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Independent review of the costs and benefits of rainwater harvesting and grey water recycling options in the UK

Final Report for Waterwise

WEStrategy002

Report for Waterwise - WEStrategy002

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Non-technical summary

Rainwater harvesting (RWH) and grey water recycling (GWR) are ways of generating alternative sources of water. This can be used for some non-potable uses instead of mains water which is treated to meet strict drinking water standards. To date, both RWH and GWR systems have been implemented with mixed experience in the UK. There remains a gap in research and accreditation for these systems 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Agency in 2010 and 2011, outlined the costs and benefits for domestic installations, but these are now largely out of date.

This work aims to address this research gap. Drawing on academic and industry research, case studies and industry examples, an appraisal of RWH and GWR systems and the costs and benefits of the existing technologies in different contexts have been modelled. The cost benefit analysis sought to access the various impacts associated with each system and monetise these impacts to allow for a comparison. Systems are broken down by the size and type of building they would be installed. The analysis allows for a comparison of the private net impact (does the system pay for itself through a reduced water bill) as well as the wider impacts. The findings summarised below form an update to the information guides published by the Environment Agency.

Key findings from the review of RWH technologies in the UK

Rainwater harvesting describes a variety of methods for the collection and storage of rainwater for potable and non-potable use. 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 storm water attenuation.

RWH systems can be either retrofitted to existing buildings or incorporated at the development phase. Generally speaking installing RWH systems in new builds is easier and cheaper than retrofit. This is primarily due to the capital investment required and challenges associated with installation of such systems, in particular the siting of storage tanks and changes to pipework. 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 (located in the loft) low storage capacity (<1m^3) header tanks. These system configurations are better suited for retrofit as the installation is less invasive.

In addition to satisfying local water demand, RWH is increasingly being considered as an option for contributing to stormwater management. Capturing rainwater or surface water at source can help reduce the volume and flow into drains and sewers, thus preventing the inundation of surface water drainage systems and treatment facilities. As a consequence load reduction mitigates sewer overflows and decreases watershed pollution in storm events while RWH systems also reduce the runoff and the transport of pollutants directly into water bodies.

Analysis of the costs and benefits of domestic RWH installations broken down by size show a total net benefit across all collection areas and demand requirements in domestic buildings, and the vast majority of non-domestic buildings (the exception is small and very large buildings with high demand). The overall benefit increases both as the collection area and demand increases, this is primarily due to the size of the storage tank. Further to this when the wider social (indirect) benefits, such as reduced demand on water infrastructure, CO_2 savings and flood damage reduction are also considered, the potential benefits over a 20 year system lifetime increase substantially. However, it should be noted that all building types and sizes also have the potential for a private net cost if water demand is low (see below).

Range of costs and benefits for installing RWH based on the collection area of a residential building

Collection area	Example building types	Costs: CAPEX + OPEX ('000 £)	Water cost savings ('000 £)	Private net benefits ('000 £)	Societal benefits ('000 £)	Total net benefit ('000 £)
Small (<500m²)	Standalone dwellings, Houses, Bungalows;	£12 - £19	£1 - £19	-£9 - £26	£21 - £77	**£10 - £100**
Medium (500 – 2000m²)	Some larger houses or two semi-detached houses;	£25 - £38	£8 - £200	-£17 - £150	£50 - £163	**£35 - £340**
Large (2000 – 5000m²)	Row of terraced houses or blocks of flats;	£20 - £35	£7 - £150	-£15 - £120	£35 - £335	**£20 - £450**
Very Large (>5,000m²)	Large scale residential developments (including hybrid developments)	£35 - £60	£70 - £340	-£17 – £280	£30 - £920	**£14 – £1,200**

The costs and benefits for non-domestic buildings follow a similar narrative as that for domestic buildings, the primary difference is that water prices are lower for commercial customers and therefore the savings made from offsetting it with rainwater are also lower (see below)

Range of costs and benefits for installing RWH based on the collection area of a commercial building

Collection area	Example building types	Costs: CAPEX + OPEX ('000 £)	Water cost savings ('000 £)	Private net benefits ('000 £)	Societal benefits ('000 £)	Total net benefit ('000 £)
Small (<500m²)	Small commercial shops (such as a corner shop);	£12 - £19	£1 - £19	-£11 - £28	£8 - £51	**-£3 - £80**
Medium (500 – 2000m²)	Retail and commercial stores, leisure centres;	£25 - £38	£8 - £200	-£17 - £160	£23 - £150	**£6 - £315**
Large (2000 – 5000m²)	Office blocks, hotels and shopping centres;	£20 - £35	£7 - £140	-£15 - £110	£16 - £190	**£1 - £300**
Very Large (>5,000m²)	Large scale commercial developments (including hybrid developments)	£25 - £60	£7 - £315	-£17 – £260	£15 - £500	**-£3 – £742**

Previous reports suggest that RWH systems emit more carbon than water supplied by the mains water network. However, the scale of carbon emissions depend on the design of the system and components used, and a number of more recent studies have shown the emissions associated with RWH to be much more favourable. This study has shown that RWH installations across all building sizes emit less

CO_2 when compared to the CO_2 emissions embedded in mains water over the installations 20 year lifetime. The amount of CO_2 embedded within a RWH system does not grow significantly as the size increases, however the amount of CO_2 saved, through reduced water demand can increase significantly with the size and demand of the system.

Overall, it is concluded that large RWH systems present an attractive opportunity, both privately and socially, which is likely why they are currently being installed in larger developments (such as the Southbank development in London). However smaller installations are not privately beneficial for the installer and are therefore unlikely to see large scale uptake until they become so, either through falling prices or government backed schemes and interventions.

Key findings from the review of GWR technologies in the UK

Grey water generated from baths, showers and washbasins can be considered high volume, low strength wastewater with high potential for reuse. By separating grey water from more polluted wastewaters (e.g. from toilets) means it can be treated and used as an alternative source of water for non-potable purposes. Public perception studies suggest there is general willingness and positivity regarding GWR provided public health is not compromised.

GWR systems vary significantly in their complexity and size and their requirements depend upon the application. Design and technologies of the basic systems which involve limited treatment and thus result in 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 need for dual plumbing of the drainage system often makes retrofit options for GWR systems limited to individual, domestic buildings. However, 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 also 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.

The energy requirements of GWR systems 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 data 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.

Analysis of the costs and benefits of installing a GWR system broken down by the expected yield of the system show that for the smallest system types, those typically installed in individual houses or potentially for a small block of flats systems there is a net private cost for all systems (see table below). For larger buildings, including larger blocks of flats, large multi house residential developments or community developments the water savings exceed the cost of installing the system. The exception are buildings (or developments) with very high yields where the introduction of GWR systems becomes cost effective.

A slightly different narrative emerges when the net social impact (this includes the CO_2 impacts as well as reduced stress of water infrastructure) are considered over the 20 year lifetime. There is a net cost for low and small yield buildings, however for medium and larger buildings, essentially, all buildings or developments with more than one dwelling, there is a social net benefit.

Costs and benefits of installing a GWR system in a building based on the systems yield (greywater produced)

Yield	Example building types	Costs (CAPEX + OPEX; '000 £)	Total water cost savings ('000 £)	Private net benefits ('000 £)	Societal benefits ('000 £)	Total net benefit ('000 £)
Low (<500m^3)	Smaller households (such as retired people or young adults), small commercial shops.	£ 45	£ 5	-£ 40	2	**-£ 37**
Small (500 – 1,500m^3)	Larger households (potentially families).	£ 100	£ 52	-£ 48	£18	**-£ 30**
Medium (1,500 – 4,000m^3)	Retail and commercial stores, leisure centres, some offices.	£ 120	£ 108	-£ 13	£34	**£ 25**
Large (4,000 – 10,000m^3)	Large commercial settings such as shopping centres, multi-unit offices or flats.	£ 170	£ 190	£ 21	£67	**£ 88**
Significant (>10,000m^3)	High rise offices or blocks of flat, hotels, multi-purpose developments.	£ 270	£ 780	£ 510	£275	**£ 787**

Overall GWR systems installed in larger buildings such as large tower blocks or multi-house residential developments present an attractive opportunity, both privately and socially. However smaller installations are not privately or socially beneficial for the installer and as such large scale uptake is unlikely until they become so, either through falling prices or government backed schemes and interventions.

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Glossary

Term/Abbreviation	Definition
Air gap	Visible, unobstructed and complete physical air break between the lowest level of water discharge and the level of potentially contaminated fluid downstream (critical water level) within a receptacle.
AISC	Average Incremental Social Cost.
Attenuation	The process of storing and slowly releasing surface water run-off.
BREEAM	BRE Environmental Assessment Method.
BSI	British Standards Institute.
CAPEX	Capital expenditure (of installing the system).
CfSH	Code for Sustainable Homes.
CIRIA	Construction Industry Research and Information Association.
GLA	Greater London Authority.
GWR	Grey water recycling.
IWM	Integrated Water Management.
LCA	Life cycle analyses.
LPA	Local Planning Authority.
NJUG	National Joint Utilities Group.
NbS	Nature Based Solutions.
Non-potable water	Water treated to non-potable standards.
OPEX	Operating cost (of maintaining the system).
PCC	Per capita consumption.
PHC	Per household consumption.
Rainwater	Water arising from atmospheric precipitation.
RWH (Rainwater harvesting)	The collection of rainwater that falls onto surfaces such as roofs and the ground around a building which is routed to a storage vessel for future use.
Rainwater yield	Volume of rainwater harvested from the collection surface.
Runoff coefficient	Runoff factor which is based on the fact that some roof types and surfaces are more efficient than others at collecting rainwater.
Stormwater	Surface water in large quantities resulting from heavy rainfall.
Stormwater control	Measures to control the rate and quantity of surface water run-off.
SuDS	Sustainable Drainage Systems.
Surface water	Water from precipitation, which has not seeped into the ground and which is discharged to the drain or sewer system directly from the ground or from exterior building surfaces.
UKRMA	UK Rain Management Association.
UV	Ultraviolet.
WHO	World Health Organisation.
WRAS	Water Regulations Advisory Scheme.
WRMP	Water Resource Management Plan.

1 Introduction

1.1 Background

Rainwater harvesting (RWH) and grey water recycling (GWR) are ways of generating alternative sources of water. This can be used for some non-potable uses instead of mains water which is treated to meet strict drinking water standards. RWH and GWR technologies are increasingly being considered at the building-level as a means for addressing water scarcity and stormwater attenuation. There has also been growing interest in RWH and GWR systems in response to the increasing awareness around environmental issues and the demand for greater sustainability both in domestic and commercial buildings. However, to date, both RWH and GWR systems have been implemented with mixed experience in the UK.

While over the last decade there have been advances in RWH and GWR 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 in 2010 and 2011, outlined the costs and benefits for domestic installations of RWH systems and GWR respectively, 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 RWH and GWR technologies has been developed and used to model the costs and benefits of the existing technologies in different contexts, scales, building types and new or retrofitted buildings.

1.1.1 Water resources in the UK

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 water shortages and flooding will become an increasing problem in a number of regions across the country. With population in the UK set to increase significantly by 2050, 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.

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.

Water companies Water Resources Management Plans (WRMPs) are updated every five years with the aim of ensuring that there is a sufficient supply of water to meet the anticipated demands of customers over a minimum 25-year planning period, even under conditions where water supplies are stressed. Historically RWH and GWR have tended not to be selected in the options appraisal process to form part of final WRMPs mainly as a result of cost. However, in the latest round of WRMPs (2019) there has been greater recognition of their potential role in achieving long term sustainable reductions in demand management. Where this is the case, the need for policy support to make this feasible without increasing customer bills has also been identified.

Defra's 25 Year Environmental Plan (HM Government 2018) sets out government action to help the natural world regain and retain good health. The policies in the plan include '*Respecting nature in how we use water: i. Reforming our approach to water abstraction ii. Increasing water supply and* *incentivising greater water efficiency and less personal use*)'. Under this the importance of water companies taking bold action to reduce water demand is emphasised and it is stated that the Government will work with the water industry to set an ambitious personal consumption target and agree cost effective measures to meet it.

1.1.2 Water demand and water efficiency

At a national level population growth is driving household water demand and economic growth is a significant factor in terms of water use by businesses (Water UK 2016). Population growth and economic activity is highly variable between different regions (Water UK 2016). The latest reported average per capita consumption (PCC) for England and Wales is 143 l/p/d[1]. However, the ways in which water is used and the quantities used in buildings, whether domestic or commercial, varies both from building to building.

In its 2018 report the National Infrastructure Commission stated that increasing efficiency savings and near universal smart metering would reduce the average to 118 litres by 2050 (National Infrastructure Commission 2018). 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).

Recent guidance from CIRIA 'Delivering better water management through the planning system' (CIRIA 2019) supports planning for water through the delivery of integrated water management (IWM). It identifies that water management is vital for good town planning and planning for water enables towns and cities to be greener, healthier wealthier, more attractive and more resilient to climate change. The guidance highlights that '*an efficient approach is needed to manage how water is used, harvested and recycled within buildings and ….. innovative approaches involving RWH and GWR can significantly reduce volumes of both treated water to a site and wastewater entering the sewerage system'*.

