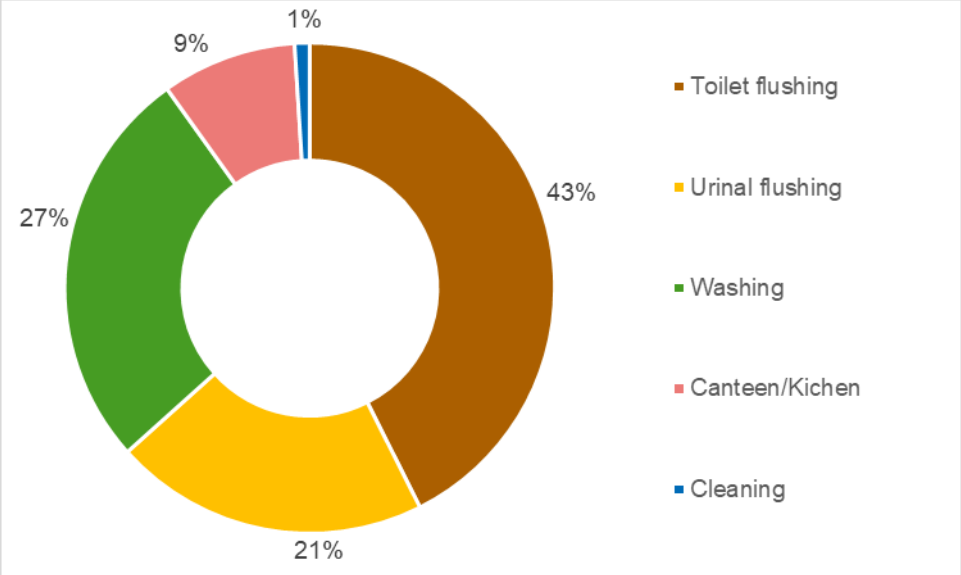

Since 2006 there has been a downward trend in overall PCC, with evidence for reductions in water used for flushing WCs due to the successive reduction in WC cistern sizes. However, there is a consistent increasing trend in the proportion of household water used for personal washing (Artesia, 2018).

### A2.4.2 Non household water use

Non-household demand is commonly categorised according to broad sectors including agriculture and horticulture, the service sector and non-service sector. The service sector is most applicable with respect to the scope of this study and the application of GWR systems (noting that there is great potential for water reuse in general in the agriculture and industrial operations just not in terms of the GWR systems discussed here). The service sector can be a significant component of non-household demand and includes commercial properties, hotels, leisure centres, hospitals, schools and local authorities. These settings can also offer the greatest potential for GWR systems both economically and in terms of balancing out the inherent variability in water consumption by individuals or households.

Water use in service sector buildings differ from that in domestic settings, and there will be significant variability between the different properties types and operations undertaken and included facilities. A typical consumption pattern for offices is shown in Figure A2.2, with the greatest majority of use is accounted for by the washrooms.

Figure A2.2 – Water use in offices (Source CIRIA, 2006)




Water consumption in service sector settings can be described in a number of ways. CIRIA identified key performance indicators to described national trends and benchmarks for offices and hotels (CIRIA, 2006). For offices both water consumption in $m^3$ per person per year and water consumption in $m^3$ per square meter per year were analysed and both showed strong correlation with water use in the office. It was suggested that in order to provide appropriate guidance to the office sector benchmarks for offices would also be presented as litres per day (assuming 253 days per business year). Typical use was identified as 15.8l/ employee/day and best practice use 7.9l/employee/day (CIRIA, 2006).

For hotels the key performance indicator chosen was cubic meters per bed space per annum. The analysis undertaken also identified that there was a significant correlation between the star rating of the hotel and water consumption. Another significant factor was whether the hotel included facilities such as a swimming pool. The benchmark values are presented in Table A2.1 below.

Table A2.1 Benchmarks for hotels (values for those with swimming pools in brackets) (Source CIRIA, 2006)

| Category | Benchmarks ($m^3$/bedspace/annum) | | | |
|---|---|---|---|---|
| | Hotel Rating | Best Practice | Typical | Above Average |
| Cat 1 | 1 star | 5 (9) | 10 (25) | 15 (60) |
| Cat 2 | 2 or 3 | 10 (20) | 20 (60) | 50 (185) |
| Cat 3 | 4 or 5 | 15 (60) | 30 (130) | 65 (220) |
| Other | No rating | 10 (40) | 30 (90) | 70 (170) |

Water companies forecast non-household demand as part of their Water Resource Planning. In its latest Water Resource Management Plan (WRMP) South East Water found that non-household demand (of which the service sector represents of 45% of demand) has generally been relatively flat over the past 10 years and expects that to continue (South East Water, 2019). However, Thames Water undertook research into non-potable water reuse as a demand management option for their latest WRMP. This identified significant projected growth of required additional office floor space (5.3 million $m^2$) in the Opportunity Areas associated with the London Plan that fall within the Thames Water supply area (Thames Water, 2017). There is significant uncertainty in non-domestic future demand forecasting notably in relation to the effect of the economy on significant factors (e.g. employment rates) (South East Water, 2019). It is noted that at the time of writing the COVID-19 pandemic was ongoing and post-Brexit trade deals were being negotiated.

### A2.4.3 Demand for grey water

As shown in Figure A2.1, the volume of water used to flush the toilet in a typical household is smaller than the volume of water available from showers and baths alone. This suggests that water demand for toilet flushing could be met by reusing this grey water (let alone other sources of grey water). However, the amount of grey water produced in a household can vary greatly ranging from as low as 15 l/p/d per person per day to several hundred per person per day. Factors that account for such huge disparities are mostly attributed to geographical location, lifestyle, climatic conditions, type of infrastructure, culture and habits, among others (Oteng-Peprah et al, 2018). For this reason it has been shown that GWR systems can operate more effectively in multi-residential or institutional settings as the variability in grey water production is smoothed out. For example excess grey water from domestic sources can contribute to the demand of office buildings.

### A2.4.4 Perceptions of GWR systems

Public perception, which is a social phenomenon, can be seen as the difference between an absolute truth based on facts and virtual truth shaped by popular opinion (Oteng-Peprah et al, 2018). There is reported and understandable concerns over public acceptability of GWR (the 'yuck' factor) (Oteng-Peprah et al, 2018); (McClarana et al 2020; Ifelebuegu et al, 2016; and Policy Connect, 2018). However, several studies have been conducted to assess public perception towards grey water reuse in different parts of the world using different strategies (e.g. interviews, questionnaires, focus group discussions). Many of these studies have identified clear support for the concept of GWR as an environmentally sustainable method of protecting freshwater resources and pollution (Oteng-Peprah et al, 2018). Public support for GWR is often greater for areas which are water stressed and areas with unreliable water supply. A recent UK study looking at people's perceptions and intentions around coping with drought found that GWR was perceived as one of the most effective measures to take, with 22% of participants claiming to already be using grey water in some capacity (Artesia 2018). However, it should also be noted that changes in support for wastewater reuse in general can occur over time in response to periods of drought[27]. Countries such as the US and Australia often endure more consistent droughts which keeps concepts such as wastewater reuse at the top of the agenda. In the UK the perception about just how much water there is available may need to change, with drought and related mitigation strategies too quickly forgotten about after the event has passed.

A recent Waterwise study investigated public perception of RWH and GWR for domestic use. This included a literature review that identified evidence of a general willingness to recycle water sourced from showers and baths in a GWR system provided the organisation setting standards for reuse was trusted, and public health was not compromised (Waterwise, 2019). A micro-survey (201 responses mostly between 25 and 54 years old) undertaken as part of the Waterwise study showed that when asked how interested respondents would be in having a GWR system that in their homes, 86% described themselves as being either "very interested" or "somewhat interested" (43% and 43% respectively), 11% indicated that they were "unsure", and only 3% described themselves as "somewhat disinterested" or "very disinterested" (2% and 1% respectively). The generally high level of positivity towards the idea of reuse systems has been reported elsewhere and suggests that it could be interpreted as a reflection on resource and environmental awareness as well as changing attitudes towards water conservation (growing pro-sustainability attitudes). The Waterwise study described the main factors that might prevent people from implementing GWR systems to be cost, disruption to the home during installation, a lack of understanding of how the systems would work, concerns about maintenance, and concern about water quality. It was also shown that users level of comfort and confidence in GWR would increase with the amount of education they were given.

## A2.5 GWR systems, designs and technologies

GWR systems vary significantly in their complexity and size from small systems with very simple treatment, to large systems with complex treatment processes. Treatment systems that have been used to reduce the level of contamination in grey water are contaminant-specific, and each is applied along

[27] Pers comms (Thames Water)

the conventional wastewater treatment sequence (pre-treatment, primary, secondary and tertiary treatment) (Oteng-Peprah et al, 2018). Table A2.2 characterises the levels and treatment technologies usually implemented for GWR.

Table A2.2 – Grey water treatment processes (Source Oviedo-Ocaña et al 2018)

| Type | Remove | Processes |
|---|---|---|
| Preliminary | Fats, hairs and suspended particles | Solid and fat removal and filtration |
| Primary | Settleables and suspended solids | Sedimentation and filtration |
| Secondary | Biodegradable matter and heavy metal | Filtration, biodegradation and adsorption |
| Tertiary | Nutrients and microbiological agents | Disinfection, nano-filtration and ion exchange |

Treatment systems adopt either a physicochemical or biological means of treatment. Physicochemical methods adopt physical and/or chemical methods of treatment including filtration, adsorption and reverse osmosis, among others. Biological treatment methods adopt a combination of microbes, sunlight and oxygen manipulation (Oteng-Peprah et al, 2018).

### A2.5.1 Types of GWR systems

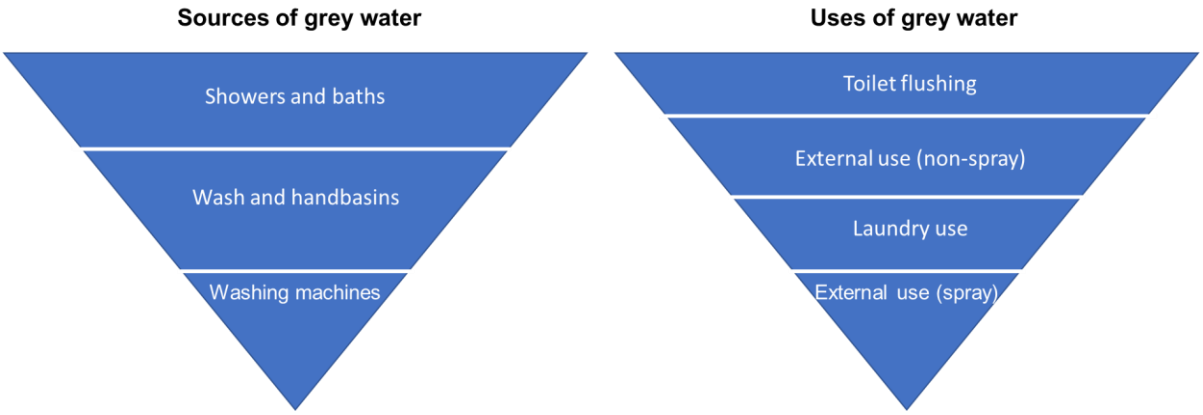
In the UK, GWR systems need to comply with BS 8525 (BS 8525 -1:2010 - Grey water systems – Part 1: Code of practice and BS 8525-2:2011 - Grey water systems – Part 2: Domestic grey water treatment equipment – Requirements and test methods) which groups GWR systems according to the type of filtration or treatment they use, as shown in Table A2.3.