1.2 Aims and objectives

The main objective of this study is to update, expand and collate the information on RWH and GWR in the UK to form a basis on which manufactures, water companies and policy makers can make decisions. The study has been undertaken according to the following tasks:

- A literature review of RWH from academic research, water industry, and manufacturing experience to enable production of an updated version of the Environment Agency 2010 reports.
- A literature review of GWR from academic research, water industry and manufacturing experience to enable production of an updated version of the Environment Agency 2011 report.
- Model the costs and benefits of existing RWH technologies in different contexts, scales, building types and new or retrofitted buildings (including the energy, carbon and resource costs). Also considering the opportunities posed by linking the design to sustainable urban drainage.
- Model the costs and benefits of GWR technologies in different contexts, scales, building types and new or retrofitted buildings (including the energy, carbon and resource costs). Also considering the opportunities posed by linking the design to sustainable urban drainage.
- Identify policy options for encouraging RWH and GWR in the UK.
- Model the costs and benefits of different policy options to assess the impacts on PCC and non-domestic water usage as well as to the zero carbon agenda

Only the first four tasks are presented in this report with the other tasks covered in a separate report.

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

1.3 Scope

1.3.1 RWH systems

The review has broadly followed the definition of rainwater harvesting as identified for the purpose of the British Standard (BS 8515:2009 + A1:2013) i.e. systems which capture precipitated rainfall from surfaces such as roofs and the ground around building exteriors and store it for non-potable water uses in the home, workplace and garden (British Standards Institute 2013). 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. Further to this the review has also considered dual purpose systems designed as part of wider stormwater control and attenuation schemes.

1.3.2 GWR systems

This study has broadly followed the definition of grey water as identified for the purpose of the British Standard (BS8525:2010) i.e. bathroom grey water, that from domestic baths, wash and hand basins, showers and clothes washing machines (British Standards Institute 2010). However, it focuses on bathroom grey water rather than that from washing machines or kitchen sinks. The GWR systems covered by this work are commercially available systems for domestic and commercial uses of relevance to homeowners, house builders, planners, architects and building managers. These can vary significantly in their complexity and size from small systems with very simple treatment to large systems with complex treatment processes. Larger reuse plants that process inputs from industrial processes or a network of grey water sources (e.g. decentralised community recycling systems at the cluster level) are not considered within the scope of this study.

1.4 Report Structure

The remainder of this report presents the outputs associated with the first four tasks of the study as follows:

- Section 2: Presents information from the literature review of RWH and outputs from the modelling of costs and benefits of existing RWH technologies in different contexts, scales, building types and new or retrofitted buildings. This information forms an update to the Environment Agency 2010 report (the literature review of RWH from academic research, water industry, and manufacturing experience is presented in full in Appendix A1).
- Section 3: Presents information from the literature review of GWR and outputs from the modelling of costs and benefits of GWR technologies in different contexts, scales, building types. This information forms an update to the Environment Agency 2011 report (the literature review of GWR from academic research, water industry and manufacturing experience is presented in full in Appendix A2).

2 Approach

The approach to undertaking the literature review of RWH and GWR systems and that involved in modelling the costs and benefits of existing RWH and GWR technologies is outlined below. Further detail is presented in the following sections and associated appendices.

2.1 Literature review

The key objective of the literature reviews was to identify and collate academic and industry research into RWH and GWR systems. This included information regarding designs and technologies but also 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. The approach combined a robust review of existing academic literature and industry research relating to RWH and GWR systems with a targeted stakeholder engagement programme to gather and collate the relevant data and information to inform the subsequent cost benefit analysis exercise. Further details on how the literature reviews were undertaken is provided in Appendix A1.

2.1.1 Stakeholder engagement

The stakeholder engagement exercise enabled the study to gain a wider understanding beyond published work, gain greater sector insight and identify further case studies and examples not in the public domain. Table 2-1 presents the stakeholder organisations that contributed to the study arranged by stakeholder and grouping. Further details on the approach to the stakeholder engagement element of the literature reviews is provided in Appendix A1.

Table 2-1: Stakeholder engagement interviews

Group	Stakeholder
Equipment suppliers, installers and manufacturers	UKRMA Aquality Stormsaver SDS Limited Halsted Rain Limited
Water retailers	Castle Water Affinity for Business Waterscan
Water industry / Retailers	UK Water Retailer Council
Water Industry	Anglian Water Affinity Water Thames Water
Academia	University of Exeter
Non-Government	GLA CIRIA / Susdrain
Developers	Redrow Countryside Properties Berkeley Group

2.2 Modelling of the costs and benefits

A cost benefit analysis is a systematic process for calculating and comparing the costs and benefits of a project. These impacts are quantified and assessed over the entire lifetime of a project (here the lifetime of a RWH or GWR system which is assumed as 20 years).

The quantification and financialization of the benefits is often the most challenging aspect as they may not be directly observable or realised. Moreover, where the benefits are not financially realised (such as a reduction in CO_2) it can be more challenging to report these with a sufficient degree of confidence. The analysis seeks to access the various impacts associated with each system and monetise these impacts to allow for a comparison.

In this analysis RWH and GWR systems are broken down by the size and type of building they would be typically installed. It allows for a comparison of the private net impact (does the system pay for itself through a reduced water bill) as well as the wider impacts of a RWH or GWR system. The benefits are split up into direct benefits (where there is a financial saving or benefit) and indirect benefits (where benefits may be less readily observed or quantified). The costs and benefits accessed are listed in Table 2-2:

Table 2-2: RWH and GWR CBA impacts assessed

Rainwater harvesting CBA	Grey water recycling CBA
Costs	
Capital expenditure (CAPEX)	Capital expenditure (CAPEX)
Operational expenditure and maintenance (OPEX)	Operational expenditure and maintenance (OPEX)
Embedded and emitted carbon from the system	Embedded and emitted carbon from the system
Benefits	
Mains water savings	Mains water savings
Mains water carbon saving	Wastewater discharge (sewage) savings
Reduced damage from flooding	Mains water carbon saving
Reduced demand for additional water infrastructure	Reduced demand for additional water infrastructure

It should therefore be recognised that a CBA forms only one part of an analysis of the viability of a project and other considerations should be given equal weight including public policy, feasibility and other methods of reducing overall water demand.

The calculations are primarily based on real installation data provided by RWH and GWR suppliers and supplemented by further information in order to calculate the indirect benefits. The analysis is conducted over the lifetime of a RWH or GWR system which is assumed to be 20 years. The annual impacts, such as the water saving, maintenance costs and carbon savings are assumed to be constant across this period, however changing costs, such as the price of water and carbon, are reflected in the model.

The net impacts are the total benefits minus the costs, over the systems lifetime, discounted to 2020 prices.

3 Rainwater Harvesting

3.1 Introduction

This section provides an appraisal of rainwater harvesting (RWH) systems for non-potable uses in a variety of building types including domestic dwellings and commercial and industrial premises. It provides guidance for homeowners, house builders, planners, plumbers, architects and building managers.

It contains information on the types of RWH systems that are available and their application in new developments and refurbishments, including their design, installation and maintenance requirements. The costs and benefits of RWH systems are also outlined alongside examples that have been installed and are currently in use.

3.1.1 What is rainwater harvesting?

The ancient practice of rainwater harvesting (RWH) can be traced back at least 4000 years. RWH is a general term used to describe the collection of rainwater that falls onto surfaces such as roofs and the ground around a building which is routed to a storage vessel for future use.

The captured rainwater can then be used for a variety of non-potable applications either within the building, for example, the flushing of toilets or with some additional treatment for the washing machine, or for irrigation of gardens. While the quality of the rainwater collected is generally acceptable for these purposes it will contain traces of atmospheric and environmental pollutants, such as bird faecal matter, as such some degree of contamination must always be assumed and accounted for in the design of the system.

3.1.2 Why consider a RWH system?

Our water resources in the UK are currently under significant pressure and 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 our rising population and the way we use water means that water shortages and flooding will become an increasing problem in a number of regions across the country.

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. Exploring ways to reduce demand for mains water is essential to ensure a sustainable future for water resources. One of the options is to install RWH systems to substitute mains water use for purposes where drinking water quality is not required.

3.1.3 What are the benefits?

As harvested rainwater can be used as an alternative water source to mains supply the primary benefit to the end user will be a reduction in mains water and associated mains water costs. The level of potential savings that can be achieved will depend on the amount of rainwater that can be collected, the quantity of potable water saved and whether the property has a water meter. In commercial and 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.

However, it should be noted that any financial savings can only be realised by customers that are connected to a metered water supply which at present is around 50% of households in the UK[2] and almost all commercial and industrial customers. Greater savings can also be achieved when the RWH system is installed during construction as opposed to being retrofitted, which is often more costly and can be disruptive.

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

In addition to the financial benefits the reduction in consumption of potable mains water will also reduce the amount of energy and chemicals required for treating and pumping. Pressure on existing water supplies will also be reduced. This means that less water will be needed to be taken from our rivers, lakes and other groundwater sources and more will remain within the environment maintaining flows and sustaining our ecosystems.

A further benefit can be the attenuation of surface water runoff during rainfall events. RWH systems capture rainwater or surface water at source which can help reduce the volume of flow of rainwater into our drains and sewers thus reducing the pressure on drainage systems in times of high flow and contribute to reducing the risk of flooding and pollution events. RWH systems can be designed for both water reuse and attenuation functions, and can be integrated as part of sustainable drainage systems (SuDS).

3.2 Household and non-household water demand

This section considers how we use water in the home and at work and the areas of use can utilise rainwater in place of mains potable water.

3.2.1 Household water use

Household water consumption can be reported in two ways:

- per household consumption (PHC) in litres/household/day; and
- per capita consumption (PCC) in litres/person/day.

Both PCC and PHC vary from house to house and region to region. The latest reported average PCC for England and Wales is 143 l/p/d[3]. While the average household consumption is around 349 l/h/day[4]. People living in properties with a water meter also tend to use less water (133 l/p/d) compared to those in homes without one (166 l/p/d).

Figure 3-1 shows the different areas 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.

Figure 3-1: Breakdown of the different areas of water use in the home (Source Artesia 2018)

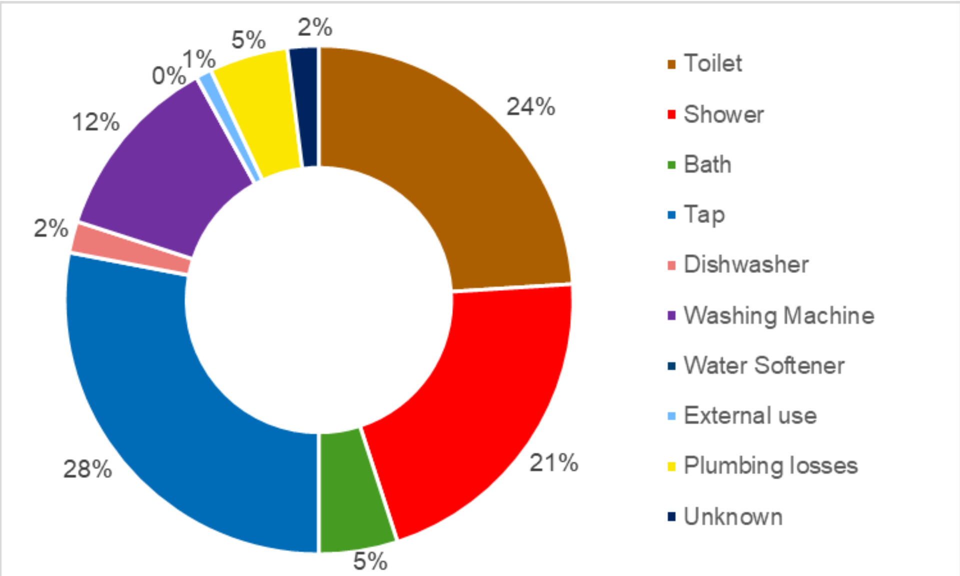


Figure 3-1 highlights that toilet flushing accounts for around 24% of daily personal use in the home. By substituting mains water for rainwater for toilet flushing the average PCC will reduce by around 34 l/p/d

[3] https://www.discoverwater.co.uk/amount-we-use
[4] https://energysavingtrust.org.uk/sites/default/files/reports/AtHomewithWater%287%29.pdf

to 108 l/p/d. A further 18.5 l/p/d could also be saved if rainwater was used to supply the washing machine and water to the garden, thus reducing PCC to around 90 l/p/d.

3.2.2 Non household water use

In total non-household consumption accounts for around 20% of all water put into the mains supply system in England and Wales. While its use varies significantly depending on the sector and size of the business, there is significant scope to use rainwater for activities such as toilet flushing and the irrigation of grounds in many commercial buildings.

The savings that can be achieved are also generally higher in commercial premises than in private dwellings as they typically have larger roof areas and a greater demand for non-potable water. Further savings may also be achieved through the reduction in stormwater being discharged from the property.

3.3 RWH systems, designs and technologies

Rainwater harvesting describes a variety of methods for the collection and storage of rainwater for potable and non-potable use. 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 storm water attenuation.

3.3.1 Types of RWH system

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. These systems can be classified depending upon how the harvested rainwater is stored and distributed within the installation. The British Standard (BS8515:2009 + A1:2013) provides guidance on the design, installation and maintenance of RWH systems for the supply of non-potable water, and applies to both retrofitting and new builds (British Standards Institute 2013). The Standard outlines three different system types:

- Direct or direct pumped system (as outlined in Figure 3-2): Harvested water is collected in storage tank(s) and pumped directly to the points of use within the building.
- Gravity or gravity only system: Harvested water is collected in the storage tank in an elevated position and fed by gravity to the points of use; and,
- Indirect or combination system: Harvested water is collected in the storage tank, pumped to an elevated cistern or header tank and fed by gravity to the points of use.

While these systems cover the broad types there are also additional variations and a number of different system designs and configurations are available. 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.

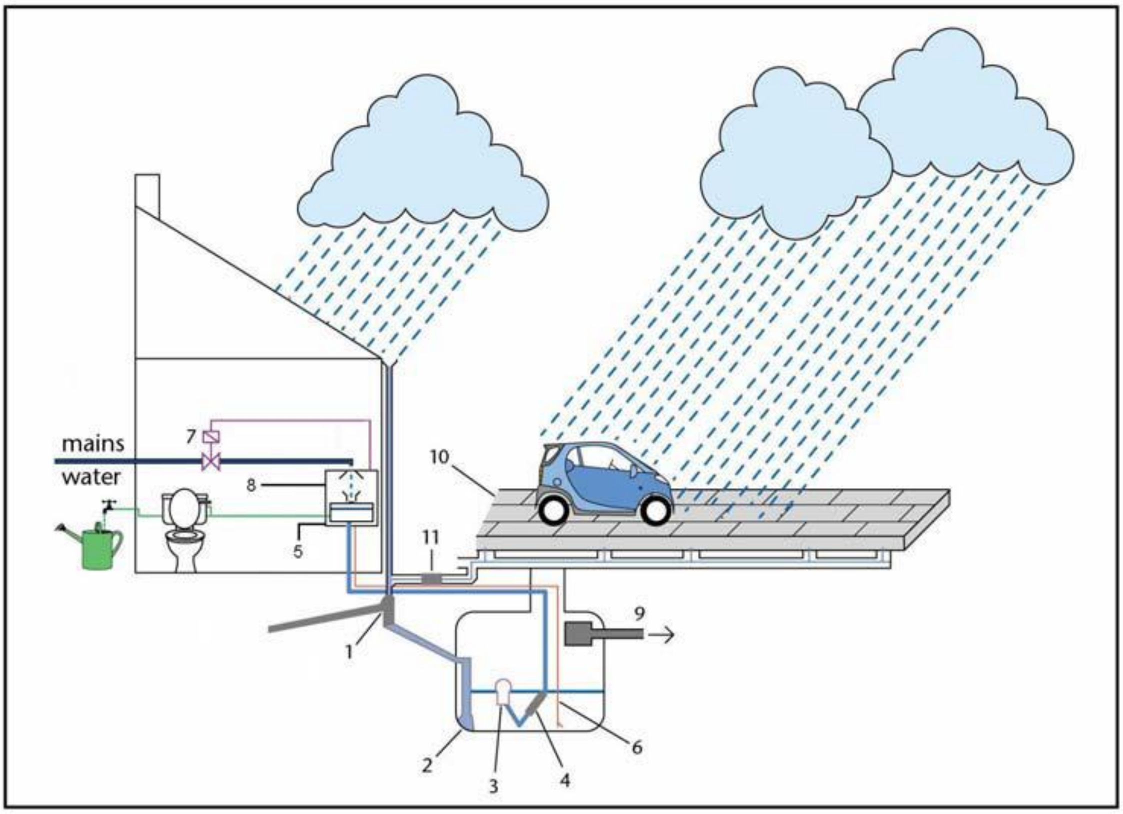
A comparison of the advantages and disadvantages of pumped flows delivered via direct-feed or header tank systems are provided in Table 3-1.

Table 3-1: 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.

Conventional RWH systems are relatively simple, consisting primarily of a catchment area, typically a building roof, a conveyance system (i.e. guttering and downpipes), a storage tank and interconnecting pipe work**.** Additional features such as filtration and treatment units may also be required depending upon the intended end use for the harvested water. Depending on the end use the system may also need to be connected to the mains supply to provide a backup in times of low flows. Figure 3-2 shows the configuration of a typical RWH system and the interaction of its main components. Each of the key components are outlined further below.

Figure 3-2: A typical RWH system (Reproduced from Environment Agency 2010)



(1) Filter; (2) Calmed inlet; (3) Suction filter; (4) Pump; (5) Control unit; (6) Water level monitor; (7) Automatic change over; (8) Type AA air gap; (9) Overflow trap; (10) Permeable pavement; (11) Oil trap.

3.3.1.1 Collection area

The most common collection surface is the rooftop, though other hard surfaces (e.g. paving or carparks) can also be connected to a rainwater storage tank. The size of the collection area and its construction material can affect the efficiency of water collection and water quality but in general the larger the collection area the more rainwater that can be collected.

Rainwater can also be collected from other surfaces (10) around a building but is likely to be more heavily polluted than that collected from a roof surface and may require additional treatment (e.g. an oil trap; 11).

3.3.1.2 Rainwater storage tank

The storage tank is a key component of the RWH system and one of the largest cost items. A key feature of rainwater storage tanks is a calmed inlet (2) which prevents water flowing into the tank from disturbing any settled sediment on the bottom of the tank. Tanks can be formed of a variety of materials including, polyethylene (PE), glass reinforced plastic (GRP), steel or concrete and can be located either above or below ground. The size of the storage tank affects both the volume of water that is possible to store and the initial capital investment required. Typically tanks are sized based on the capacity to hold around 18 days average rainfall although a range of tank sizes are available from small 500l capacity domestic tanks, through to large scale tanks which can hold around 300,000l. Where required further storage capacity can be provided through linking tanks together or through engineered ponds particularly as part of an integrated water management approach.

3.3.1.3 Electrical pump

In most RWH systems one or more electrical pumps (4) are commonly (but not exclusively) used to ensure that the appropriate water pressure is maintained across the building for the various uses or where it is necessary to distribute the collected rainwater from a ground level / underground storage point to an elevated position.

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 with the latter.

3.3.1.4 Filtration units

Filtration of harvested rainwater is the generally the first step of treatment (1) and prevents 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. A suction filter (3) located in the storage tank also prevents the uptake of floating matter when the water is drawn up for use.

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. The British Standard (BS8515:2009 + A1:2013) suggests that all filter systems have an efficiency of at least 90%[5] and a maximum particle size of <1.25mm is specified (British Standards Institute 2013).

3.3.1.5 Pipework

Rainwater from the tank travels through a separate set of pipes, as specified in the Water Supply (Water Fittings) Regulations 1999[6]. 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 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 3-3).

In non-domestic properties labels specifying the nature of the supply should be applied within 100mm, either side of the colour coding banding (Figure 3-3). 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 3-4).

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[5] 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.
[6] 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).

Figure 3-3: Examples of recommended marking and labelling for pipework within buildings (Reproduced from WRAS)

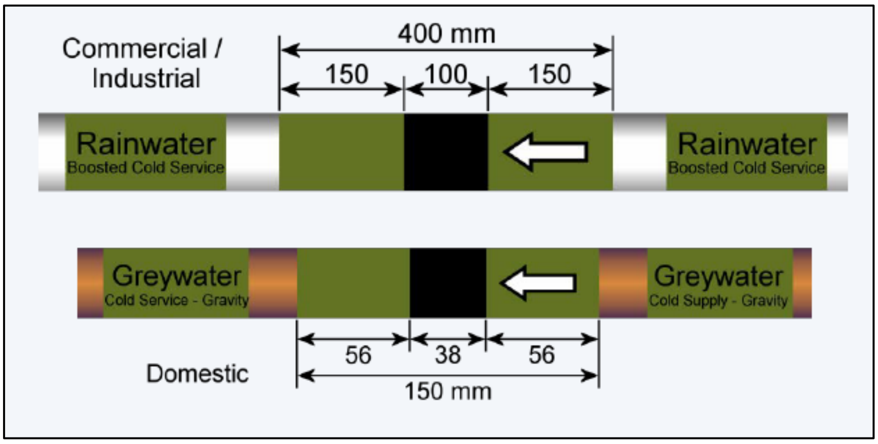


Figure 3-4: Examples of labels for use at the stop valve and other points of use (Reproduced from WRAS)

3.3.1.6 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 (5) monitors the water level in the storage tank via a water level monitor (6) and can display this information to the user. If levels drop too low, the system switches to the mains water supply (7) and if it gets too high, an overflow trap (9) allows excess water and floating material to be skimmed off to a soakaway or storm drain. A non-return valve also needs to be fitted to prevent contamination of the tank by backflow, together with a rodent barrier.

3.3.1.7 Mains back up supply and backflow prevention

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. The Water Supply (Water Fittings) Regulations[7] require that the mains water system is adequately protected from any potential contamination in the event of backflow occurring. The system must have a type AA or AB air gap (8) installed in order to prevent back flow of rainwater into the mains.

[7] 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).

3.3.1.8 Other treatment

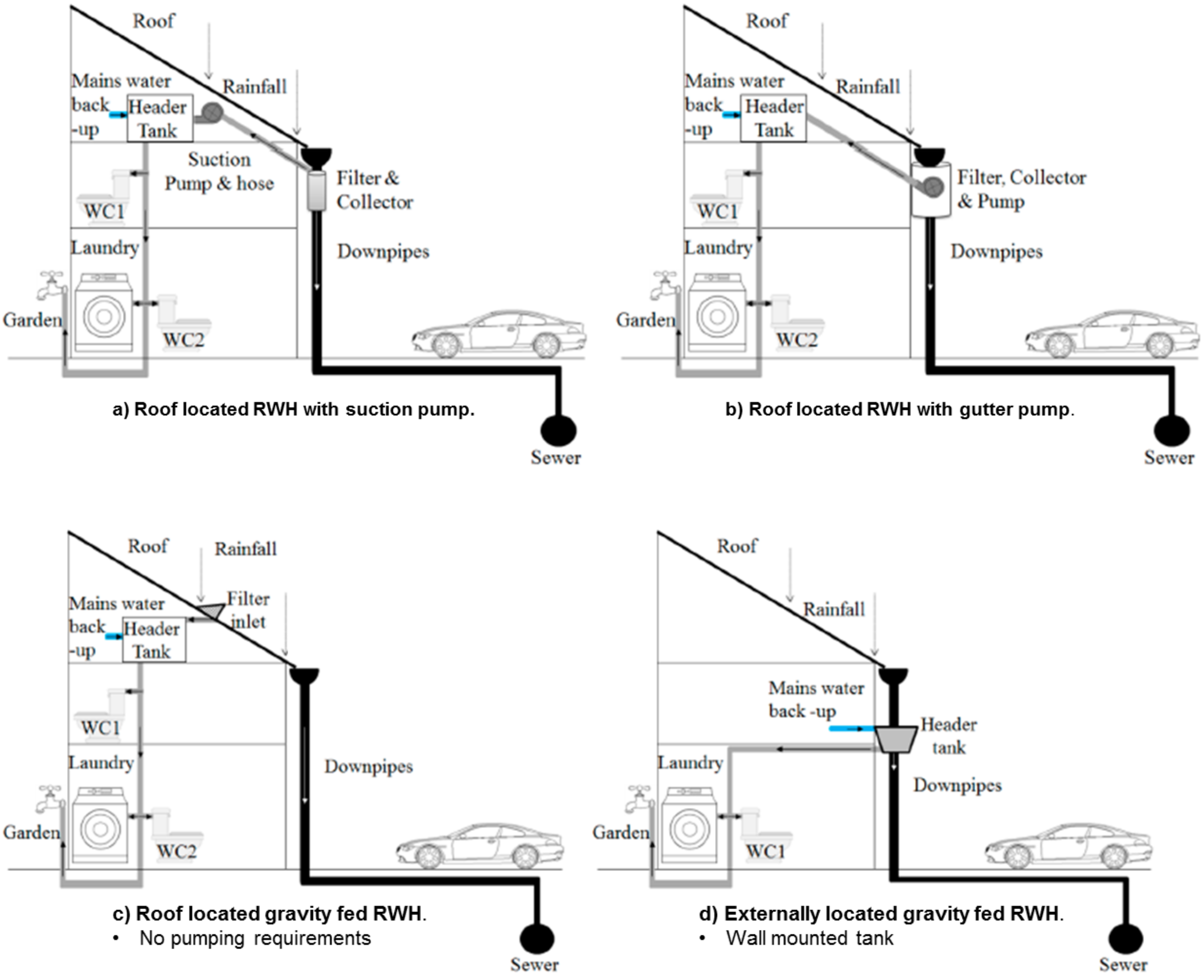
Depending on the intended end use of the harvested rainwater further treatment of the stored water may be necessary for example, by ultraviolet light, chemical treatment and or membrane filtration.

3.3.2 Innovative RWH designs and technologies

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 (located in the loft) low storage capacity (<1m^3) 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 3-5). These system configurations are better suited for retrofit as the installation is less invasive.

More recently RWH has also been combined to good effect within sustainable urban drainage systems as part of wider stormwater control and attenuation schemes. In these dual purpose systems 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 3-6).