Most GWR systems have common features such as:

- a tank for storing the treated water;
- a pump;
- water treatment; and
- a distribution system for transporting the treated water to where it is needed.

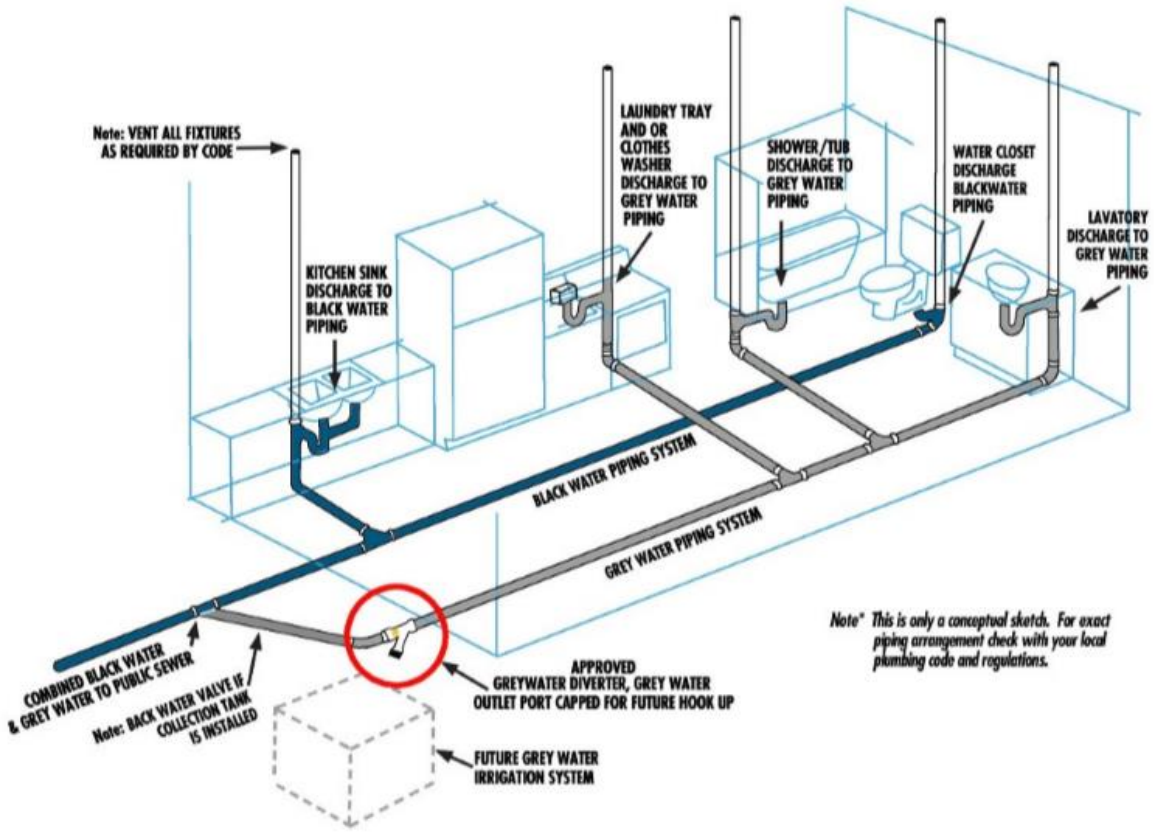
In order to prevent the collection and treatment of water that cannot be used, the Grey Water Systems Code of Practice (described more fully in Section A2.9) recommends that demand should drive the specification of the GWR system. Furthermore, so that the GWR system can offer the best quality treated water for non‑potable uses without having the additional burden of treating the most heavily contaminated grey water, the Code of Practice recommends a hierarchy of sources and uses of grey water, as shown in Figure A2.3.

Figure A2.3 – Hierarchy of sources and uses of grey water



As shown in Figure A2.4, depending on the how many applications the GWR system supplies and how integrated it is there will be the need for dual plumbing of the drainage system to some extent in order to capture the water from showers, baths, sinks and washing machines. However, there are a variety of systems on the market and smaller units designed for domestic use may not involve such extensive dual plumbing. Some GWR systems for example can be fitted behind a unit in a bathroom so that grey water from the bath and shower supply the toilet in the same room. Larger commercial applications will naturally have a greater level of complexity.

Figure A2.4 Dual plumbing for capture of grey water for reuse (Source: Thames Water 2017)



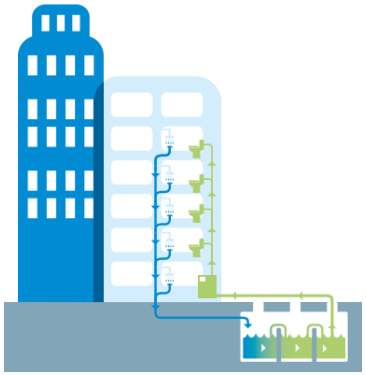

As well as the description of the main types of GWR systems according to the type of filtration or treatment they use (as defined by BS 8525:2010), Table A2.3 also presents some examples in use today.

Table A2.3 Types of GWR systems (as described in BS 8525-1:2010 - Grey water systems – Part 1: Code of practice)

| Type | Description | Notes and examples | |
|---|---|---|---|
| Direct reuse systems (no treatment) | These systems use simple devices to collect grey water from appliances and deliver it directly to the points of use, with no treatment and minimal, or no, storage, e.g. a grey water diverter valve.<br><br>NOTE 1 It is possible to reuse grey water without any treatment, provided that extended storage is not required. As untreated grey water quality deteriorates rapidly, the collected grey water ideally needs to be reused as soon as it has cooled.<br><br>NOTE 2 Where no treatment is included in the grey water system, applications are restricted to sub-surface irrigation and non-spray applications | Examples of direct reuse systems include diverter valves, and siphon pumps, which divert grey water from baths and showers to a water butt where, once cooled, it can be used for garden watering. Direct reuse systems are simple, inexpensive devices; hence cost is not a major barrier to uptake. They are more suited to households than commercial or industrial applications.<br><br>WaterGreen Syphon Pump is simply a 3.5m tube with a built in syphon primer bulb and a standard hosepipe fitting on the end. You just put one end in the bath and the other connected to a hosepipe, through your bathroom window. The water can then be syphoned off for use in gardens. | <br>Source: The WaterGreen (Droughbuster) Syphon Pump<br><br> <br>Source: Water Two Grey water Diverter |
| Short retention systems | These systems apply a very basic filtration or treatment technique, such as skimming debris off the surface of the collected grey water and allowing particles to settle to the bottom of the tank. They aim to avoid odour and water quality issues by ensuring that the treated grey water is not stored for an extended period. | These systems can be small and fairly cost effective. However, examples of this type of system are limited since a number of models have been removed from the market over the last decade. The Ecoplay (which is no longer in production) is a self-contained unit which collects bath and/or shower wastewater to supply toilet flushing. It has been used for both new build installations and retrofit. It collects the grey water in a cleaning tank. A skimmer removes light surface debris such as foam, hairs and soap, while heavier waste particles sink and are flushed away to waste. Recycled water is then transferred to the storage tank. The unit retains enough water for approximately 20 flushes. | <br>Source: Ecoplay, CME. |

| Type | Description | Notes and examples | |
|---|---|---|---|
| Basic physical/chemical systems | These systems use a filter to remove debris from the collected grey water prior to storage while chemical disinfectants (e.g. chlorine or Bromine) are generally used to stop bacterial growth during storage. | Whilst this type of system is available for purchase as an 'off the shelf' packaged product, it is not 'fit and forget' technology, requiring regular maintenance to ensure that the system remains efficient.<br>The Aquaco Aquawiser Domestic Direct Grey Water System[28] collects, filters, disinfects and stores grey water collected from showers, baths and hand basins for supplying water to flush WCs. | <br>Source: Aquaco water recycling Ltd. |
| Biological systems | These systems use aerobic or anaerobic bacteria to digest any unwanted organic material in the collected grey water. In the case of aerobic treatment, pumps or aquatic plants can be used to aerate the water. | Biological systems vary in their complexity and form. Different systems supply oxygen in different ways; some use pumps to bubble air through the water in storage tanks while others use plants, such as reed beds to aerate the water. Those that involve the use of reed beds add oxygen and allow naturally occurring bacteria to remove organic matter. However, they require some expertise to create and/or maintain and availability of a suitable, relatively large outside area. More recently integrated technologies (e.g. green roofs and green walls) have been explored as part of GWR treatment.<br>The Green Roof Water Recycling System (GROW)[29] developed by Water Works UK (WWUK) is essentially a tiered garden of native plants, whose roots can perform the same cleansing function as a reed bed. Grey water is treated as it flows through the plants' root system. The treated water is safe to use for toilet flushing, cleansing public areas, and watering the garden. | <br>Source: Water Works UK Ltd. |

[28] https://www.aquaco.co.uk/datasheets/
[29] http://www.wwuk.co.uk/grow.htm

| Type | Description | Notes and examples | |
|---|---|---|---|
| Bio-mechanical systems | These systems, the most advanced for domestic grey water reuse, combine biological and physical treatment, e.g. removing organic matter by microbial cultures and solid material by settlement. They encourage bacterial activity by bubbling oxygen through the collected grey water | Membrane filtration is often used to treat the water to a high standard, allowing for longer storage periods and greater flexibility in terms of use. There are a number of suppliers of bio-mechanical systems in the UK. These systems are capable, and best suited to deal with multi-residential, commercial and institutional sites e.g. hotels, student accommodation or high rise structures with living accommodation.<br>An example is the SDS GWOD[30] which operates on a fast treatment principle to meet demand quickly and reduce the need for large water storage tanks. It uses a hollow fibre ultrafiltration membrane incorporating an automatic backwash process. |  <br>Source: SDS Ltd. |
| Hybrid systems | These systems use a mix of the system types detailed above.<br>NOTE 3 Grey water systems can also be integrated with rainwater harvesting systems. | Combined rain and grey water systems are possible but the added efficiency from the rainwater depends on the building use.<br>The Aquality[31] system works by grey water passing through a coarse filter (1) to remove large dirt particles, it then enters an aerobic treatment buffer tank (2) where it is aerated (3). Finally, the water passes through the Bio-Membrane Technology (BMT) membrane (4) and into a clear water storage tank (5). The water is then pumped via the Aqua Control booster pump (7) set to the serviced appliances. Treated water can be stored for relatively long periods and the system can be combined with rainwater harvesting systems. | <br>Source: Aquality |

[30] https://www.sdslimited.com/products/sds-greywater-recycling/
[31] https://www.aqua-lity.co.uk/greywater-recycling

### A2.5.2 Modern GWR designs and technologies

Development in GWR systems over the last decade has been mixed depending on the type of system. Design and technologies of the basic (e.g. direct reuse) systems have changed little. Some examples of short retention systems have had technical issues (e.g. not meeting water quality standards or having maintenance issues) and have been removed from the market (Thames Water 2017). Similarly the basic physical/chemical systems may not achieve BS 8525 standards and although capable of treating water quickly have been reported as being unreliable (Thames Water 2017). In terms of biological systems, the group is broad and includes rotating biological contactors (RBC), upflow anaerobic sludge blankets (UASB) and sequencing batch reactors (SBR) (Toifl et al, 2019). Each of these biological treatment processes has the proven ability to adequately treat grey water and reduce nutrients and organic compounds. However, microorganisms are not necessarily removed and so they all require a disinfection step to make the recycled water safe for reuse (Toifl et al, 2019). These GWR systems combined with UV disinfection have a history of development as GWR became more common in Germany. However, there are reported issues and the process relies heavily on the biology operating effectively at all times and any disturbance of the biology can have an impact on the water quality and operation of the system (Thames Water 2017). The most significant developments relate to the bio-mechanical systems and hybrid systems and the use of membrane-based technology. In addition to these trends in GWR system design and technologies there have also been advances in the way GWR systems connect and interact with the buildings they are servicing, as well as other connected systems, to form complete building solutions for water recycling (Joustra and Yeh, 2016).