Figure 3-5: Innovative RWH systems emerging in the UK market: High level roof runoff inlet (Reproduced from Melville-Shreeve et al, 2015)



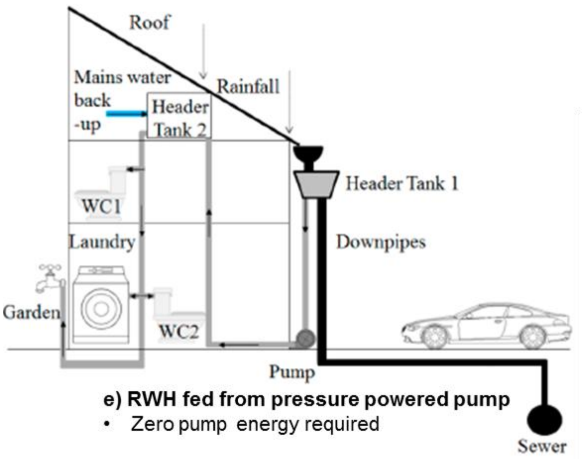
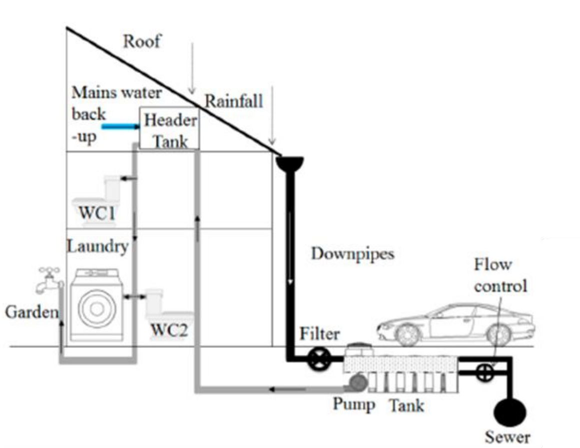
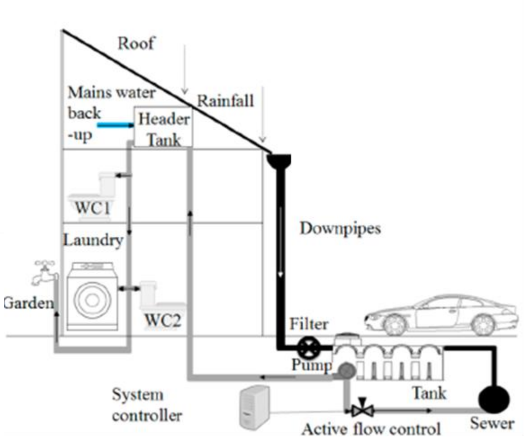


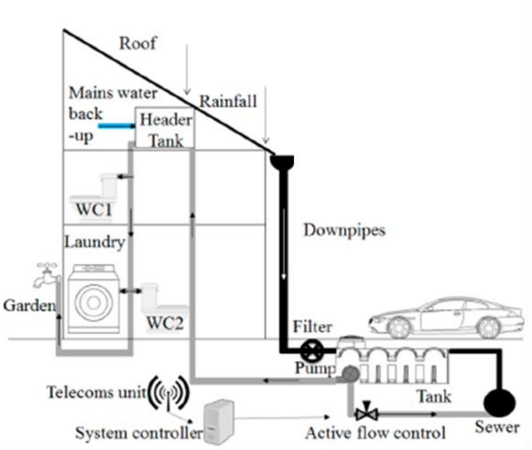
Figure 3-6: Innovative RWH systems emerging in the UK market: Dual purpose systems (Reproduced from Melville-Shreeve et al, 2015)



f) Traditional RWH with passive stormwater attenuation
- Upper region of tank drains via trickle orifice following storm



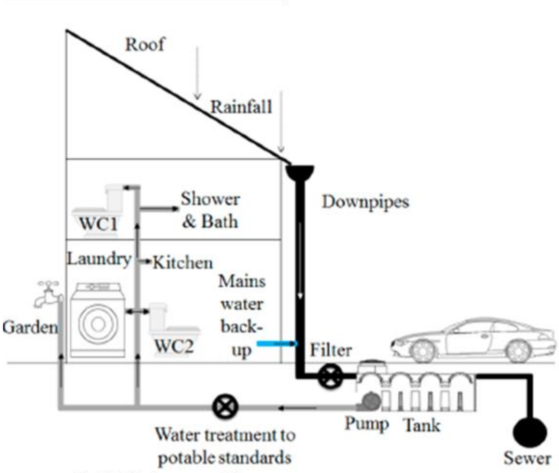
g) Traditional RWH with active stormwater attenuation.
- Active controller drains tank using pump as required



h) Traditional RWH with real time control for stormwater attenuation.
- Controller drains tank using pump based on instruction from telecoms system.

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 3-7).

Figure 3-7: Innovative RWH systems emerging in the UK market: Treatment to potable standards (Reproduced from Melville-Shreeve et al, 2015)



i) RWH for potable use.
- Potable standard treatment for full domestic use.

3.3.3 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. Maintenance should be undertaken in accordance to the manufacturer's guidelines however it is recommended that:

- Keep gutters free of debris to prevent blocking the system;
- Clean filters approximately three times a year, depending on tree cover over the collection area;
- Visually inspect the tank at least once a year;
- Check the mains water top-up once a year.

Under no circumstances should the rainwater storage tank be entered unless it's by a trained professional who has the appropriate equipment and training to work in confined spaces. Maintenance of large scale applications such as communal RWH systems should also be undertaken by a trained professional as part of an annual maintenance contract.

3.4 Application of RWH systems

RWH systems can be either retrofitted to existing buildings or incorporated at the development phase. Generally speaking installing RWH systems in new builds is easier and cheaper than retrofit. This is primarily due to the capital investment required and challenges associated with installation of such systems, in particular the siting of storage tanks and changes to pipework.

Retrofitting RWH systems can however be undertaken at a range of scales for both domestic and commercial buildings. Basic RWH systems configured around a high-level roof-runoff inlet, which facilitates the replacement of the large ground-level tank with wall-mounted or internal (located in the loft) low storage capacity (<1m^3) header tanks (see Section 3.3.2) can provide some benefits. Although smaller, these more basic systems may not save as much mains water as larger complex systems but they do offer simplicity, reliability and more cost effective parts and pumping requirements.

Due to their large potential collection areas and high potential demand for non-potable water commercial and industrial buildings are largely better candidates for the retrofit of RWH systems. Furthermore, 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.

New build installations also allow the necessary design and plumbing to be incorporated to allow for a wider range of RWH approaches. Where RWH is considered strategically involving planners, developers and water companies, significant benefits can be achieved and infrastructure costs avoided. Alternatively architects, designers, builders, and developers can future proof buildings so that they are rainwater-ready for example through the installation of dual pipework systems during construction.

3.4.1 Considerations when installing a RWH system

The suitability of a RWH system in a particular application is dependent on a number of factors including; how much water can be collected; how much water can be stored and costs. System performance must also be considered and is dependent upon the interplay between the characteristic of the catchment area, potential rainfall, water demand and the storage tank capacity.

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 = P x A x R x C

Where:

P = Local precipitation (mm/annum);

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

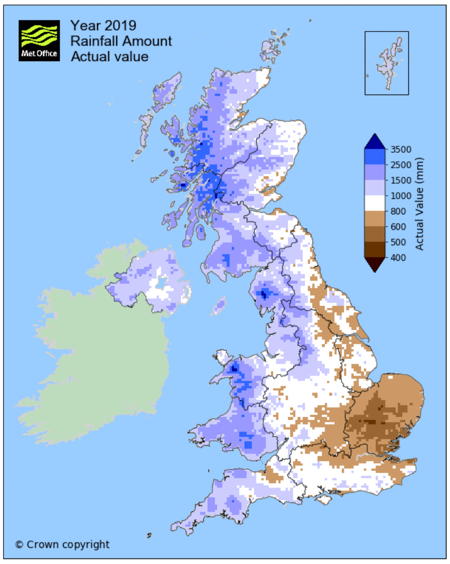
RC = Runoff coefficient - a measure of how efficiently water that is deposited upon a surface will be conveyed to storage.

Each of these factors are considered further below.

3.4.2 Annual rainfall

The patterns of rainfall are highly variable across different geographic regions and from season to season. As such the effectiveness of RWH as an alternative source of mains water can vary both regionally and temporally. In particular during periods of very low rainfall when mains water demand can be at its greatest. Figure 3-8 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 and Wales experienced much 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 3-8: Annual recorded rainfall of 2019[8]



3.4.3 Collection area and system performance

The collection area of a RWH system is the surface on which rainfall will land and collect before being transported to the storage area. Generally the larger the collection area the more rainwater that can be collected.

For rooftop RWH systems either the entire roof, or a section of roof area, will serve as the catchment area depending upon the arrangement of the guttering system, drainpipes, and the demand requirements of the building. RHW systems can also encompass the collection of surface water diverted from hardstanding areas around properties either for direct storage or as part of a wider SuDs system,

3.4.3.1 Collection losses

Not all the rain that falls on the collection area will be captured. There are a range of factors that can influence collection losses including climatic variables such as 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. 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 are more efficient than others at collecting rainwater as expressed in (Table 3-2) below.

Table 3-2: Runoff coefficients

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

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

3.4.4 Filter efficiency

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.

3.4.5 Rainwater storage tank sizing

As a general rule the storage tank size should be the lesser of 5%[9] of the annual rainwater yield, or 5% of the annual non-potable water demand. Three methods of tank sizing are outlined in the British Standard (BS8515:2009 + A1:2013) depending on the application and system complexity (simple, intermediate and detailed). Example calculations for a simple domestic system and an intermediate commercial system is provided in Figure 3-9. Further information on the detailed approach for larger RWH systems, where demand is irregular or where the yield is uncertain is available in British Standard *(*BS8515:2009 + A1:2013).

3.4.6 RWH in stormwater management

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**.** Dual purpose “retention and throttle” RWH systems designed and evaluated within proprietary drainage software show that RWH systems could be developed that provide 95% of the non-potable water demand whilst also maintaining sufficient attenuation capacity to control stormwater runoff during the 1 in 100 year design storm (Melville-Shreeve et al., 2014).

Figure 3-9: Example tank sizing calculations for a simple domestic system and an intermediate commercial system

Example 1: Simple domestic system

Three bedroom detached house with a pitched tiled roof and an effective collection area of 50m^2. The assumed runoff coefficient is 0.9 (as set out in Table 3-2 above). A manufacturer assumed filter efficiency of 90% and average annual rainfall in local area of 850mm/yr is also assumed. Tanks are normally sized on an annual rainwater yield of 5%.

Factor	**Unit**
Effective collection area	50m^2
Runoff co-efficient	0.9
Filter efficiency	0.9
Annual rainfall	850 mm/yr
Rainwater yield	0.05

Tank size = 50 x 0.9 x 0.9 x 850 x 0.05 = **1,721 litres or 1.7 cubic metres (m^3)**

[9] This equates to 18 days a year and is needed to take account of rainfall and demand variability. In practice there are diminishing returns for tank sizes designed using 7 or 8 days.

Example 2: Intermediate commercial system

Rainwater storage requirements based on relationship between potential rainwater yield (supply) and non-potable water demand within the building. The lesser of these two factors should be used to estimate the tank size.

Two storey office building with 200 full time equivalent staff. The building has a flat roof without gravel and an effective collection area of 1,065m². The assumed runoff coefficient is 0.8 (as set out in Table 3-2 above). A manufacturer assumed filter efficiency of 90% and average annual rainfall in local area of 615mm/yr is also assumed.

Factor	Unit
Effective collection area	1,065m²
Runoff co-efficient	0.8
Filter efficiency	0.9
Annual rainfall	615 mm/yr

Rainwater yield = 1,065 x 0.8 x 0.9 x 615 = 471,582 litres or 471 cubic metres (m³)

Non-potable demand (WC and urinal flushing) = 650m³/ year

As non-potable demand is > rainwater yield tank size based on storing 5% of annual rainwater yield as follows:

Tank size = 471*0.05 = **23,579 litres or 23.5 cubic metres (m³)**

3.5 Cost and performance

3.5.1 Costs of RWH systems

A key consideration prior to installing a RWH system is the cost of the system and potential return on investment. The findings from a detailed cost benefit analysis is presented in Section 3.6.

The cost 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. A general trend is observed with the price of a RWH system, which increases as the collection area and demand increases.

A small scale domestic system can cost from between £2,500 and £6,000 depending on the size of the storage tank. However, the costs of larger commercial systems can range from £8,000 to £70,000 for a 5m³ and 100m³ storage tank respectively. In general installing RWH systems in new builds is easier and cheaper than retrofit because of excavation required for installation of the tank and changes required to the existing plumbing arrangement.

The overall cost effectiveness of a RWH system is site-specific and depends on a number of factors including:

- Current water charges – the higher the cost of water the higher the benefits of a RWH system; and
- Maintenance costs – the level of maintenance required by the system during its life.

3.5.2 Energy use

The energy requirements and carbon emissions associated with a RWH system will vary depending on system type, scale, installation arrangements and water demand.

The main energy requirements in the operation of a RWH system are typically for pumping the collected water from the storage tank to the points of use and the system control unit.

3.5.2.1 Pumping

There are a number of variables that will have a direct impact on the energy used for pumping in a RWH system. These include the system type, location of the storage tank, the distance the water has to be pumped and the energy consumption and type of the pump.

- An underground storage tank may require greater effort from the pump than if located above ground.
- In a direct system the harvested water is pumped directly from the storage tank to the points of use within the building.
- In an indirect RWH system, the presence of a header tank allows water to be stored at an elevated level and the points of use are then gravity fed. This design reduces the overall pumping requirements of the system and allows the main pump to be used more efficiently, again reducing energy use.
- In a gravity system, pumping is not required as the collected water is fed directly by gravity to the points of use within the building.