#### A2.5.2.1 Bio-mechanical systems and hybrid systems

Membrane processes have the advantage of consistently producing high water quality, as they are a physical barrier to a wide range of pollutants including microorganisms, but require a small footprint for their implementation. For these reasons, membrane processes have significant potential to be used for GWR applications (Pidou, 2016). MBRs combine a biological treatment stage including activated sludge and separation of the biomass from the treated effluent with membranes which either employ microfiltration or ultrafiltration. In the specific case of the MBR, the biofilm that forms on the surface of the membrane, as a result of the contact with the biomass, increases the selectivity of the membrane and improved rejection of solutes smaller than the pore size of the membrane (Pidou, 2016). Over the last decade with further demand, especially for membranes due to MBR technology becoming the dominating treatment process, membrane suppliers started to develop bespoke membranes for grey water treatment. This allowed the treatment efficiency to increase and therefore a reduction in price per $m^3$ treatment capacity (Thames Water, 2017).

The market is relatively young and new concepts constantly evolve to treat grey water more effectively or to higher standards (Thames Water, 2017). There are new membrane systems developed offering further treatment efficiencies, space and operational cost reductions. For example one manufacturer reports that their MBR system[32] is a "*significant leap forward*" in design developed on the back of a decade of using the traditional MBR systems imported from Germany. However, there are also modern GWR systems that do not employ the membrane technology. One manufacturer has recently put to market a GWR system that is stated to be "*fit and forget*" that removes dirt, soap and other pollution without using a filter, membrane or chemicals. The treatment system combines five technologies; sedimentation, flotation, dissolved air flotation, foam fractionation and an aerobic bioreactor with disinfection using UV light as the final treatment step.

#### A2.5.2.2 Nature Based Solutions

In many countries around the world grey water is commonly treated by natural systems in areas without a public sewer system and available land space (Olanrewaju and Ilemobade, 2015). This philosophy is applied in the use of constructed wetlands which employ an artificial wetland constructed utilizing ecological technology to mimic conditions that occur in a natural wetland. The technology adopts special flora and fauna, soil and microorganisms to remove pollutants of interest (Oteng-Peprah et al, 2018). These would come under the biological systems category in Table A2.3 above. Green walls and green

[32] https://www.aquaco.co.uk/grey-water-recycling/mbr-system/

roofs are becoming integrated parts of modern buildings providing a range of benefits (e.g. aesthetics, insulation and urban greening) and have recently been proposed for grey water treatment systems. These and constructed wetlands have been grouped under the term Nature Based Solutions (NbS) (Boano et al, 2020). NbS are described as actions that work with and enhance nature to help address societal challenges. The concept is grounded in the knowledge that healthy natural and managed ecosystems produce a diverse range of services on which human wellbeing depends. NbS is an 'umbrella concept' for other established nature-based approaches which includes Green Infrastructure (Boano et al, 2020).

### A2.5.3 Integrated GWR and RWH systems

The BS 8525-1:2010 - Grey water systems – Part 1 highlights that where a GWR system or RWH system alone cannot provide sufficient water for non-potable use, the integration of two systems can offer a viable solution (BSI, 2010). It highlights important points that need to be addressed before integrating the two systems including:

- A thorough assessment should be made of each system individually to determine whether it alone can meet the demand of the intended applications.
- The benefits of providing additional storage for stormwater control such as Sustainable Drainage Systems (SuDS) are recognised in BS 8515 and, therefore, consideration should be given to the potential effects of an integrated approach.
- The integrated systems can either be operated as separate, independent systems or be combined into a single supply source.
- Where systems from different manufacturers are to be combined into a single supply, the compatibility of the systems should be investigated and taken into account.
- All elements of the system situated downstream of the point of integration should conform to BS 8525.
- Where grey water (treated or untreated) and rainwater are integrated in storage tanks/cisterns, all overflows or bypass arrangements should discharge into the foul sewer as only surface water is permitted to be discharged into water courses.
- Local wastewater companies should be consulted regarding these overflow and bypass connections to foul or surface water drains.

Integrated GWR and RWH systems can bring notable benefits when planned strategically for larger scale especially mixed use developments. However, at the individual building level, the benefits of an integrated GWR and RWH need to be considered as the added efficiency from the rainwater depends on the building use. Clearly integrating GWR and RWH systems increases the complexity considerably and will often involve bespoke design and require dedicated specialist support regarding its maintenance. Indeed, installation and maintenance of rainwater harvesting and GWR often fall under the classification of 'specialist equipment' as it is important that those that undertake the installation of such systems are fully aware and conversant with current water industry legislation and guidance.

## A2.6 Application of GWR systems

### A2.6.1 Retrofit

Retrofitting a GWR system has typically been more costly than incorporating a system into new construction. This is especially true at a commercial level, since existing buildings might not already separate grey water from the blackwater of toilets and urinals. Having to retroactively separate grey water requires additional plumbing. Therefore, retrofit options for GWR systems are predominantly limited to the smaller scale, individual, domestic sites. Retrofitting is an important issue given that most housing stock already exists it is estimated that approximately 80% of the homes that will be standing in 2050 have already been built (Policy Connect, 2018).

Policy Connect (2018) suggests rebate schemes for retrofitted GWR systems could be trialled in city regions learning from rainwater and grey water harvesting rebate schemes currently being trialled in several cities in Canada, in Tucson USA and in Joondalup, Western Australia. Grants to retrofit communities with GWR and RWH could be funded by matched contributions from water customers and

water companies, who are the beneficiaries of the reduced water usage of these systems. The value for money to the taxpayer of such schemes needs to be carefully evaluated. No further information could be obtained regarding the how successful the grants were in driving uptake.

Through stakeholder engagement, Greater London Authority (GLA) noted they have grappled with elaborate retrofit schemes e.g. *where water companies fund large scale retrofit schemes regarding the water efficiency benefit, but it is quite complicated and significant water company buy in is required*[33]. Dialogue with the GLA also identified a potential approach for GWR retrofitting programmes in line with work currently being undertaken as part of the London SuDS Action Plan[34]. The main focus of the action plan is on the retrofitting of sustainable drainage to existing buildings, land and infrastructure. It is recognised that funding pressures mean there will not be funds specifically for a large-scale drainage improvement programme. Instead the key is to identify when and where other planned maintenance, repair or improvement works are scheduled and then to identify opportunities to retrofit sustainable drainage as part of those works. This way sustainable drainage can be introduced at a much lower cost.

### A2.6.2 New build residential installations

Generally speaking increasing water efficiency in new build homes is easier and cheaper than retrofit (Policy Connect, 2018). New build residential installations allow the necessary design and plumbing to be incorporated to allow for a wider range of GWR approaches. Alternatively architects, designers, builders, and developers can plan future proof buildings so that they are grey water-ready. Where GWR is considered strategically involving planners, developers and water companies, significant benefits can be achieved and infrastructure costs avoided. This is exemplified by Integrated Water Management (IWM) Strategies, which are non-statutory planning-level framework to assist a local planning authority (LPA)/GLA in setting requirements for delivering sustainable water and flood risk infrastructure in an integrated way. GWR is included in IWM Strategies as a form of alternative water supply measures. The IWM inform masterplanning and identify opportunities to manage combined water problems. They are focussed on GLA Opportunity Areas and are co funded by GLA, Thames Water and London Boroughs. The GLA are currently working with Thames Water on an IWM Strategy for the Isle of Dogs where more holistic water management options are being investigated including how to ensure that new developments are as water efficient as possible (beyond that derived from a standard fixtures and fittings approach)[35].

### A2.6.3 Commercial installations

As a consequence of the issues described above (a move away from small scale domestic installations and retrofits) and the barriers identified in Section A.2.7 over the last decade (2010-2020) there has been greater emphasis on larger scale projects at the development phase (e.g. community projects, commercial installations and multi-purpose developments) where the return on investment is often more favourable. This was also suggested through the stakeholder engagement exercise undertaken as part of this study, dialogue with manufacturers suggests GWR systems are best suited to large commercial market (such as hotels, supermarkets, and multipurpose developments for example) due to the nature of their water use supply versus demand equilibrium. The business case for the large commercial market is may be lot stronger in terms of environmental and cost savings. It is noted that some companies focus exclusively on large commercial and new build developments and considered retrofitting of systems not to be commercially viable.

### A2.6.4 Maintenance

Maintenance requirements vary depending on the system type and complexity. Some of the very simple systems are effectively maintenance free, while, systems that have been developed for multifunctional sites may require maintenance regimes undertaken by the supplier. Maintenance procedures should be undertaken in accordance with the manufacturer's maintenance recommendations. The BS 8525-

[33] Pers comm GLA
[34] https://www.london.gov.uk/what-we-do/environment/climate-change/surface-water/london-sustainable-drainage-action-plan
[35] Pers comm GLA

1:2010 Grey water systems – Part 1: Code of Practice provides a maintenance schedule for use in the absence of any manufacturer's recommendations, this has been provided in Table A2.4 below.

Table A2.4 – BS 8525-1:2010 Maintenance schedule (Source: (BS 8525-1:2010)

| System component | Operation | Notes | Frequency[A] |
|---|---|---|---|
| Filters, membranes, biological support media and strainers | Inspection/ Maintenance | Check the condition of the filter(s) etc. and clean or replace, if necessary | Annually |
| Biocide, disinfectant or other consumable chemical | Inspection/ Maintenance | Check that any dispensing unit is operating appropriately; replenish the chemical supply if needed | Monthly |
| UV lamps (where fitted | Inspection/ Maintenance | UV lamps (where fitted | Every 6 months |
| Storage tank/cisterns | Inspection (Maintenance) | Check that there are no leaks, that there has been no build-up of debris and that all tanks and cisterns are stable and the covers are correctly fitted.<br>(Drain down and clean the tanks and cisterns) | Annually<br>(every 10 years) |
| Pumps and pump controls | Inspection/ Maintenance | Check that there are no leaks and that there has been no corrosion; carry out a test run; check the gas charge within any expansion vessels or shock arrestors | Annually |
| Back-up water supply | Inspection | Check that the back-up water supply is functioning correctly and that the air gaps are maintained | Annually |
| Control unit | Inspection/ Maintenance | Check that the unit is operating appropriately, including the alarm functions where applicable | Annually |
| Water level gauge (if fitted) | Inspection | Check that any gauge indication responds correctly to the water level in the supply tank or cistern | Annually |
| Wiring | Inspection | Visually check that the wiring is electrically safe | Annually |
| Pipework | Inspection | Check that there are: no leaks, the pipes are watertight and any overflows are clear. This includes the collected and treated grey water supplies, any backwash supply and the back-up water supply. | Annually |
| Markings | Inspection | Check that warning notices and pipework and valve identification are correct, visible and in place | Annually |
| Supports and fixings | Inspection/ Maintenance | Adjust and tighten, where applicable | Annually |
| Backwash | Inspection/ Maintenance | Check functionality | Annually |

*Notes:* A: Frequencies are recommended if no information is given by the manufacturer

#### A2.6.4.1 Domestic

In general a few simple frequent checks may be all that is required to ensure a modern domestic GWR system functions at its optimum, and as the manufacturer intended. It is critical that users are made aware of this and that it is in their interests to follow the maintenance requirements as specified by the manufacturer. If they fail to do this, it could lead to either system failure or expose them to increased levels of contamination in the water they hope to reuse. It is therefore critical these factors are considered during the design stage when selecting the most suitable alternative water system. However, as identified in A2.5, as technology develops more modern designs are becoming simpler

and more user friendly. BS 8525-1:2010 states that '*upon handover of the grey water system, the user should be provided with sufficient information to enable them to operate and maintain the system satisfactorily. The user should be advised of any procedures or precautions which need to be followed, e.g. in the form of an operation and maintenance manual or a list of "Dos and Don'ts* '". BS 8525-1:2010 also provides a list of what this should cover to enable the reliable operation of the grey water system.

#### *A2.6.4.2* Commercial

A combined design, installations and maintenance service is often provided for by the manufacturers of such systems. For example one manufacturer highlights that their specialist teams often install and maintain their designed systems which include an integrated non-potable water management strategy utilising rainwater harvesting, GWR, and SuDS. As identified below, maintenance requirements and the lack of ownership or prevalence of business models for maintenance to date has been a recognised challenge to the uptake of GWR systems in the UK.

## A2.7 Barriers and challenges to the technology

While the GWR equipment sector has become established, the technology has not become mainstream in new developments in the UK. A project undertaken for Defra and Water UK Policy Consulting Network Ltd in 2016 looked to identify the barriers to the take up of GWR and RWH systems in new properties in the UK. This was in response to the perception that conflicting requirements in standards and codes presented a barrier and that British Standards prevented some white goods in the UK from using alternative sources of water (i.e. rainwater or grey water), whilst the same products were approved for such use in Germany. The project reviewed the appropriate standards and codes in the UK and the author spoke with people engaged in water re-use and water efficiency in the UK and with a white goods manufacturer in the UK and Germany.

The report identified no conflict within UK standards or codes that presented barriers to take up of GWR systems. However, there was no positive encouragement or incentive to specify or install GWR systems in new properties. Furthermore, the UK Building Regulations, whilst encouraging water efficiency actually provide a disincentive to proposing GWR systems through the additional and complex water efficiency calculation. The water efficiency calculation methodology as set out in Appendix A of Approved Document G is to be used to assess compliance against the water performance targets in Regulation 36 (the requirement for all new dwellings to achieve a water efficiency standard of 125 litres use of wholesome water per person per day). Such a calculation is not required when GWR systems are not proposed (Mills, 2016). The barriers and challenges (not associated with standards or regulations) identified by the work undertaken by Policy Consulting Network Ltd were identified as:

- A lack of understanding of GWR systems and the uncertainty that generates.
- Ensuring that systems are safe to use, now and in the future.
- Other system issues around reliability, pump failures and maintenance.
- New homebuyers not requesting such systems.
- House builders and HBF not therefore seeing any benefit in providing such systems.
- The scarcity of figures on benefits - i.e. costs saved and payback period.
- The need for education and awareness raising with consultants, designers, installers and developers.
- The requirement for a cultural shift amongst the public.
- The lower cost of water in the UK compared to some other countries where there is a much higher take-up of water re-use.

Other barriers and challenges to the technology reported in the literature include the need for education and awareness raising with consultants, designers, installers and developers (Water Efficiency Network, 2016). Education and information is an issue in that cross connections of GWR with other systems still happen. Installers, consultants and designers need to know what should be there, and what should not, when installing systems. Associated with lack of education of these systems and perceived lack of robustness of GWR systems is the fear in terms of treatment of water and resulting quality. It was identified that when making the decision to install GWR, RWH or SuDS into and around domestic properties, and during their construction, there needs to be information made available on

their benefits and payback (Water Efficiency Network, 2016). Barriers to uptake of GWR also relate to the need to adapt infrastructure in the home, and social issues such as the fear of being perceived negatively by others ((Bryan et al. 2019; and Waterwise 2019).

The series of stakeholder interviews undertaken as part of this study included discussion around the barriers and challenges to the technology, which has been summarised as follows:

- Capital cost:
  - The low unit price (£/$m^3$) of water in the UK and relatively high capital cost of installation lead to long payback periods particularly on small scale installations and retrofits thus investments are often not considered financially viable.
  - Developers are not willing to invest as the capital expenditure of installing the system (CAPEX) is not reflected in the selling price of the properties.
  - Information on installation costs, potential savings and hence payback was not available and/or not considered robust.
- Absence of specific policy and regulatory drivers. In particular the withdrawal of the Code for Sustainable Homes in 2015.
- Lack of customer demand / interest in contrast to other measures that reduce $CO_2$ emissions such as solar panels[1].
- The actual performance of existing systems is poorly understood and the wider benefits are often not clear. There is currently a lack of monitoring of existing systems and general information and guidance.
- The technologies are not feasible in all applications and are dependent on the amount of grey water that can be collected (yield) and demand within the building.
- Disruption during installation and location of tank. In particular, when considering the retrofit of systems in existing buildings.
- Requirement for the system to be maintained including:
  - The cost of maintenance.
  - Lack of ownership/business models for maintenance (developers tend to want to sell and move on rather than be saddled with legacy associated with ownership and maintenance requirements)[1,8,13]
  - Lack of skills, expertise and knowledge base.
  - User behaviour e.g. switching to mains supply when there is an issue or fault.
- Public perceptions around water quality.
- Liability issues for developers.
- Issues for developers concerning long-term mortgageability of properties.
- Additional risk to developers associated with the required pipework especially in large developments where there is already significant pipework connecting to energy centres for example.
- For large scale developments, decisions regarding GWR are made very early in the process, there is the need for some culture change to raise awareness so that GWR is considered early enough.

## A2.8 Costs and performance

### A2.8.1 How much water can be saved?

#### A2.8.1.1 Domestic

As highlighted in Section A2.4 assuming there is sufficient grey water to meet the demand, a household could typically save between 25% and 50% mains water use. This could represent between 86l/h/d and 172l/h/d (based on an average household consumption of 342l/h/d. This would result in a saving of

between ~£50 and ~£100 per year (based on the average water company charges[36]). In addition, GWR systems also reduce the volume of water discharged into the sewerage system. Therefore based on the above consumers could save between ~£50 and ~£100[37] each year on the wastewater element of their bills. It should be noted that these values are based on average household consumption values, greater savings will be achieved where consumption is higher for example in larger houses with more occupants.

#### A2.8.1.2 Commercial

There is limited reported information in the academic literature regarding the savings that can be achieved from commercial GWR systems. Information presented on manufacturers' websites report modern GWR systems that provide between 30% and 50% of water requirements of typical office or warehouse buildings. Through the stakeholder engagement exercise undertaken for this study information obtained for existing commercial GWR systems included examples providing more than 50% of water requirements including: offices (75-86%); apartment/hotels (51%) and; houses of worship (97%). The volumes of grey water used in these commercial settings generally range between 3,000 and 17,000m$^3$ /year with annual cost savings between ~£10k and ~£40k.

### A2.8.2 Capital and operational costs

#### A2.8.2.1 Domestic

Referring back to the broad types of GWR systems described in Table A2.3, the very basic direct reuse systems which include simple devices to collect grey water from appliances and deliver it directly to the points of use, with no treatment a grey water diverter valve can cost as little as £20. Obviously, in this case if large volumes of this grey water are used to gardens in place of mains water relatively substantial savings can be achieved with very little capital investment. However, in terms of GWR systems that operate continuously, automatically and provide supply that is of use throughout the year, capital costs are reported to range between £900 and £3000.

The EU-funded project Aqua Gratis has delivered a simple and inexpensive solution that promises a 30% reduction in domestic water consumption. The Aqua Gratis system fits behind the toilet, collects wastewater from the shower or bath, filters and processes the wastewater and re-uses the water to flush up to 4 toilets in the house. The price is relatively low (£900) which may be even lower with increases in production volume benefitting from the simplicity of design and easy manufacturability. A Domestic Direct Grey Water System described in Table A2.3 currently priced at £2,250. A recent system described as a 'Fit & forget' turnkey product with a stylish design and innovative technology with easy installation and small footprint is priced at ~£3,000. These prices don't include preparatory work or ongoing operation and maintenance costs.

The payback period (a static measure of investment that allows selecting a project on the basis of how long it will take to recover the initial investment through cashflows) is often used as a measure to compare and express financial feasibility of GWR systems. Historically the payback period of domestic GWR systems has been relatively long (11 to 20+ years) and potentially longer than the operational life of the system ((Olanrewaju and Ilemobade, 2015; Oviedo-Ocaña et al 2018; Environment Agency, 2011). The more modern designs with improved efficiency, operation and maintenance regimes report payback periods as short as 4 years. Noting the influence the payback period has on how attractive of feasible installing a GWR system is suggests potential regarding policy options that help reduce the payback period to the point where the system becomes attractive.

#### A2.8.2.2 Commercial

The capital and operational costs of commercial GWR systems can be significant, however, these systems are considered to present high system efficiency. Again, there is limited information reported in the academic literature. Information established through stakeholder engagement as part of this study for existing commercial GWR systems identifies that capital costs generally range between ~£40k and ~£150k and operational costs ranging between ~£1k/year and ~£7k/year. Payback periods of 3-5 years

[36] Based on average charge of 1.5/m$^3$
[37] Based on average charge of 0.78/m$^3$

are being reported by some manufacturers. Historically payback periods were reported to be longer (e.g. 14 years (Olanrewaju and Ilemobade, 2015).

### A2.8.3 Carbon and energy impacts

As already discussed there are many different types of grey water systems available, their energy requirements and carbon emissions will vary depending on system type, installation arrangements and level of the demand. The carbon emissions of a grey water system can be divided into those resulting from manufacture, transportation and installation of system components (embodied emissions) and those resulting from use of the system itself (operational emissions).