A broad range of pumps are available and it's important to select a pump designed to suit the individual system 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. 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.

It is also important to make sure the pump chosen is correctly sized for the application. 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.

3.5.2.2 Ultraviolet treatment

In some applications where water quality is seen as a particular priority, ultraviolet (UV) treatment may be installed. UV disinfection requires energy, and, depending on the UV system configuration, the disinfection cycle will be a key driver of the total energy consumption in a RWH system. Energy intensities for UV of up to 2.15 kWh/m^3 have been reported however, UV disinfection systems with on demand operation can promote a reduction of the energy intensity when potable water standards are required.

3.5.3 Carbon emissions

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).

3.5.3.1 Embodied carbon

The embodied carbon emissions of a product or system is defined as the 'cradle to site' carbon footprint and includes sourcing of the materials, manufacture and distribution. The embodied carbon should be considered over the lifetime of the asset.

The largest embodied emissions are generally associated with the RWH storage tank, thus the size and type of material the tank is comprised are important factors. However if undamaged, a rainwater tank should last significantly longer than the typical 15 year manufacturer's warranty, thus the relative importance of embodied carbon emissions from the tank decreases over time.

A further consideration is the material used to surround the storage tank during underground installation. The use of pea gravel rather than concrete has led to lower reported emissions. In contrast, the embodied emissions associated with electrical pumps increases over time as typically they need replacing every 5-10 years.

3.5.3.2 Operational carbon

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. The level of operational emissions will depend on the energy requirements of the system and the source of electricity – where renewable energy is used to power the system emissions will be much lower.

3.5.3.3 Carbon implications

Previous reports suggest that RWH systems emit more carbon than water supplied by the mains water network with operational energy and carbon intensities of the systems studied higher than those for mains water by around 40%, for a typical rainwater application. However, the scale of carbon emissions will depend on the design of the system and components used and other studies have shown the emissions associated with RWH to be much more favourable.

Innovations in pump design and in low or no energy RWH systems have reduced the energy requirements of RWH systems and thus overall carbon emissions. Improvements, such as the use of variable speed pumps and pressure vessels have promoted 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. 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. 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.

Further to this there are a number of wider, less tangible benefits associated with the installation of RWH systems which are often not recognised in economic appraisals as they are not easily monetised. These are considered below.

3.5.4 Wider benefits

While RWH systems are primarily adopted to reduce potable water consumption from the centralised water distribution network, which through a reduction in abstraction provides a positive benefit to the environment, they can also be used to reduce frequency, peaks and volumes of urban runoff. By 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 surface water runoff thus preventing the inundation of the surface water drainage systems and treatment facilities. As a consequence load reduction mitigates sewer overflows and decreases watershed pollution in storm events while RWH systems also reduce the runoff and the transport of pollutants directly into water bodies

3.6 Modelling of the costs and benefits of RWH systems

This section considers the modelling of the costs and benefits of RWH. It sets out the data and assumptions that are used to evaluate RWH systems. The output of the section presents the costs, alongside the direct and indirect benefits of a RWH system over an expected 20 year lifetime. These costs and benefits are determined based on two factors which underpin the type of RWH system that would be required: the collection (roof) area of the buildings it is installed in and the demand for rainwater.

The section shares a number of similarities with the modelling section on GWR (Section 4.6) in terms of methodology and data. However, as they are separate systems and can be installed in isolation of one another, they are presented separately.

Finally, this section focuses solely on modelling the costs and benefits of installing RWH in new buildings and developments. This is primarily due to the data available, the modelling is based on real world data provided by suppliers, the majority of which was for installations in new developments. There was therefore insufficient data to assess the costs and benefits of retrofitting a RWH installation in an existing building. Despite this, a few brief points on retrofitting RWH systems can be made here.

The retrofit of the types of systems discussed can be prohibitively expensive given the invasive nature of the work involved (particularly for large developments). There are however less invasive RWH techniques that can be retrofitted, these typically involve smaller tanks that can be installed in the roof of a building. While they are often not suitable for larger buildings, they do offer a less invasive way to capture some rainwater in small buildings. Data on these types of installations has not been provided and therefore the potential costs and benefits of them have not been modelled.

3.6.1 Data sources / data used

The primary data source underpinning the cost benefit analysis (CBA) is a survey sent out to the suppliers of RWH systems to collect data on the type of installations and the buildings they are installing in. Key data collected from this survey is presented in Table 3.3. An overview of the other key data sources used in the analysis are included in Table 3-4.

Table 3-3: Key data extracted from supplier surveys

Rainwater harvesting systems
Building type.
Rainwater collection area (M^2).
Was it installed in a new building or retrofitted.
System type.
Size of tank.
Capital cost.
Operating costs.
Estimated annual rainwater used (M^3).
Annual mains water usage (M^3).

Table 3-4: Additional data sources

Name	Source	Explanation
Water prices.	Water companies websites.	Information on the price of water supply and wastewater was collected for the 11 companies that provide both water and wastewater in England and Wales. Collection was limited to these companies as they provided a good coverage and a representative sample of the country. An average of these numbers was used to determine a baseline water price for residential and non-residential buildings.

Name	Source	Explanation
Water supply infrastructure costs.	(Morales-Pinzón et al, 2012)	Provides data on the social and private cost and building additional water infrastructure based on £ per m^3 of additional water capacity.
Flood reduction benefit from RWH tanks.	(Ossa-Moreno et al, 2017)	Provided information on the potential benefit of RWH tanks to offset the damage from surface water through its collection.
Flood risk assessment for different UK geographies.	(Campisano et al, 2015)	UK flood risk assessments were used to determine the relative risk and severity of floods in different areas of the UK. River basins were used to categorise the different impact areas. Domestic dwellings at high risk of flooding and non-residential properties at risk of high risk flooding (defined as 'consequences to the economy') were used to determine the benefit associated with installing RWH in residential and non-residential properties.
Population data.	River basin management plans.	Population data at the river basin area and regional level was collected.
Amount of carbon in mains.	(DeBusk et al, 2013)	One of the indirect impacts assessed is how reducing mains water consumption can also reduce a household's carbon footprint.

3.6.1.1 Grouping RWH systems data

Data underpinning the type and size of RWH system was provided by supplier companies. In total information on 125 different rainwater harvesting installations that took place in England and Wales since 2012 was received from 3 different suppliers. This data was primarily for commercial installations, however, it allowed an estimate of the costs associated with installing a RWH system to be derived with confidence and the potential benefits of water savings that can be made. Limited data was provided for domestic installations.

Based on 125 available data points, an initial assessment was carried out to group the installations based on rainwater yield and water demand. Systems were grouped based on the collection area of the site and estimated water usage on site. Discrete variables were assigned to each site. In cases where the collection (roof) area (in M^2) had not been provided, the building type, its name and its use were compared to similar sites in order to produce an estimate. Demand categories were based on the estimated water use of the building. Similarly, in cases where this data was not available, the building type and its use were used to compare against similar buildings. The final classifications were the following:

Collection areas:

- Small = <500m^2,
- Medium = 500-2000m^2,
- Large = 2000-5000m^2,
- Very large = 5000m^2+

Demand levels (annual usage, and example building type):

- Low (1) = 1-1000m^3 (individual household, small commercial buildings i.e., shops),
- Small (2) = 1000-2500m^3 (commercial, public space, industrial building),
- Medium (3) = 2500-5000m^3 (office block)
- High (4) = 5000-10,000m^3 (residential development)
- Significant (5) =10,000+m^3 (large scale community or residential development)

Installations were assigned a size (collection area) category and a demand category, there were therefore 20 unique classifications that a building could be categorized as. After sorting the installations, three groupings ended up with no installations in them, these were: a small collection area with high demand, a small collection area with significant demand, and a very large collection area with a small demand. While it is possible that these intersections could exist, this was not considered to be a significant problem as it is unlikely that a site with a small collection area would have a very high demand and inversely unlikely that a site with a large collection area would have very small demand.

These groupings, and the costs and benefits produced for each group, are not expected to provide exact results as they simply present what could be considered a potential benefit based on past examples. Each installation grouping is based on an average of seven data points, making them potentially susceptible to anomalous or unique examples. However, the number of classification groups has been kept relatively large given the number of different building types and sizes that RWH systems could potentially be installed. If the number of groups were smaller than the range of data points within each group, any final estimates of the costs and benefits could have become unrepresentative.

Finally, there is a potential self-selection bias of the data underpinning this analysis. The evidence comes from buildings where RWH has already been installed and is therefore considered a 'good' investment. The circumstances which underpin this decision may not be the same as those for a building of similar size and demand and therefore the resulting costs and benefits may be different.

3.6.1.2 Costs of rainwater harvesting

The costs associated with installing a RWH system are split up in to three main costs:

- The capital expense of installing the system (CAPEX).
- The operating cost of maintaining the system (OPEX).
- The carbon cost including the carbon embedded in the tank and the physical system and the ongoing carbon cost associated with maintenance.

Information on all three costs was aggregated into the classification groups defined above, and an average CAPEX, OPEX and carbon cost was calculated for each grouping. The system is assumed to be installed in 2020 and have a lifespan of 20 years, the operating cost is assumed to be constant during this period and are discounted to the year 2020, the costs are assumed to be for a new installation. The results are shown in Table 3-5.

The collection area and demand groups provide an estimate on the size and type of system that is required for a building. It is necessary for a 2-diemensional understanding of a system, in terms of size and demand as both influence the overall size and scale of the system, for example a bungalow and a three story house might have the same roof size, and therefore same collection area, but have a higher demand in the latter, and therefore a larger system would potentially be installed.

A general trend is observed with the price of a RWH system increasing as the collection area and demand increases. When considering the average CAPEX cost by collection area and demand this is broadly true. There are some outliers in this cost information, most notably the average CAPEX for a building with 'significant' demand. There are two potential explanations for this, firstly, there are very few installations with an annual water demand over 10,000 m^3 a year. This is likely to be a large community or residential development with a bespoke system, while the costs are high, there are simply not enough examples of this type to gain an accurate understanding of the costs involved.

Secondly, in some very large developments, the practice can be to install a system of a number of smaller tanks which may reduce the overall cost. Finally, during these large scale community developments installing RWH will often be linked to other requirements such as the need for sustainable urban drainage (SuDS) this may reduce the cost of installing a system. However, there were insufficient data points to exclude or analyse linked systems like this separately.

Table 3-5: Average capital and operational expenditure and carbon cost of installing a rainwater harvesting system

Size	Demand	CAPEX	OPEX (annual)	OPEX (total)	Carbon cost	Total
Small	Low	£5,210	£ 416	£ 6,333	£ 590	**£12,133**
Small	Small	£11,674	£ 432	£6,566	£ 690	**£18,930**
Small	Medium	£ 11,300	£433	£ 6,579	£ 1,143	**£19,022**
Small	High	-	-	-	-	**-**
Small	Significant	-	-	-	-	**-**
Medium	Low	£ 17,963	£ 413	£ 6,281	£ 1,357	**£25,601**
Medium	Small	£ 26,273	£ 434	£ 6,605	£ 701	**£33,579**
Medium	Medium	£ 25,831	£ 712	£ 10,831	£ 1,070	**£37,732**
Medium	High	£ 15,303	£542	£ 8,237	£ 1,102	**£24,642**
Medium	Significant	£ 12,972	£ 622	£ 9,467	£ 1,075	**£23,514**
Large	Low	£ 14,645	£411	£6,246	£ 795	**£21,686**
Large	Small	£ 20,823	£ 793	£12,067	£ 933	**£33,823**
Large	Medium	£ 23,673	£ 650	£ 9,879	£ 1,151	**£34,703**
Large	High	£ 15,590	£537	£ 8,172	£ 1,154	**£24,916**
Large	Significant	£ 17,377	£ 2,164	£ 32,913	£ 1,444	**£51,734**
Very Large	Low	£ 17,085	£ 411	£ 6,251	£ 724	**£24,060**
Very Large	Small	-	-	-	-	**-**
Very Large	Medium	£ 18,427	£ 498	£ 7,572	£ 2,225	**£28,224**
Very Large	High	£ 41,382	£ 784	£ 11,918	£ 2,210	**£55,510**
Very Large	Significant	£ 19,492	£ 665	£ 10,117	£ 9,994	**£39,603**

Despite this, it is not possible to say for certain why larger systems are presented with lower CAPEX costs or if these are errors or not. Nevertheless, the study observes the overall trend of costs increasing as the size of the system increases. The change in CAPEX by collection area and demand are presented in Table 3-6 and 3-7

Table 3-6: Average CAPEX cost based on collection area

Collection area	CAPEX cost
Small	£ 10,046.00
Medium	£ 19,668.40
Large	£ 18,421.60
Very Large	£ 24,096.50

Table 3-7: Average CAPEX cost based on demand

Demand	CAPEX cost
Low	£13,725.75
Small	£ 19,590.00
Medium	£ 19,807.75
High	£ 21,068.75
Significant	£ 16,613.67

3.6.2 Benefits of rainwater harvesting

The benefits associated with a RWH system are split up into direct benefits, primarily the water saving at the site and into indirect benefits, these include CO_2 savings, flood damage reduction and reducing need for additional water infrastructure. The benefits are often dependent on geography and therefore calculations take into account the location (region) of the proposed site in order to understand the benefits (where this is not known, an average value is estimated).