The Environment Agency (2011) report 'Grey water for domestic users: an information guide, 2011' and other past research (Memnon et al, 2016) identified that, apart from short retention systems, more carbon is generally emitted when using a GWR system to treat and supply a litre of grey water than a litre of mains water. In operation, the extent of the energy use and carbon emissions resulting from on-site grey water treatment and reuse is determined mainly by the volume of effluent treated and the degree of required pumping (total head that the booster pump has to overcome) (Memnon et al, 2016).More recent research regarding energy requirements and carbon emissions associated with GWR systems is limited. However, there are some reports that suggest because low carbon grey water recycling technology provides treatment and recycling close to the point of use of domestic water there is the potential for carbon efficiency and a lower energy demand from that derived from large-scale water treatment and wastewater treatment infrastructure (Hyde, et al 2018; Hyde, et al 2017; and Boano et al, 2020). Low carbon benefits to the environment that may not be widely appreciated include the overall reduction to the carbon footprint realised by locally re-treating water that was originally treated elsewhere, and reducing the volumes of wastewater returned to that same location for treatment and disposal (Hyde, 2017).

The type of GWR system is important to consider regarding carbon energy impacts. A study into the sustainability of shared GWR in urban mixed-use regeneration areas found that a shared constructed wetland treatment GWR system would result in a 11% saving of carbon emissions over a 15 year period (compared to conventional mains supply), whereas a shared MBR GWR system increased carbon emissions by up to 27% (Moslemi Zadeh, 2013). Obviously these are two extremes and to be expected considering the differences in technology. However, it is noted that operational energy related implications of both mains supply and GWR systems are likely to reduce with further technological innovations and wider uptake of renewable energy sources. Therefore compact systems that are effective and only require electricity (albeit a significant amount) to operate (rather than any treatment materials) may be viewed differently in the future.

### A2.8.4 Wider environmental benefits

GWR systems do have impacts on society and the environment in terms of sustainable water resource management. There are benefits regarding increased resilience with respect to climate change and future water scarcity identified in Section A2.1. Wider benefits also relate to the environmental and social benefits associated with reduced demand/pressure on freshwater water resources in the environment and the services they provide (e.g. habitat biodiversity, water regulation, water purification, recreation and aesthetic value). The reduction in demand and reduction in wastewater flows as a result of GWR can have benefits with respect to water supply and wastewater network capacity and the requirement for infrastructure improvements (Clarke, 2016) Alleviation on wastewater network capacity also has the potential to reduce the risk of the negative impacts of wastewater discharges to the aquatic environment (e.g. that associated with combined sewer overflows) (Clarke, 2016); can potentially reduce reduction of flooding in and around homes and as a result have health and wellbeing benefits for communities. Effective re-use of grey water can clearly have many benefits for the environment, reduce customer bills, increase wastewater infrastructure capacity and limit the need for larger hard engineering infrastructure with associated costs.

### A2.8.5 Existing services and incentives to encourage uptake of the technology

A number of water companies in England, particularly those operating in water stressed regions, have offered discounts on infrastructure connection charges for new developments that go beyond the 125 l/p/day water consumption target set out in the Buildings Regulations (see Table A2.5).

Table A2.5 – Examples of water company incentives offered on infrastructure connection charges

| Water company | Charges / property | Incentive / discount | Water efficiency target | Outcome / comments |
|---|---|---|---|---|
| Anglian Water | £740 per plot | 100% | 100l/p/day | The water efficiency incentive aimed to help reduce water use in new homes across the region. Where premises were built to a water efficiency standard of 100 litres per person per day, the fixed element of the zonal charge could be refunded. The water efficiency incentive was available in 2018-2019 and 2019-2020.. |
| Southern Water | £790 dual services | £565 | 110 l/p/day | Part of Southern Water's Target 100 programme[38]. |
| Severn Trent Water | £382 (clean water only) | 100% | 110 l/p/day | Further discount of £124 if no surface water connection is made to a public sewer, or £93 if the surface water connects to a public sewer via a sustainable drainage system (SuDS)[39]. |
| Essex and Suffolk Water (Northumbrian Water Limited) | Not specified | 100%[40] | 105 l/p/day | Take up has been low due to lack of developer awareness[41]. |

While these types of incentive are likely to have encouraged developers to consider GWR as potential option to reduce water consumption in new buildings anecdotal evidence suggests take up has been limited as the water efficiency targets can generally be met via the installation of water efficient fixtures and fittings. In addition, the level of incentive only offsets a small proportion of the additional capital costs associated with GWR systems, which also require maintenance throughout the lifespan of the asset. This was highlighted by other water companies where infrastructure charges are low. For example, Thames Water whose charges are around £350/dwelling suggest that "….*discounts offer little incentive to drive uptake of these technologies'*.

[38] https://www.southernwater.co.uk/media/2227/t100_acttoday.pdf
[39] https://www.stwater.co.uk/building-and-developing/regulations-and-forms/application-forms-and-guidance/infrastructure-charges/
[40] https://www.eswater.co.uk/globalassets/customer-pdfs/developer-pdfs/esw/infrastructure_charges_guidance_v1_october_2018_south.pdf
[41] Pers comm (Thomas Andrewartha)

# A2.9 Water quality

## A2.9.1 Water quality of grey water

There is substantial research regarding water quality of grey water and that of treated recycled grey water (Oteng-Peprah et al, 2018; Lavanya and Kannan, 2019). In general, the composition of grey water varies, and it is largely a reflection of the lifestyle and the type and choice of chemicals used for cleaning, bathing and laundry (if included as a source of grey water) (Oteng-Peprah et al, 2018; and Ifelebuegu et al, 2016). The composition may also be affected by the raw water supply characteristics, as well as chemical and biological degradations of some compounds within the grey water transportation and storage network. Generally, grey water contains high concentrations of easily biodegradable organic materials and some basic constituents which are largely generated from households (Oteng-Peprah et al, 2018; Rakesh,et al, 2020). These include nutrients such as nitrates and all its derivatives, phosphorus and its derivatives, but others include xenobiotic organic compounds (XOCs) and biological microbes such as faecal coliforms, salmonella and general hydrochemical constituents (Oteng-Peprah et al, 2018; and Toifl et al, 2019). Studies have also shown the presence of pharmaceuticals and heavy metals in grey water.

The main hazards of grey water, which mainly relate to human health risk and adverse effects to the environment, can be identified through a water quality analysis and are often grouped into three categories that need to be considered when assessing the risks (Toifl et al, 2019). These are:

- Physical – temperature, flow, suspended material, turbidity;
- Chemical – pH, metals, salts, nutrients, organic compounds and xenobiotics;
- Biological – biodegradability, bacteria, viruses and protozoa.

Table A2.6 presents typical physico-chemical properties of grey water from published reviews (as summarised in (Oteng-Peprah et al, 2018; and Boano et al, 2020).

Table A2.6 Physico-chemical features of domestic grey water and comparison to BS 8525-1:2010 guidelines (Source (Pidou, 2016, Boano et al, 2020, and Oteng-Peprah et al, 2018

| Parameter | Units | UK | Spray application guideline values | WC flushing/Garden watering |
|---|---|---|---|---|
| Ph | pH | 6.6–8.1 | 5-9.5 | 5-9.5 |
| Total Suspended Solids | TSS (mg/l) | 37–505 | (≤10)[A] | |
| Biological Oxygen Demand | $BOD_5$ (mg/l | 8.7–252 | (≤10)[A] | |
| Chemical Oxygen Demand | COD (mg/l) | 33–587 | | |
| Total Nitrogen | TN (mg/l) | 4.6–15.2 | | |
| Total Phosphorus | TP (mg/l) | 0.4–0.9 | | |
| Total Coliforms | TC (Most Probable Number (MPN)/100ml) | $10^2$– $10^7$ | 10 | 1000 |
| Faecal Coliforms | FC (MPN/ 100ml) | $10^2$-$10^5$ | (≤10)[A] | |
| *Escherichia coli* | E.coli (MPN/ 100ml) | 10 - 3.9 x$10^5$ | Not detected | 250 |

A: Values in Brackets are WHO guidelines.

Pollutants from grey water can produce adverse effect if it accidently comes in contact or ingested by people, for example during toilet flushing, spraying during gardening or eating a home-grown plant that was exposed to grey water (Friedler and Gross 2016; Ifelebuegu et al, 2016). No international water quality standards for grey water reuse exist, countries have individually set their own guidelines or standards. As the primary aim of the standards is to limit health risks to humans, some countries apply

different standards depending on the application and the proximity of the users to the reused grey water (Pidou, 2016). British standards are discussed further in Section A2.10 but are included in Table A2.4 above for the relevant parameters. Comparing the typical characteristics of grey water and the standards for reuse demonstrates the need for treatment (Pidou, 2016).

### A2.9.2 Water quality of recycled grey water

As identified in Section A2.5 GWR treatment systems have typically adopted either a physicochemical or biological means of treatment. Physicochemical methods adopt physical and/or chemical methods of treatment including filtration, adsorption and reverse osmosis, among others. Biological treatment methods adopt a combination of microbes, sunlight and oxygen manipulation (Oteng-Peprah et al, 2018). In general grey water treatment efficiency depends on operational conditions and on the grey water source and composition (Boano et al, 2020).

The treatment efficiencies of some selected grey water treatment systems are presented in Table A2.7. In terms of physical grey water treatments, filtration is the conventional technique to remove turbidity colloids and residual suspended solids (Boano et al, 2020). Among the chemical grey water treatment processes, the most adopted are coagulation and flocculation. Biological methods for grey water treatment are divided into aerobic and anaerobic ((RBC), upflow anaerobic sludge blankets (UASB) and sequencing batch reactors (SBR)). A disinfection step such as UV disinfection is often added to treatment processes to make the recycled water safe for reuse (Toifl et al, 2019). MBR works on a combination of biological, microfiltration and ultrafiltration systems to achieve treatment and can satisfy most standards for water reuse (Pidou, 2016).

Table A2.7 Treatment efficiencies of some selected grey water treatment system (Source: Oteng-Peprah et al, 2018; and Boano et al, 2020)

| Parameter | Units | Physical (filtration) | Chemical (coagulation and flocculation) | Biological (RBC) | Biological (SBR) | NBS | MBR |
|---|---|---|---|---|---|---|---|
| Total Suspended Solids | TSS (mg/l) | 53-93% | | 9-12% | | 64-98% | Up to 100% |
| Biological Oxygen Demand | BOD5 (mg/l | 89-98% | 85-89% | 27-53% | 80-98% | 63-98% | 93-97% |
| Chemical Oxygen Demand | COD (mg/l) | 37-94% | 64% | 21-61% | 80-98% | | 86-99% |
| Total Nitrogen | TN (mg/l) | 5-98% | 13% | | | 44-59% | 6-72% |
| Total Phosphorus | TP (mg/l) | Up to 100% | | | | 24-63% | Up to19% |
| Total Coliforms | TC (MPN/100ml) | | | | | 1-2 log removal | |
| Faecal Coliforms | FC (MPN)/ 100ml) | | | 88.5 – 99.9% | | 1-2 log removal | Up to 99% |
| *Escherichia coli* | E.coli (MPN/ 100ml) | Up to 100% | >99% | 88.5 – 99.9% | | 1-2 log removal | |

The choice of technology for GWR will primarily be driven by the water quality to be achieved for the reuse application. Subsequent consideration for the selection of a particular technology is a function of

several factors including influent quality, capital and operational cost, available space and its ability to cope with variations in the influent quantity and quality (Pidou, 2016).

As risk to human health are related to different end points or end-uses, considering the main focus of this review, water quality and implications regarding risk to human health are considered in the context of using recycled grey water for toilet flushing, toilet flushing, irrigation/outside water use and laundry.

### A2.9.3 Contamination

Sound design, and careful construction and maintenance are required in order to ensure the use of the treated grey water does not pose any residual risks. These include the risks to users of mains water arising from potential cross-contamination of mains systems through misconnection or other errors. risks to users of grey water from contamination that could arise from the grey water itself, which might occur if the grey water were not treated or stored appropriately prior to use.

Contamination can occur as a result of backpressure or back siphonage, both of which can cause contaminants to be drawn back up pipework into the water supply. Reused water, including that which has been treated, is considered to be fluid category 5 (the most dangerous of pollutants posing a serious health hazard) and must not under any circumstances be allowed to come into contact with the wholesome domestic drinking water supplies.

## A2.10 Regulation and guidance

As described in Section A2.3 until relatively recently GWR was very uncommon. As GWR became more popular a framework of policy and regulation that governs installation and use of grey water / water reuse developed. The primary aim of the policy and regulation is to limit health risks to humans. Codes of practice, standards and testing protocols have been defined to protect the public and to ensure that reliable non-potable water systems are designed, installed and maintained (Pidou, 2016). The regulations cover the following main areas:

- Water consumption and water efficiency in buildings (Building Regulations)
- Product standards to ensure systems are fit for purpose and define the water quality requirements to ensure public health ensuring public health (British Standards)
- Water quality and the design, installation, operation and maintenance of plumbing systems, water fittings and water-using appliances (Water Supply (Water Fittings) Regulations)

A review of water reuse (not just GWR) standards was undertaken by Mills (2016) who identified the relevant British Standards, other relevant codes and guidance applicable to the UK as follows:

- BS 8515:2009 + A1:2013 Rainwater harvesting systems - Code of Practice.
- BS 8525-1:2010 Grey water systems – Part 1: Code of Practice.
- BS 8525-2:2011 Grey water systems – Part 2: Domestic grey water treatment equipment. Requirements & test methods.
- BS 8595:2013 Code of practice for the selection of water re-use systems.
- Building Regulations 2010 (amended 2015) – Sanitation, hot water safety and water efficiency. Approved Document G - Part G1 – Cold water supply and Part G2 – Water efficiency.
- Water Supply (Water Quality) Regulations 2001.
- Water Supply (Water Fittings) Regulations 1999.
- Private Water Supplies Regulations 2009.
- Alternative Water Systems Information Leaflet and Guide. WRAS.
- Water re-use systems, guidance and advice. Water UK.
- Reclaimed water. CIBSE Knowledge Series 2005.

In the main, the regulations and guidance have not changed over the last decade to that described by (Mills, 2016) above. There have been updates to the Buildings Regulations and WRAS guidance which are discussed below. There are also regulations and guidance relevant to the use of grey water for irrigation of either crops or green infrastructure.

### A2.10.1 Buildings Regulations 2010 (amended 2015)

The Building Regulations is a statutory instrument that seeks to ensure that the policies set out in the relevant legislation are carried out. They cover the construction and extension of buildings and are supported by Approved Documents which set out detailed practical guidance on compliance with the regulations. In England and Wales, Approved Document G (Part G: Sanitation, hot water safety and water efficiency) sets out a minimum standard for water consumption in new dwellings of 125 l/p/day with an optional target of 110 l/p/day where specified. Approved Document H (Part H: Drainage and waste disposal) also covers rainwater and grey water tanks and stormwater drainage.

The Building Regulations define 'wholesome water' as: "*Water supplied to the building by a statutory water undertaker or a licensed water supplier through an installation complying with the requirements of the Water Supply (Water Fittings) Regulations 1999 (SI 1999/1148 as amended) may be assumed to be wholesome water".* It also states that *"Water treated to the high standards of wholesome water is not essential for all of the uses that water is put to in and about buildings, e.g. toilet flushing, irrigation".* It includes under 'alternative sources of water' both harvested rainwater and reclaimed grey water, together with water from wells and boreholes.

With respect to alternative sources of water' the Building Regulations state: "*Water from alternative sources may be used in dwellings for sanitary conveniences, washing machines and irrigation, provided the appropriate risk assessment has been carried out. A risk assessment should ensure that the supply is appropriate to the situation in respect of the source of the water and the treatment of it, and not likely to cause waste, misuse, undue consumption or contamination of wholesome water"*. And that "*Any system/unit used to supply dwellings with water from alternative sources should be subject to a risk assessment by the system designer and manufacturer, and appropriate testing carried out to demonstrate that any risks have been suitably addressed. A risk assessment should include consideration of the effect on water quality of system failure and failure to carry out necessary maintenance".*

Approved Document G - Part G1 – Cold water supply signposts relevant information and guidance documentation which includes:

- *Guidance on the marking of pipework conveying water from alternative sources can be found in the WRAS Information & Guidance Note No. 9-02-05, Marking and identification of pipework for reclaimed (grey water) systems*.
- *Guidance on installing, modifying and maintaining reclaimed water systems can be found in the WRAS Information and Guidance Note No. 9-02-04 Reclaimed water systems and in BS 8515:2009 Rainwater harvesting systems. Code of practice.*
- *Information on the technical and economic feasibility of rainwater and grey water can found in MTP (2007) Rainwater and grey water: technical and economic feasibility*
- *Information on the specification of rainwater and grey water systems can be found in MTP (2007) Rainwater and grey water: a guide for specifiers.*
- *Guidelines for rainwater and grey water systems, in relation to water quality standards, can be found in MTP (2007) Rainwater and grey water: review of water quality standards alternative and recommendations for the UK*

Approved Document – Part G2 covers water efficiency of new dwellings. It also mentions GWR: "*In some cases rainwater harvesting and grey water recycling may be used as a means of reducing water consumption to achieve higher water efficiency performance levels".* It identifies that for GWR (in accordance with BS8525) the water efficiency calculation methodology set out in Appendix A of Approved Document G must be followed.

### A2.10.2 Water quality guidelines and monitoring

As identified above there has been no update regarding the Grey water systems – Part 1: Code of Practice over the last decade. This gives recommendations on the design, installation, alteration, testing and maintenance of grey water systems utilizing bathroom grey water to supply non-potable water in the UK. It states that it is essential that grey water systems are designed in a way that ensures the water produced is fit for purpose and presents no undue risk to health, although there are currently no

specific regulatory requirements for water quality that apply to systems which use grey water for non-potable water use. It is noted that the recommendations and tables given in Clause 6 of the BS 8525-1:2010 Grey water systems – Part 1 have been adapted from those made in the even earlier 2007 Government Market Transformation Programme (MTP) report listed above in Section A2.10.1. The MTP guidelines are themselves based on the EU Bathing Waters Directive (Directive 2006/7/EC)[42], the principle being that water that is safe for total immersion and occasional ingestion, will be safe for toilet flushing, outside cleaning and garden watering.

The important aspects of the guidance for monitoring water quality are presented below. Water quality should be measured in relation to the guideline values given in Table A2.8 for parameters relating to health risk, and Table A2.10 for parameters relating to system operation, which provide an indication of the water quality that a well-designed and maintained system is expected to achieve for the majority of operating conditions. The results of bacteriological monitoring should be interpreted with reference to Table A2.9. The results of general system monitoring should be interpreted with reference to Table A2.11.

Table A2.8 BS 8525-1:2010 guideline values (G) for bacteriological monitoring

| Parameter | Pressure washing, garden sprinkler use[A] and car washing | WC flushing | Garden watering[A] | Laundry, i.e. washing machine, use |
|---|---|---|---|---|
| Escherichia coli number/100 ml | Not detected | 250 | 250 | Not detected |
| Intestinal enterococci number/100ml | Not detected | 100 | 100 | Not detected |
| Legionella pneumophila number/100ml | 10 | N/A | N/A | N/A |
| Total coliforms[B] number/100ml | 10 | 1000 | 1000 | 10 |

Notes:
A: If treated grey water is to be used in kitchen gardens on domestic crops, information regarding the preparation of these crops prior to consumption (e.g. boiling, peeling or thorough washing in potable water) should be provided for the user in the handover documentation.
B: "Total coliforms" is an indicator parameter for operational interpretation. The bacteriological guideline values given for treated grey water reflect the need to control the quality of treated water for supply and use.

Table A2.9 BS 8525-1:2010 interpretation of results from bacteriological monitoring

| Sample result[A] | Status | Interpretation |
|---|---|---|
| <G | Green | System under control |
| G-10G | Amber | Re-sample to confirm result and investigate system operation |
| > 10G[B] | Red | Suspend use of grey water until problem is resolved |

Notes:
A: G = guideline value
B: In the absence of E.coli, Intestinal enterococci and Legionella, where relevant, there is no need to suspend use of the system if levels of coliforms exceed 10 times the guideline value.

[42] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32006L0007&from=EN

Table A2.10 BS 8525-1:2010 Guideline values (G) for general system monitoring

| Parameter[A] | Pressure washing, garden sprinkler use[A] and car washing | WC flushing | Garden watering[A] | Laundry, i.e. washing machine, use |
|---|---|---|---|---|
| Turbidity NTU | <10 | <10 | N/A | <10 |
| Ph | 5-9.5 | 5-9.5 | 5-9.5 | 5-9.5 |
| Residual chlorine mg/l | <2.0 | <2.0 | <0.5 | <2.0 |
| Residual bromine mg/l | 0 | <5.0 | 0 | 0 |

*Notes:*
A: In addition to these parameters, all systems should be checked for suspended solids and colour. The treated grey water should be visually clear, free from floating debris and not objectionable in colour for all uses. Colour is particularly relevant for washing machine use.

Table A2.11 BS 8525-1:2010 interpretation of results from system monitoring[A]

| Sample result[B] | Status | Interpretation |
|---|---|---|
| <G | Green | System under control |
| >G | Amber | Re-sample to confirm result and investigate system operation |

*Notes*:
A: When monitoring pH, if levels are outside this range, the system status becomes "amber" and re-sampling is necessary. Where colour or suspended solids are present at levels which are objectionable, it is necessary to investigate the system operation to resolve the problem.
B: G = guideline value

BS 8525-1:2010 notes that it might be necessary to include some type of disinfection, e.g. UV or chemical disinfection, to attain the more stringent bacteriological standards suggested, in situations where higher exposure might occur or for systems within public premises (see the Health and Safety Executive (HSE) Approved Code of Practice and guidance L8 [22]).