3.6.2.1 Direct benefits (mains water saving)

The direct benefit of rainwater reuse is minimising the amount of water used from the mains supply. All households using a RWH system are assumed to have a metered system and therefore a reduction in water supplied by the mains will reduce the properties' water bill.

The average water use reported by supplier companies for installations of a specific collection area and demand is used to provide an estimate of the annual water use. This average figure is then multiplied by the average water price in the England and Wales based on the 11 companies that provide water and sewage services.

Table 3-8 shows the amount of water saved and the modelled saving on water bills split out by building type. The expected annual saving is also split by residential and commercial buildings due to the differing water prices. The assumed price (per m^3) for residential water is assumed for be approximately £1.50 whereas the average price for water paid by a commercial client is modelled as approximately £1.44.

The amount of water offset by the RWH system is assumed to be constant over the 20 year lifespan of the system however the change in water price over this period has been accounted for based on a DEFRA's 2015 water bill projection model (Defra, 2015). The annual change in price is a variable for both household and commercial customers.

Table 3-8: Annual mains water reduction and saving

Collection Area	Demand	Amount of mains water saved per year (M^3)	Annual cost saving for residential buildings (£)	Annual cost saving for commercial buildings (£)
Small	Low	52	£ 79	£ 70
Small	Small	1,189	£ 1,795	£ 1,592
Small	Medium	2,234	£ 3,373	£ 2,992
Small	Large	-	£ -	£ -
Small	Significant	-	£ -	£ -
Medium	Low	380	£ 574	£ 509
Medium	Small	1,268	£ 1,915	£ 1,699
Medium	Medium	2,571	£ 3,883	£ 3,444
Medium	Large	5,247	£ 7,924	£ 7,029
Medium	Significant	8,905	£ 13,448	£ 11,930
Large	Low	316	£ 477	£ 423
Large	Small	1,521	£ 2,297	£ 2,038
Large	Medium	3,310	£ 4,999	£ 4,434
Large	Large	4,953	£ 7,480	£ 6,636
Large	Significant	6,612	£ 9,985	£ 8,857
Very Large	Low	323	£ 487	£ 432
Very Large	Small	-	£ -	£ -
Very Large	Medium	4,133	£ 6,242	£ 5,537

Collection Area	Demand	Amount of mains water saved per year (M^3)	Annual cost saving for residential buildings (£)	Annual cost saving for commercial buildings (£)
Very Large	Large	4,079	£ 6,160	£ 5,465
Very Large	Significant	15,000	£ 22,653	£ 20,096

3.6.2.2 Indirect benefits

Like the direct benefits, the majority of indirect benefits stem from a reduction in the demand of mains. The exception is the flood damage reduction which is based on the size of the RWH tank.

CO_2 reduction from mains water

The reduction in water from the mains infrastructure assumes a reduction in the CO_2 embedded in that system. Analysis undertaken by the Environment Agency[10] has been used to access the price of carbon embedded in mains water. This is then inflated to reflect the increased carbon price. The amount of carbon in the water is assumed to be constant over the 20 year appraisal period and the analysis assumes approximately 7 tCO_2/Ml[11]. The carbon price however is expected to increase. The yearly cost of the carbon embedded in the mains water that is offset by a RWH system is set out in Table 3-9.

Table 3-9: Annual carbon cost of the water in the mains system offset by a RWH system

Collection Area	Demand	Annual CO_2 savings (tonnes)[12]	Annual cost
Small	Low	1	£ 17.25
Small	Small	28	£ 394.20
Small	Medium	52	£ 740.81
Small	Large	-	-
Small	Significant	-	-
Medium	Low	8	£ 126.04
Medium	Small	29	£ 420.57
Medium	Medium	60	£ 852.76
Medium	Large	123	£ 1,740.34
Medium	Significant	209	£ 2,953.63
Large	Low	7	£ 104.81
Large	Small	35	£ 504.49
Large	Medium	77	£ 1,097.87
Large	Large	116	£ 1,642.82
Large	Significant	155	£ 2,192.92
Very Large	Low	7	£ 106.97
Very Large	Small	-	-
Very Large	Medium	97	£ 1,370.84
Very Large	Large	96	£ 1,352.93
Very Large	Significant	353	£ 4,975.24

[10] Environment Agency (2008) Greenhouse gas emissions of water supply and demand management options
[11] This may not be entirely reflective of what happens in the water sector as there are currently plans to decarbonise the water supply. However this acts as a proxy if no action is taken. Introducing RWH is one (perceived) measure of reducing CO_2 in the grid and therefore it is consistent to access is based on the current CO_2 levels
[12] This figures may be inaccurate. No data was available on the amount of carbon in water, only the price of the carbon $1m^3$ of water. This was then divided by the BEIS 2020 traded carbon price which may be inconsistent with the initial carbon price used in EA (2008) Greenhouse gas emissions of water supply and demand management options

Reducing the need for new water infrastructure

Water demand is expected to grow significantly over the next 20 years, particularly in already water stressed areas. One of the key policy reasons for increasing the use of RWH is to alleviate some of this demand growth. A further indirect benefit is to capture how this use of these systems reduces the need for new water infrastructure.

The Average Incremental Social Cost (AISC) of water infrastructure, calculated by the National Infrastructure Commission was used to calculate the benefit in reducing water consumption, through installing RWH, on national infrastructure. The AISC is given in £/m^3 of water[13] and therefore an understanding of the benefits can be achieved based on the amount of water a system offsets.

A variety of infrastructure options are available and the specific type of infrastructure installed is likely to vary by location, however the specific infrastructure that would be installed in unknown and therefore an average value (£0.63 per m^3) is used.

Reducing flood damage through the use of RWH systems

RWH systems (particularly when installed en masse) have the potential to reduce the amount of flood water damage that occurs during and after a flood (caused by a storm). Damage from stormwater is reduced by water captured in RWH tanks rather than causing floods or damage to the sewer system. The average tank size for an installation of a specific collection area and demand is determined based on the installation data provided by suppliers.

Limited data is available on the benefits of RWH on flood damage reduction. The only studying which calculates the economic benefit of a system is based on a case study in London (Ossa-Moreno et al, 2017). While limited it does provide data on the benefit (£) per m^3 of tank size.

This cost is then weighted for different areas of the country based on potential and severity of flooding. UK flood risk assessments are used to determine the risk to human health and the risk to the economy (Table 3-10). These flood risk assessments were conducted at the river basin level, and the impacts were then weighted by either the population or the number of properties within that river basin catchment area, an average was then taken to account for the risks for considering the impact of installing when the region it will be installed in is unknown.

Flood damage reduction is therefore calculated by:

= (benefit per m^3 of tank (£)) x (average tank size) x (geographical weighting)

Table 3-10: UK Flood risk assessment by River Basin

River basin area	Number of people at risk of flooding	Non-residential properties at risk of flooding
Solway Tweed	1,656	224
Northumbria	4,217	833
North West	25,476	3,008
Humber	64,082	10,296
Dee	17,213	13
Severn	17,213	2,031
Anglian	42,206	4,563
Thames	77,885	5,535
South West	33,151	5,330
South East	30,223	3,671

13 This is the societal cost of water infrastructure expressed per m^3 of water.

The analysis here is conducted on a per installation level basis where it is not known where the system will be installed. A (smaller) single installation is unlikely to have much impact in reducing damage from storms and floods, however in an area where a large number of installations are installed, or where larger installations are introduced, such as in new housing developments or community schemes, these benefits may start to materialise, particularly when linked to other schemes such as SuDS. Therefore, while it is necessary to carry out the analysis on a per installation basis, and for all installations, the resulting benefit will depend entirely on the number of systems installed in a given area.

3.6.3 Results

Table 3-11 and Table 3-12 shows the costs and benefits of a rainwater harvesting systems broken down by size, the net impacts are assessed over an assumed 20 year lifetime and all impacts are discounted to 2020 prices.

RWH systems show a total net benefit across all collection areas and demand requirements in domestic buildings, and the vast majority of non-domestic buildings (the exception is small and very large buildings with high demand). However, all building types and sizes have the potential for a private net cost if water demand is low. The overall benefit increases both as the collection area and demand increases, this is primarily due to the size of the tank. Benefits are dependent both of on the ability to collect the rainwater (collection area) and the demand for it will influence the tank size and water reduction. A full breakdown of the costs and benefits by collection area and demand is provided in the Appendix 3 (see Table A3-1).

The costs also remain relatively constant by ranging between (approximately) £12,000 and £60,000. The range of private net benefits[14] and total net benefits is much more significant, private net benefits range between -£9,000 and £31,000 for a small building, and -£17,000 and £875,000 for the largest buildings and developments. When you consider the social benefits such as reduced infrastructure costs and flood reduction these net benefits increase further. For the very largest buildings with significant demand total net benefits could potential reach £1.2 million over 20 years[15].

The range of potential benefits is significantly larger than the costs and range between £20,000 and £1.2 million. These benefits include both the direct benefit reduction from mains-water saving and the indirect benefits, which includes the potential flood damage reduction, reduce water infrastructure costs and carbon savings. All these results are shown for installations in new buildings. A lack of data has prevented testing the costs and benefits for retrofitting installations however initial estimates suggest that this could increase the costs by up to 50%.

Table 3-11: Range of costs and benefits for installing RWH based on the collection area of a residential building

Collection area	Example building types	Costs: CAPEX + OPEX ('000 £)	Water cost savings ('000 £)	Private net benefits ('000 £)	Societal benefits ('000 £)	Total net benefit ('000 £)
Small (<500m²)	Standalone dwellings, Houses, Bungalows;	£12 - £19	£1 - £19	-£9 - £26	£21 - £77	**£10 - £100**
Medium (500 – 2000m²)	Some larger houses or two semi-detached houses;	£25 - £38	£8 - £200	-£17 - £150	£50 - £163	**£35 - £340**

[14] The private net benefit is calculated as the savings on water minus the CAPEX and OPEX costs.
[15] Very large collection areas with significant demand represent significant community developments such as the South bank case study or large residential developments.

Collection area	Example building types	Costs: CAPEX + OPEX ('000 £)	Water cost savings ('000 £)	Private net benefits ('000 £)	Societal benefits ('000 £)	Total net benefit ('000 £)
Large (2000 – 5000m^2)	Row of terraced houses or blocks of flats;	£20 - £35	£7 - £150	-£15 - £120	£35 - £335	**£20 - £450**
Very Large (>5,000m^2)	Large scale residential developments (including hybrid developments)	£35 - £60	£70 - £340	-£17 – £280	£30 - £920	**£14 – £1,200**

Notes: Building types are based on provided examples and an exact costing will depend on the size and scale of the project and different building types may fall in different collection area sizes. Water cost savings are the savings made from reduced mains water demand. Private net benefits look at the water savings vs total cost. Total net benefits also include CO_2 savings, infrastructure costs and flood alleviation.

The costs and benefits for commercial buildings follow a similar narrative as that for domestic buildings, the primary difference is that water prices are lower for commercial customers and therefore the saving made from offsetting it with rainwater are also lower (Table 3-12).

The major difference not explored here is the type of buildings that commercial spaces typically occupy. These tend to be larger and likely with a greater collection area and water demand (particularly compared to a single house). Similar to residential buildings a net private cost for buildings with the lowest demand is observed, a total net cost (including private and social benefits) for the smallest and very largest buildings if they have very low demand (this type of buildings is likely quite rare in practice) is also seen, and for larger demand requirements, both the private and total net benefits increase as demand increases.

Table 3-12: Range of costs and benefits for installing RWH based on the collection area of a commercial building

Collection area	Example building types	Costs: CAPEX + OPEX ('000 £)	Water cost savings ('000 £)	Private net benefits ('000 £)	Societal benefits ('000 £)	Total net benefit ('000 £)
Small (<500m^2)	Small commercial shops (such as a corner shop);	£12 - £19	£1 - £19	-£11 - £28	£8 - £51	**-£3 - £80**
Medium (500 – 2000m^2)	Retail and commercial stores, Leisure centres;	£25 - £38	£8 - £200	-£17 - £160	£23 - £150	**£6 - £315**
Large (2000 – 5000m^2)	Office blocks, hotels and shopping centres;	£20 - £35	£7 - £140	-£15 - £110	£16 - £190	**£1 - £300**
Very Large (>5,000m^2)	Large scale commercial developments (including hybrid developments)	£25 - £60	£7 - £315	-£17 – £260	£15 - £500	**-£3 – £742**

Notes: Building types are based on provided examples and an exact costing will depend on the size and scale of the project and different building types may fall in different collection area sizes. Water cost savings are the savings made from reduced mains water demand. Private net benefits look at the water savings vs total cost. Total net benefits also include CO_2 savings, infrastructure costs and flood alleviation.

There are a few key limitations that should be recognised and highlighted when considering these results. Firstly the analysis is heavily underpinned by the data received from the system suppliers, which for RWH amounted to 125 installations. While a sufficient range and different types of installations has allowed good estimates to be produced for different building types more examples would have allowed for more confidence in the average water use and tank size which underpins many of the calculations. Nevertheless, these results are only indicative of the types of costs and benefits one can expect to see and a site specific cost benefit analysis should be carried out by anyone considering installing a RWH system.