Water quality is likely to fluctuate as different people use the collection appliances, such as baths and showers, in different ways and the collected grey water is therefore subject to varying levels of dirtiness and use of surfactants. However, tables A2.8 to A2.11 provide an indication of the water quality that a well-designed and maintained system is expected to achieve for the majority of operating conditions.

The guidance states that frequent water sample testing is not necessary; however, observations for water quality should be made during maintenance visits to check the performance of the grey water system (BSI, 2010). Tests should then be undertaken to investigate the cause of any system that is not operating satisfactorily in accordance with the water sampling described in Annex D of the Code of Practice.

Part 2 of BS 8525 specifies requirements and test methods for packaged and/or site-assembled domestic grey water treatment equipment. The test procedures (for a nominal treatment capacity of up to 10 m3 per day) are carried out on grey water treatment equipment under controlled conditions using public mains water and synthetic grey water. Part 2 of BS 8525 is aimed at manufacturers and designers of grey water treatment systems as well as testers of grey water treatment systems. The test methods are not intended for commissioning or validation of the on-site performance of the domestic grey water treatment equipment (BSI, 2011).

### A2.10.3 Water fittings

The Water Supply (Water Fittings) Regulations 1999[43] govern the efficient use and protection of drinking water in England and Wales. The purpose of the regulations is to prevent waste, misuse, undue consumption, erroneous measurement and most importantly contamination of drinking water. They apply to all plumbing systems, water fittings and equipment supplied from the public water supply. These Regulations require that the correct level of backflow prevention is provided to prevent contamination of the public mains water supply. For grey water systems this is usually in the form of an air gap, which will prevent non-potable water entering the mains water supply. Backflow prevention for specific appliances needs to be reviewed with the manufacturer to ensure that a suitable fluid category 5 (air gap) backflow prevention has been incorporated into the appliance.

Under Regulation 5 of the Water Fittings Regulations anyone who proposes to install a water reuse system that incorporates a back-up supply from the public mains must notify the water supplier and not begin work without consent. Some water companies, such as Anglian Water, highlight that all water reuse systems will be inspected recorded and registered.

### A2.10.4 Water Regulations Advisory Scheme (WRAS)

As identified in the Buildings Regulations 2010: Approved Document G guidance on the marking of pipework conveying water from alternative sources can be found in the WRAS Information & Guidance Note No. 9-02-05 Marking and identification of pipework for reclaimed (grey water) systems. The purpose of WRAS is to contribute to the protection of public health by preventing contamination of public water supplies and encouraging the efficient use of water by promoting and facilitating compliance with the Water Supply (Water Fittings) Regulations.

WRAS Information & Guidance Note No. 9-02-05[44] states that:

- It is important that all pipework supplying reused water is readily identifiable to those who come across it for the first time.
- Pipework should be both recognisable and distinguishable from that supplying mains water.
- Pipes must be marked and labelled.

The WRAS Information and Guidance Note should always be referred for full details and distinctions between different settings (e.g. the difference between domestic and commercial pipework), some key information is included below and shown in Figure A2.5.

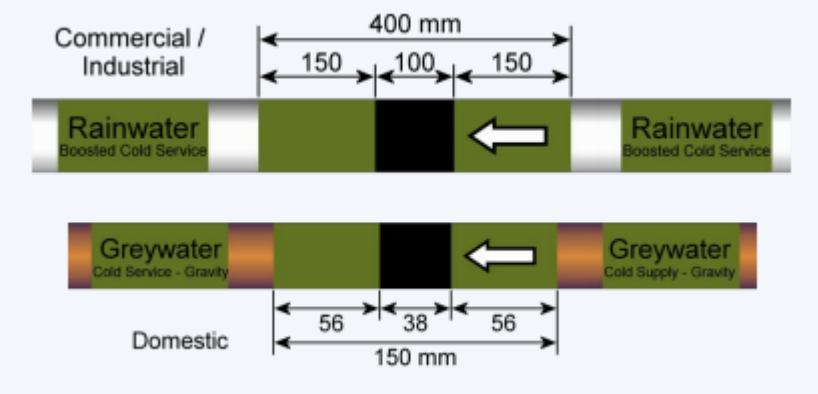
In accordance with BS 1710:1984 'Identification of pipelines and services' pipes that distribute reused water should be colour coded with a green-black-green banding:

- The basic identification colour, green, identifies the contents as water and the banding should be approximately 150mm wide.
- The code indicator colour, black, identifies the contents as unwholesome reused water and should be approximately 100mm in width.

In domestic properties the pipework is likely to be smaller, but the same principles apply. Insulated pipes should be labelled and markings along pipes.

[43] Statutory Instrument 1999 No. 1148 (http://www.hmso.gov.uk/si/si1999/19991148.htm) and Statutory Instrument 1999 No. 1506 (http://www.opsi.gov.uk/si/si1999/19991506.htm).
[44] www.wras.co.uk/downloads/public_area/publications/general/ign/ign_9.02.05_version_feb_2015.pdf/

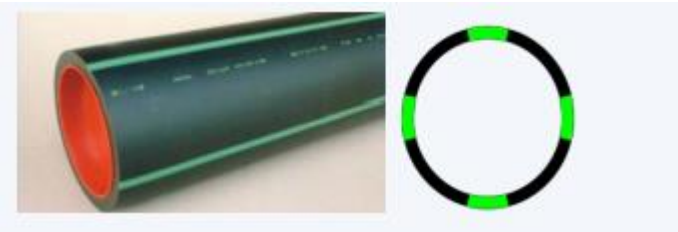
Figure A2.5 Suggested labelling of internal pipes containing reclaimed water for both nondomestic and domestic properties (extract from WRAS Information & Guidance Note No. 9-02-05)




Colour coding of pipework is essential to help prevent any possibility of misconnecting onto a water reuse system during the replacement of fittings or renovation. It will also help prevent cross-connections that could lead to contamination of the drinking water supply (Anglian Water, 2017).

For pipework belowground a contrasting colour for reuse systems must be used, the WRAS and National Joint Utilities Group (NJUG) recommend that black pipe with green stripes is used (Anglian Water, 2017). See Figure A2.6.

Figure A2.6 Example of the colour coding recommended for external reused water pipework (extract from WRAS Information & Guidance Note No. 9-02-05)



The WRAS guidelines also recommend all storage and point of use appliances supplied by a reused water system be identified by signage which clearly identifies that an unwholesome reused water system is in use. Figure A2.7 below is taken from the WRAS Information & Guidance Note.

Figure A2.7 Examples of labels for storage cisterns and point of use appliances e.g. washing machines, WCs, outside taps (extract from WRAS Information & Guidance Note No. 9-02-05)

In addition to primary point of use labelling the guidance also recommends that a label be attached to the incoming stop valve or other key points so that users are aware that a reused water system has been installed. Figure A2.8 below is taken from the WRAS Information & Guidance Note.

Figure A2.8 Examples of labels for use at stop valve and other key connection points (extract from WRAS Information & Guidance Note No. 9-02-05)

Fitting labels and marking pipes will ensure users are fully aware what quality of water is being supplied to their appliances. This contributes to the health and wellbeing not only for current users but for future occupiers, by raising awareness that a water reuse system has been installed (Anglian Water, 2017).

### A2.10.5 Other regulations and guidance

It is not necessarily an environmental offence to discharge small volumes of treated bathroom grey water directly to the environment, provided they are not polluting. Therefore it is possible to use GWR for irrigation and for use regarding green infrastructure. The Environment Agency state that risk assessments[45] are not required for grey water discharges from domestic properties unless:

- a trade discharge is included in the effluent, or
- there is a discharge to ground or surface water of >15 $m^3$ per day, or
- the discharge to ground is more than 2 $m^3$ per day, and the location is in a groundwater Source Protection Zone, SPZ1 (an area of highest risk to groundwater quality).

Recently, with the aim of preventing water shortages, European Parliament approved the Water Reuse Regulation (May 2020). This Regulation lays down minimum requirements for water quality and monitoring and provisions on risk management, for the safe use of reclaimed water in the context of integrated water management. The purpose of the Regulation is to guarantee that reclaimed water is safe for agricultural irrigation, thereby ensuring a high level of protection of the environment and of human and animal health, promoting the circular economy, supporting adaptation to climate change, and contributing to the objectives of Directive 2000/60/EC by addressing water scarcity and the resulting pressure on water resources, in a coordinated way throughout the Union, thus also contributing to the efficient functioning of the internal market.

## A2.11 The use of GWR in other countries

In contrast to experience in the UK the prevalence of GWR systems in some other countries is much higher. The findings of a targeted review of the policy options and interventions adopted to encourage the uptake of GWR systems in Germany, Australia, Japan and United States was undertaken and is presented below.

### A2.11.1 Germany

Often seen as leading the way in Europe in the use of RWH and GWR systems it is reported that almost one third of new buildings built in Germany in 2017 were equipped with a rainwater collection system for non-potable uses (mainly for irrigation, toilet flushing, and laundry use) (Campisano et al.,2017). Early development and application of GWR started in Germany in the late 1980's and 1990's. In 2005 there were an estimated 400 GWR systems in operation and now there are thousands (Grant, 2016).

[45] https://www.gov.uk/guidance/risk-assessments-for-your-environmental-permit

In contrast to RWH there is little evidence of any regulatory or financial incentives that encourage the uptake of GWR systems in Germany. The primary driver for the installation of GWR appears to be environmental although financial benefits can also be gained. As a result of the self-build nature of the construction industry in Germany, about 95% of the supplied systems are installed in single and double-family households with a treatment capacity of about 600 litres a day (The College for Estate Management, 2013).

The regulatory framework specifies that all GWR have to be registered with the Health Office in order to guarantee that no cross connections exist with the drinking water network and that pipes are labelled according to regulations. The hygiene requirements for recycled grey water, which is primarily used for toilet flushing, are oriented towards the EU-Guidelines for Bathing Waters. The use of recycled grey water for irrigation purposes is currently minor (Nolde, 2005).

### A2.11.2 Australia

As a result of prolonged drought, Australia has also seen significant advances in the application of GWR although there are still challenges. Between 2009 and 2011, under the Water for Future Initiative (WFI), the Australian Federal Government introduced a rebate scheme for the purchase and installation of new RWH or GWR systems for non-potable purpose. The National Rainwater and Grey water Initiative provided households with a rebate of up to $500 per installation and during the period 14,625 rebates, equivalent of $7 million, were offered through the scheme (Thames Water, 2017). In addition to the Federal Government rebate scheme, many Australian State governments have developed regulatory mechanisms to promote RWH or GWR systems. For example in the state of Victoria a rebate is available of up to $500 for a grey water permanent tank system that recycles wastewater from laundries and bathrooms for toilet or garden use.

In addition to the rebate schemes in some states municipal water companies also offer discounts on stormwater charges to encourage the collection and use of rainwater within the property. For example, Sydney Water offer a reduction in fixed quarterly stormwater charges from $19.83 to $6.19 against the installation of a rainwater tank. Further to this low impact discounts on stormwater charges for businesses for the collection and reuse of stormwater from commercial properties. This also extends to other on site water efficiency initiatives including grey water treatment and reuse[46].

### A2.11.3 Japan

In Japan, the government does not provide incentives for household residents to implement GWR systems. However, 70% of Japanese support the utilization of rainwater or recycled water as there is high awareness of the need to conserve water, and water costs are relatively high in urban areas (Yi-Kai Juan et al., 2016). In Tokyo, it is mandatory to install a GWR system for a building with an area of over 30,000m$^2$ or with potential non-potable demand of 100m$^3$ per day (The College for Estate Management, 2013).

### A2.11.4 USA

There are currently no national guidelines in place regarding grey water reuse and individual states are responsible for its governance. Existing regulations and plumbing codes in the different states suggest that there are impediments to overcome but also potential incentives for grey water reuse. As of 2013, only around half of the States promoted the safe use of grey water in its regulation.

The key areas highlighted for concern are the acceptability of grey water segregation as a separate wastewater stream, allowable grey water storage, onsite treatment requirements, and permitted grey water use applications (primarily for outdoor irrigation with limited indoor use permitted) (Yu et al., 2013).

[46] https://www.sydneywater.com.au/SW/accounts-billing/understanding-your-bill/prices-for-your-business/index.htm

Despite these concerns, municipalities and counties in California are offering rebates and incentives for property owners who install grey water systems to irrigate their landscapes:

- Valley Water: Grey water 'laundry to landscape' rebate programme offers up to $400 for properties that connect their washing machine to the 'laundry to landscape system.
- Scotts Valley Water District: $150 rebate for residents that install a converted to allow grey water to be used for garden irrigation.
- Soquel Creek Water District: A rebate of $400 per 'laundry to landscape' system and up to $1,000 per household for a dual plumbed system for outdoor irrigation. The rebate applies to single or two-unit residential buildings only.

Further to this in Arizona, Tucson Water is offering a rebate of half the qualifying costs (up to $1,000) for residential grey water systems for outdoor irrigation. The rebate covers the design costs, materials, storage tanks, filters, pumps, backflow prevention assembly, and installation (Tucson Water, 2011).

## A2.12 Conclusions

This report brings together the findings from a review of academic and industry research into GWR systems, designs and technologies in the UK. The review also supported an assessment of the costs and performance of existing systems across a range of building types.

Based on the information presented, the following conclusions are made regarding the current approaches to GWR in the UK and the associated costs and benefits.

- Separating out grey water from the more polluted wastewaters means it can be treated and used as an alternative source of water for non-potable purposes and reduce the volume of mains water used in buildings.

- The recycled grey water can be used for a number of applications including toilet flushing, outdoor use (including other sustainable building design features and Green Infrastructure) and laundry. Some require a higher level of grey water treatment than others.

- Public perception studies suggest there is general willingness and positivity regarding GWR provided public health is not compromised.

- British Standards have produced BS 8525, GWR systems should comply with BS8525 to ensure maximum benefit and compliance with legislation.
    - BS 8525-1:2010 Grey water systems – Part 1: Code of Practice which provides recommendations for installation and maintenance of GWR systems. While there are still no international or national water quality standards BS 8525-1:2010 provides guidance and embedded water quality parameters for water reuse applications.

- In order to prevent the collection and treatment of grey water that cannot be used, demand for the recycled grey water (e.g. that for toilet flushing) should drive the specification of the GWR system.

- GWR systems treat water for non-potable reuse and do not produce water suitable for drinking. It is therefore important that:
    - the water fittings regulations are followed to avoid contamination of the mains water supply; and
    - WRAS guidance on pipe labelling is followed to avoid cross connections.

- GWR systems vary significantly in their complexity and size and there will be very different requirements and considerations depending whether it is a domestic or commercial application. There will usually be the need for dual plumbing of the drainage system, this often makes retrofit options for GWR systems limited to individual, domestic buildings.

- Design and technologies of the basic systems which involve limited treatment and resulting limited reuse options have changed little over the last decade. The most significant developments in GWR systems relate to those that involve membrane-based technology. These systems can treat grey water to a high level allowing reuse for a wider number of applications.

- The capital investment required for a GWR system can vary significantly depending on scale, from less than a £1,000 for a small scale domestic unit, to many tens of £1,000's in large scale developments.

- There are potential cost savings for both domestic and commercial applications of GWR, the larger the water demand the greater the potential savings and shorter payback period. Because of the relatively low price of water shorter payback periods of less than 5 years are more difficult to achieve for domestic buildings. There is now greater emphasis on larger scale projects at the development phase (e.g. community projects, commercial installations and multi-purpose developments).

- Energy requirements of GWR systems will vary depending on type of GWR system, installation arrangements and level of the demand. Historically it has been shown that GWR systems result in greater carbon emissions relative to mains water use. However, although more recent evidence is limited there is evidence that supply from carbon efficient GWR systems can involve lower energy demands relative to mains water. This is recognised when considering the reduction to the carbon footprint resulting from locally re-treating water that was originally treated elsewhere and the reduction in the volume of wastewater that would be returned to that same location for treatment.

- GWR (and reuse more generally) can reduce pressure on existing freshwater sources as well as local infrastructure with numerous wider benefits.

- Planning for GWR strategically at early development stage allows the necessary design and plumbing to be incorporated to allow for a wider range of GWR applications and greater cost savings and environmental benefits.

- GWR systems can be integrated with RWH systems, these can bring notable benefits when planned strategically for larger scale, especially mixed use developments. However, at the individual building level, the benefits of an integrated GWR and RWH need to be considered as the added efficiency from the rainwater depends on the building use.

## A2.13 References

Artesia Consulting. The long term potential for deep reductions in household water demand, 2018.

Anglian Water. Water reuse systems, guidance and advice given by Anglian Water and supported by Chartered Institute of Plumbing and Heating Engineering, 2017.

Barrat Developments Plc, Our Approach to Water, 2019.

Boano, F., Caruso, A., Costamagna, E., Ridolfi, L., Fiore, S., Demichelis. F., Galvão, A., Pisoeiro, J., Rizzo, A. and Masi, F., A review of nature-based solutions for grey water treatment: Applications, hydraulic design, and environmental benefits, Science of the Total Environment, 711, (2020).

British Standards Institute (BSI), BS 8525:2010 Grey water systems – Part 1: Code of practice, 2010.

British Standards Institute (BSI), BS 8525-2:2011Grey water systems – Part 2: Domestic grey water treatment equipment – Requirements and test methods, 2011.

Bryan, K. Ward, S., Barr, S., Butler, D. Coping with Drought: Perceptions, Intentions and Decision-Stages of South West England Households. Water Resources Management. 33 (1185–1202), 2019.

Campisano, A. and Modica, C., Appropriate resolution timescale to evaluate water saving and retention potential of rainwater harvesting for toilet flushing in single houses, Journal of Hydroinformatics, 17, 2015.

CIRIA, Water Key Performance Indicators and benchmarks for offices and hotels, 2006.

CIRIA, Delivering better water management through the planning system. Part A: Main Guidance. CIRIA C787A, London, 2019

Clarke, B. The Benefits, Challenges, and Impediments of Grey water Use in EPA Region 5. Great Lakes Environmental Finance Center, Cleveland State University, 2016.

Environment Agency, Grey water for domestic users: an information guide, 2011.

Environment Agency, Energy and carbon implications of rainwater harvesting and grey water recycling, 2011.

Friedler, E and Gross, A., Grey water reuse: Risk identification, quantification and management. Alternative Water Supply Systems. Eds: Fayyaz Ali Memon, 2016.

Grant, G., The Water Sensitive City, 2016.

Hyde, K. and Smith, M., Grey water recycling and reuse. In: Charlesworth, S. M. and Booth, C. A. (eds.) Urban Pollution: Science and Management, 2018.

Ifelebuegu, A., James, D. Ganjian,E., Surendran, S.. Grey water reclamation for urban non-potable reuse - Challenges and solutions: A review. Conference Paper, 2016.

Joustra, C.and Yeh, D. Decision support systems for water reuse in smart building water cycle management. Alternative Water Supply Systems. Eds: Fayyaz Ali Memon, 2016.

McClarana, N. Beheb, B., Huddlestona, P., Fernandezb, R. Recycled or reclaimed? The effect of terminology on water reuse perceptions, Journal of Environmental Management (261), 2020.

Memon, F.A., Fidar, A.M., Ward. S., Butler. D., and Alsharif. K., Energy and carbon implications of water saving micro-components and grey water reuse systems. In: Alternative Water Supply Systems. Eds: Memon, F.A., Fidar, A.M. and Ward. S., 2016.

Mills, P. Water Re-use – Standards review. Interim Report for Defra and Water UK. Policy Consulting Network Ltd. April 2016.

Moslemi Zadeh S. Sustainability Evaluation of Shared Grey water Recycling in Urban Mixed-use Regeneration Areas. PhD Thesis, University of Birmingham. 2013.

Nolde, E. Grey water recycling systems in Germany - results, experiences and guidelines. Water, Science and Technology, 51, Vol 10, 2005.

Olanrewaju, O. and Ilemobade. A.Greywater Reuse Review and Framework for Assessing Grey water Treatment Technologies for Toilet Flushing, Advances in Research 5(4): 1-25, 2015.

Oteng-Peprah, M Agbesi, A and K. DeVries, N,. Grey water Characteristics, Treatment Systems, Reuse Strategies and User Perception—a Review. Water Air Soil Pollut (229: 255), 2018.

Oviedo-Ocaña, E.R., Dominguez, I., Ward, S., Rivera-Sanchez, M.L. and Zaraza-Peña, J.M., Financial feasibility of end-user designed rainwater harvesting and grey water reuse systems for high water use households, Environmental Science and Pollution Research, 25, 2018.

Pidou, M. Membrane processes for grey water recycling. Alternative Water Supply Systems. Eds: Fayyaz Ali Memon, 2016.

Policy Connect, Bricks and Water - A plan of action for building homes and managing water in England, 2018.

Rakesh,S. Ramesh, P., Murugaragavan, R. Avudainayagam, S. and Karthikeyan, S. Characterization and treatment of grey water: A review. International Journal of Chemical Studies 2020; 8(1): 34-40, 2020.

South East Water, Water Resources Management Plan 2020 to 2080, 2019.

Thames Water, Non-Potable Water Reuse as a Demand Management Option for WRMP19 -Options Appraisal Report, 2017.

The College of Estate Management, Grey Water for UK Housing, 2013.

Toifl, M, Bulteau, G., Diaper, C., O'Halloran, R. Guidelines for safe adoption, Alternative Water Supply Systems. Eds: Fayyaz Ali Memon, 2016.

Waterwise, How Do People Feel About Domestic Water Recycling Systems?, 2019.

Tucson Water. Graywater Information Guide, 2011.

Water Efficiency Network. Water Reuse & Sustainable Surface Water Management Technical Committee Strategy 2015/16, 2016.

Yi-Kai Juan, Yi Chen * and Jing-Ming Lin.Grey water Reuse System Design and Economic Analysis for Residential Buildings in Taiwan. Water, 8, 2016.

Zita L.T. Yu, Anditya Rahardianto, J.R. DeShazo, Michael K. Stenstrom, Yoram Cohen. Critical Review: Regulatory Incentives and Impediments for Onsite Graywater Reuse in the United States. Water Environment Research, 85, No 7, 2013.