Furthermore, the collection area and demand bands that have been produced during this study are very broad and can include a number of different building types within them. For example, the vast majority of households, from installation in single terraced houses to large detached households with several people residing are classified as 'low' demand as most residential properties will use less than 1,000 m^3 per annum. Keeping the groups broad was required both due to the number of installation data points and the variety in water consumption observed between building types.

Moreover, as may be expected, there were limited examples or the larger community development installation. These installations are (when it comes to costs, set up and approach) highly context dependent. For example, large, multi-high-rise developments in city centres may make use of several smaller tanks to save on space whereas a large residential development may use one large tank. Given that there are very few examples of these to date, it is uncertain how representative those included are of similar types of installation.

Furthermore, while the analysis has attempted to take this in to consideration, the relatively small number of sites means that the variables that influence cost have not been fully accounted for, such as new build vs retrofit, above ground vs below ground or pairing with other systems such as SuDS. It was also not possible to split installation costs out by residential and commercial sites as originally intended. Where splits have been made between residential and commercial sites this has been on the basis of external factors that are known to affect the costs and benefits, particularly the different water prices of private and commercial customers

Finally, the relatively small number of installations means that the calculations are susceptive to outliers and situations where costs seem to decrease in larger sites. This is likely due to a specific context in the sites in that category that would make it a special case (such as those set out above). Nevertheless the overall trends and benefits associated with rainwater harvesting systems remain clear.

3.7 Water quality

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. Harvested rainwater should not be used as drinking water unless treated to a potable standards and there are strict regulations concerning the quality of water for drinking. Refer to the Drinking Water Inspectorate[16] for further information.

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. 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 collection surface. As such once the water is harvested and stored the quality may deteriorate from a microbiological perspective which can present potential health risks.

[16] http://www.dwi.gov.uk/

The British Standard (BS8515:2009 + A1:2013) 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 system. Tests should then be undertaken to investigate the cause of any system that is not operating satisfactorily and any complaints of illness associated with water use from the system. Guidelines for bacteriological and general systems monitoring are provided in the British Standard (BS8515:2009 + A1:2013).

3.8 Regulation and guidance

All RWH systems should be installed in accordance with the following:

- The Buildings Regulations 2010 (amended 2015);
- The Water Supply (Water Fittings) Regulations 1999;
- The British Standard (BS8515:2009 + A1:2013); and
- The manufacturer or supplier's instructions

Further advice and information is also provided by the Water Regulations Advisory Scheme (WRAS)[17] and the UK Rain Management Association (UKRMA)[18].

3.8.1 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 the minimum standards for water consumption in new dwellings. In England, this is 125 l/p/day with an optional target of 110 l/p/day where specified (HM Government 2016). In Wales, an amendment to Part G, which came into force in November 2018, stipulates a minimum standard of 110 l/p/day in new dwellings. Approved Document H (Part H: Drainage and waste disposal) also covers rainwater and grey water tanks and stormwater drainage (HM Government 2015).
- In Scotland, Section 3 (Environment) of the Buildings Standards Technical handbook 2017 covers water efficiency and surface water drainage however, specific water consumption targets are not currently specified in the technical guidance[19].
- In Northern Ireland, water and drainage are covered in Technical Booklets P and N but as in Scotland, specific water consumption targets are not currently specified in the technical guidance[20].

3.8.2 Sustainable urban drainage systems (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[21], 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,

[17] https://www.wras.co.uk/
[18] https://ukrma.org/
[19] See https://www.gov.scot/publications/building-standards-2017-domestic/0-general/01-application/
[20] See http://www.buildingcontrol-ni.com/regulations/technical-booklets
[21] http://www.legislation.gov.uk/ukpga/2010/29/contents

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 (Welsh Government 2019).

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 (Ministry of Housing, Communities and Local Government, 2019). 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[22] and in Northern Ireland SUDs are a requirement under Section 4 of the Water and Sewerage Services Act (2016)[23].

3.8.3 The Water Supply (Water Fittings) Regulations 1999

The Water Supply (Water Fittings) Regulations 1999[24] 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.

3.8.4 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.

3.8.5 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[25] Marking and identification of pipework for water reuse systems.

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[22] https://www.susdrain.org/delivering-suds/using-suds/legislation-and-regulation/scotland.html
[23] https://www.infrastructure-ni.gov.uk/sites/default/files/publications/infrastructure/water-and-sewerage-services-act-ni-2016.PDF
[24] 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).
[25] www.wras.co.uk/downloads/public_area/publications/general/ign/ign_9.02.05_version_feb_2015.pdf/

The Information & Guidance Note 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 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).

3.8.6 UK Rain Management Association (UKRMA)

The UKRMA is a trade body established by the manufacturers of surface-water and grey-water management systems, to promote water re-use as the most cost-effective way of helping to reduce future flood and water-shortage risks. The UKRMA website provides a good introduction to rainwater harvesting systems and a list of suppliers and installers of RWH equipment[26].

3.9 The use of RWH systems in other countries

The prevalence of RWH systems in many other countries is much higher than in the UK, where legal and economic conditions have been created to support or enforce the use of RWH as part of climate, environmental and social policies. In particular, where governments and local/regional authorities have under a legal framework, with financial incentives (subsidies, reductions or tax refunds) promoted measures for the installation and use of rainwater and RWH systems (see below). Further to this the high price of drinking water has increased the popularity of rainwater systems in countries such as Austria, Sweden, Switzerland, Belgium and Denmark.

3.9.1 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. 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). 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. 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.

3.9.2 Australia

Australia has one of the highest levels of implementation of RWH systems in the world, with about 1.7 million households having fitted rainwater tanks to their households. 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.

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). In addition, many Australian State governments have developed regulatory mechanisms to promote RWH systems.

3.9.3 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. The

[26] https://ukrma.org/

regulatory framework combined with national government requirement to grant financial support for subsidy programs promoting RWH is expected to provide a nationwide move to promote rainwater use. In 2015 the Japanese government also 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.

3.10 Case study examples

The Withys, Wareham
This small residential development of three private dwellings at The Withys near Wareham provides an example of small-scale domestic use of a RWH system to attenuate surface runoff and reduce mains water consumption. Each dwelling had a pitched roof with clay tiles and provided a total catchment area of the site of 185m^2. Due to poor ground conditions with a high clay content in the site geology the use of typical soakaways for the attenuation of site runoff was prevented. As such 6,000l rainwater tanks were specified for each dwelling which were split for rainwater storage and surface water retention.

These storage tanks provided a split storage capacity allowing 3,000l of surface water runoff from the 3-property development to be retained and discharged at a controlled rate, and 3,000l of harvested rainwater to be stored for non-potable applications within the development properties, including toilet flushing for 4 toilets and laundry.

Llys Enfys Care Home, Cardiff
A rainwater harvesting system was selected for implementation at the Llys Enfys Care Home in Cardiff to help assist in achieving a high BREEAM rating for the site. The property consists of a 68-room extra care facility. Due to high demand for toilet flushing (7 flushes per WC per day) a RWH system was installed to provide water savings to the site through the provision of non-potable water to the building's 76 WCs for resident and staff use.

The RWH system collects water from the 2,300m^2 catchment area of the shallow pitch membrane roof with symphonic drainage and conveys it to two 23,000L precast concrete storage tanks. The combination of the high annual rainfall and large catchment area yields up to 1,850m^3 of rainwater every year, with an estimated efficiency of 70%.

Tesco Extra, Havant
To meet the planning conditions for this Tesco Extra store in Havant, which allow for an increased site density the sustainable drainage plan required rainwater harvesting to be implemented. The site comprised a total catchment area of 800m^2 and the building incorporated a mono pitch with sheet cover and syphonic drainage.

Collected rainwater is filtered to remove any debris from the syphonic drainage system before entering a 12,000l capacity GRP tank. Due to the building construction an above ground tank was utilized within the system. The rainwater is distributed from the storage tank via a 300L stainless steel break tank by twin booster pumps on demand to the WCs and wash down points. A fine particle filter and ultraviolet filter was specified for additional treatment.

University Building, Central London
A bespoke RWH system was installed at a university building located in central London as part of a development project which needed to meet the tight space requirements of the site and the considerations under the London Plan[27] which specifies that all developments should consider the reuse of rainwater in the design of stormwater drainage.

The standalone rainwater harvesting system, operating in conjunction with attenuation, collects and stores rainwater, before filtering it through a robust treatment system for reuse in non-potable applications including toilet flushing. This system will contribute to the long-term infrastructure

[27] https://www.london.gov.uk/what-we-do/planning/london-plan

sustainability goals of London but in addition, through substitution of mains water for rainwater, it will ensure long term cost savings estimated to be around £4,500 each year. It is also estimated to provide water at a low energy cost of 1.5kW/h / m^3.

Museum of London, London[28]

Creating sustainable cities is a major issue and the Museum of London is committed to playing their part to improve London's environment. In doing so they challenged themselves to work more sustainably across all their operations and set out their environmental challenges in a Strategic Plan.

The Museum embraced the notion of large scale rainwater harvesting with its 850 m² flat roof and a 25,000 litre storage tank located in the basement. Monitoring of the system and the volume of rainwater through the Museum's Building Management System. The system supplies toilet blocks in newly refurbished corporate hire facilities as well as toilets in the Museum's bar and restaurant and Schools Lunch Space. Irrigation is also supplied by the system to the Rotunda area of green roof and Rotunda gardens.

Other commercial examples[29]

- At the Honda Dealership in Manchester a 30,000 litre tank was installed with a catchment roof area of 1,500 m² providing a water supply of around 85,000 liters a year and saving them nearly £1,700 in reduced mains charges.

- The Imperial Tobacco Head Office in Bristol used its 2,700 m² roof to feed into a 32,000 litre tank that was used to supply its toilets, with an estimated saving of over a million liters of water a year.

Downstream thinking programme, South West Water

In a pilot scheme aimed to reduce the risk of flooding residents in Exmouth are having RWH systems installed in a project funded by South West Water.

Most of Exmouth's homes are connected to a combined sewer, which takes both rainwater and wastewater. However, too much rainwater can cause sewers to overflow. By capturing and using the water close to where it falls, the amount of rainwater entering the sewer is reduced.

Around 30 houses have had special water butts or underground tanks installed at their homes. The tanks provide free water for homeowners but also provide spare capacity to hold back rainwater during storms. Half of the water captured from the householder's roof is available to use in the gardens and for flushing toilets and running washing machines. The other half of the tank trickles back into the sewer during dry conditions so that there is always capacity for the next rainstorm.

The tanks have been installed free-of-charge to homeowners as part of South West Water's Downstream Thinking programme, which is exploring sustainable approaches to drainage across the region.

Clay Farm – Cambridge[30]

Clay Farm is a mixed-use development across 109 acres of land to the south of Cambridge. The overall development was undertaken by Countryside Properties and comprises 2,300 homes, a primary and secondary school, local centre, community centre and park. The site features an integrated water management system including RWH and low water use fittings and fixtures.

The objective of the approach was twofold. Firstly, to attenuate site runoff, through mimicking the natural flow of runoff from the site and ameliorating peak flows through the use of water storage and

[28] https://www.museumoflondon.org.uk/application/files/8014/5451/4697/MOL_and_Rainwater_Harvesting_-_March_2015.pdf
[29] https://www.renewableenergyhub.co.uk/main/rainwater-harvesting-information/large-scale-commercial-rainwater-harvesting/
[30] CIRIA, Delivering better water management through the planning system, 2019

control features and, secondly, to reduce the water footprint of the site and the demand placed upon the public water supply.

A communal rainwater harvesting system has been installed on part of the site where rainwater from roofs and hardstanding areas including roads is collected in crate based storage tanks and discharged into a reedbed system. Treated rainwater is then gravity fed into a 250m^3 tank before being pumped into a centralised break tank system with mains back up facility. From the break tanks the treated water is used for WC flushing in 208 buildings.

The site was also designed with flood risk as a central consideration and where possible sustainable urban drainage systems (SuDS) are used to return water to the subsoil, reducing flood risk and ensuring biodiversity, with the assumption that 60% of the developable area is impermeable, with a pipe network to accommodate flows of the size of a 1 in 30-year rainfall event.

In addition to the communal RWH system and large scale drainage infrastructure, a range of green development measures are being included on individual development plots within the site including;

- Green roofs;
- Rainwater harvesting water butts;
- Attenuation at source measures using underground storage;
- Permeable surfaces with overflow to the piped network;
- Filter strips such as “French drains”;
- Shallow vegetated swales for conveyance and storage;
- Usage of existing ditches for flood protection and water quality;
- Dry detention basins / wet ponds;
- Canals / rills.

Overall the development has reduced mains water supply by around 5,000m^3 per year and a reduction in sewer flows has led to zero run off in non-extreme rainfall events.

Southbank Place, London

The Southbank Place mixed-use development provides 49,000m^2 of office space, 4,500m^2 of retail units, restaurants and cafés and 877 new homes across eight new buildings. This large-scale scheme built by Canary Wharf Group Plc was designed to accommodate a high demand for water and negate any impacts on the capital’s surface water drainage network. A key driver for the project was the Code for Sustainable Homes (CfSH) and BREEAM.

The overloading of urban drainage infrastructure, especially where there are new developments, creates a significant flood risk. Under The London Plan[31] all developments should consider the reuse of rainwater in the design of surface water drainage, however due to limitations on green infrastructure, and therefore no opportunity to consider the use of swales and soakaways, sustainable urban drainage (SuDS) options for the site were effectively limited to the attenuation of surface water and, due to the sub-basement levels on the build, controlled and pumped discharge to drain.

To address this an innovative water strategy was developed whereby non-potable water was collected in some buildings for us in other buildings. In addition five combined rainwater / attenuation tanks were installed with approximately 1,000m^3 storage capacity in a RWH system which responds to live weather forecast data. This dual purpose system, unlike traditional attenuation systems which deliver a continuous controlled discharge, responds to forecast weather conditions, holding rainwater in the attenuation tanks and only releasing enough to the sewer system in advance of rainfall to allow sufficient space in the tanks for the expected volume of new water. The collected rainwater is also used for non-potable applications such as toilet flushing, irrigation, vehicle washing and the building cooling systems.

[31] https://www.london.gov.uk/what-we-do/planning/london-plan

Overall the RWH system provides around 6, 900m^3 of water for non-potable uses each year, a significant proportion of Southbank's water requirements, thus reducing the demand on London's stressed water supply network and reducing additional pressures upon the surface water sewer system.

North West Cambridge[32]
The North West Cambridge Development is a 100,000m^2 site comprising 3,000 homes and other commercial uses (laboratories, office and retail). It includes the largest water recycling system in the country capturing up to 45% of rainwater to reduce potable water demand.

The surface water drainage strategy and water sensitive urban design approaches were integrated into the design from the start of development to enable opportunities to reduce flood risk and enable water harvesting and reuse to be maximised. All new houses are being built to Level 5/6 of the Code for Sustainable Homes and as such require a maximum consumption of 80 litres per person per day. In addition compliance with the Cambridge Area Action Plan requires two supplies of water; mains supply for potable use and a recycled water supply for non-potable use (e.g. washing clothes, flushing toilets and irrigation of gardens.

Rainwater is stored in the specifically designed green infrastructure areas and is treated through reedbed filters, ultraviolet light and chlorination before pumping back into homes for non-potable use. This integrated water management system captures between 25% and 45% of rainwater for recycling, with properties in the North West Cambridge development being among the most water efficient in the UK.

The system will reduce daily consumption of potable water across the site by over 45% through rainwater recycling and water efficiency measures. This equates to a saving of around 595m^3 each day when the development reaches full capacity. Furthermore, the design of the development reduces the risk of downstream flooding and ensures cleaner discharge water, reducing the risk of contamination of surface water courses.

3.11 Conclusions

This section provides information regarding the design, implementation and operation of RWH systems in a range of settings and for a range of building types. It provides an overview of the key areas for consideration when deciding to install a RWH system, including local rainfall, site specific requirements, maintenance, energy costs and carbon emissions and a summary of an analysis to model the costs and benefits of the technology. It concludes that:

- Rainwater harvesting offers a potential solution, and is increasingly being considered at the building-level, as a means for addressing water scarcity and storm water attenuation.
- Harvested rainwater can be used for a variety of non-potable applications either within a building or for irrigation of gardens. This alternative source of non-potable water therefore has the potential to reduce demand for mains water.
- Capturing rainwater or surface water at source can help reduce the volume and flow into drains and sewers, thus preventing the inundation of surface water drainage systems and treatment facilities. As a consequence load reduction mitigates sewer overflows and decreases watershed pollution in storm events while RWH systems also reduce the runoff and the transport of pollutants directly into water bodies
- A variety of RWH system designs and configurations are available and can be applied in a range of building types. RWH systems can be either retrofitted to existing buildings or incorporated at the development phase. In general installing RWH systems in new buildings is easier and cheaper than retrofitting into existing buildings.
- British Standards have produced BS 8515, RWH systems should comply with BS8515 to ensure maximum benefit and compliance with legislation.

[32] CIRIA, Delivering better water management through the planning system, 2019

  - BS 8515-1:2009+A1:2013 Rainwater harvesting systems – code of practice provides recommendations for the installation and maintenance of RWH systems.
- The suitability of a RWH system in a particular application is dependent on a number of factors including; how much water can be collected; how much water can be stored and costs. System performance must also be considered and is dependent upon the interplay between the characteristic of the catchment area, potential rainfall, water demand and the storage tank capacity.
- RWH systems need to be regularly maintained to ensure they continue to operate efficiently. Maintenance requirements can 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.
- The energy requirements of RWH systems will vary depending on type of system, installation arrangements and level of the demand. Recent innovations in pump design and in low or no energy RWH systems have reduced the energy requirements of RWH systems and thus overall carbon emissions.
- Previous reports suggest that RWH systems emit more carbon than water supplied by the mains water network. However, the scale of carbon emissions depend on the design of the system and components used and a number of more recent studies have shown the emissions associated with RWH to be much more favourable. This study has shown that RWH installations across all building sizes emit less CO_2 when compared to the CO_2 emissions embedded in mains water over a 20 year lifetime.
- The costs of installing a rainwater harvesting system are relatively constant and vary between £10,000 and £60,000 depending on the size of the tank and system required, this includes both the upfront costs and ongoing maintenance costs (over a 20 year lifetime). However, the benefits can range significantly. The majority of the data supplied for this study and thus underpinning this analysis relates to commercial installations and therefore the exact costs associated with installing a system in a residential building may vary.
- RWH systems show a total net benefit across all collection areas and demand requirements in domestic buildings, and the vast majority of non-domestic buildings (the exception is small and very large buildings with high demand). However, all building types and sizes have the potential for a private net cost if water demand is low. The overall benefit increases both as the collection area and demand increases, this is primarily due to the size of the tank. Further to this when the wider social (indirect) benefits, such as reduced demand on water infrastructure, CO_2 savings and flood damage reduction are also considered, the potential benefits increase substantially.
- For larger buildings, both domestic and non-domestic (such as office blocks, tower blocks with flats in and residential or community developments) there is the possibility for significant payback, both privately and socially if there is sufficient water demand. For the very largest buildings and developments significant benefits from flood damage reduction are achieved, as settings where large amounts of water can be captured and stored can have a serious benefit on flood alleviation.
- The integration of RWH and GWR 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 system should be considered carefully.

4 Grey Water Recycling

4.1 Introduction

This section provides an appraisal of grey water recycling (GWR) systems for non-potable uses in a variety of building types including domestic dwellings and commercial premises. It provides guidance for homeowners, house builders, planners, plumbers, architects and building managers.

It contains information on the types of GWR systems that are available and their application in new developments and refurbishments, including their design, installation and maintenance requirements. The costs and benefits of GWR systems are also outlined alongside examples that have been installed and are currently in use.

4.1.1 What is grey water recycling?

Grey water, especially where this is limited to that from baths, showers and washbasins (sometimes termed 'light grey water') can be considered high volume, low strength wastewater with high potential for reuse. Most existing buildings plumbing directs all wastewater to the sewer. Separating out grey water from the more polluted wastewaters (e.g. from toilets, often termed 'black water') means it can be treated and used as an alternative source of water for non-potable purposes. Therefore interventions that separate grey water for non-potable (generally sanitary) purposes reduce the quantity of mains water used. The term 'grey water recycling' in this study refers to the use of treated grey water. Generally, GWR systems can supply water for:

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

The review does to some extent cover direct systems 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).

4.1.2 Why consider a GWR system?

From a homeowner's perspective a modern GWR system may bring cost savings. In addition, awareness around climate and environmental issues is gaining momentum and people can gain satisfaction from getting more from their homes. The inclusion of GWR systems can also reduce reliance on mains supply, particularly valuable during droughts and 'hosepipe bans' when there would still be water available for watering gardens or washing cars.

From a commercial perspective, there is the potential for cost savings for new developments associated with the reduction in mains supply charges as well as other savings such as reductions in connection charges. In response to the increasing awareness around climate and environmental issues some businesses have strived for sustainably high performing buildings. Modern GWR systems can play an important role in this respect.

4.1.3 What savings can be achieved?

Up to 75% of water consumed in the home is transformed to grey water. The quantity of grey water that can be recycled and used depends on the demand in the building and the system employed. If used just for toilet flushing a well-designed, fully functional GWR system could potentially save a quarter of mains water used in a home. Greater savings would be achieved if the GWR system also supplied other applications such as garden watering. 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.

Reusing grey water not only reduces the consumption of mains water, it also reduces the volume of water discharged into the sewerage system. Therefore properties with water meters could save money on both their water supply and wastewater bills.

4.1.4 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/developer perspective there may be cost savings and the potential for greater appeal for developments that are sustainability led as described above. Both BREEAM[33] and the Home Quality Mark have points awarded for water re-use. Incentives or strategic agreements regarding infrastructure connections may also be offered by water companies to developers in an attempt to drive down water consumption in new developments.

The separation of grey water can reduce the volume sent to wastewater treatment plants. This creates space in the sewer network and therefore can contribute to reducing flooding risk. The use of the recycled grey water reduces the requirement for mains water and the costs and impacts associated with its supply and treatment. Therefore from an environmental and societal perspective GWR can lead numerous wider benefits including those that result from a decline in over-reliance and pressure on existing freshwater sources as well as promoting awareness of the water cycle and water conservation. Further detail on the benefits of GWR are included in Section 4.5.4.

4.2 Household and non-household water demand

4.2.1 Household water use

Household water consumption can be reported in two ways:

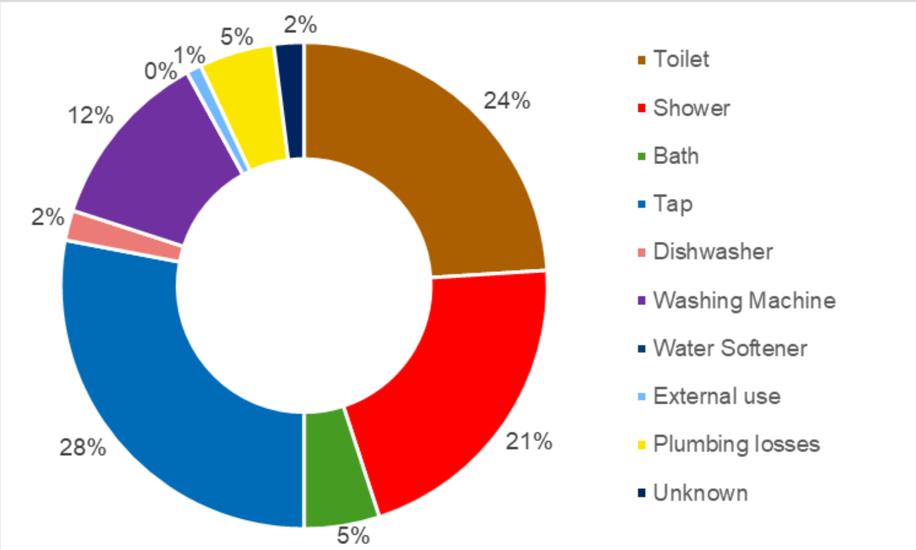
- per household consumption (PHC) in litres/property/day; and
- per capita consumption (PCC) in litres/head/day.

Both PHC and PCC vary from house to house and region to region. The latest reported average PCC for England and Wales is 143 l/p/d[34]. While the average household consumption is around 349 l/h/day[35]. People living in properties with a water meter also tend to use less water (133 l/p/d) compared to those in homes without one (166 l/p/d).

Figure 4-1 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.

[33] BREEAM is an international scheme that provides independent third party certification of the assessment of the sustainability performance of individual buildings, communities and infrastructure projects.
[34] https://www.discoverwater.co.uk/amount-we-use
[35] https://energysavingtrust.org.uk/sites/default/files/reports/AtHomewithWater%287%29.pdf

Figure 4-1: 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.

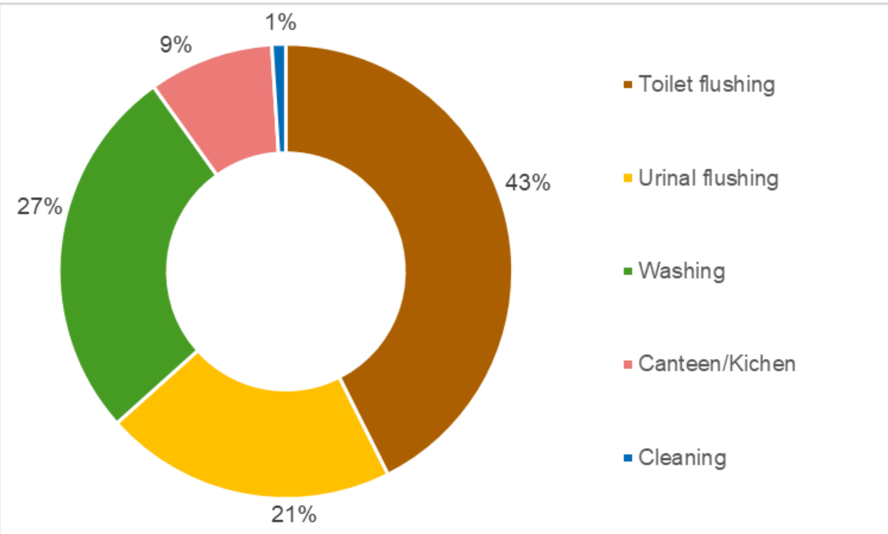
4.2.2 Non household water use

In total non-household consumption accounts for around 20% of all water put into the mains supply system in England and Wales. 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 application of GWR systems. 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 variability in water consumption by individuals or households (this is discussed further in the sections below).

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. A typical consumption pattern for offices is shown in Figure 4-2.

Figure 4-2: Water use in offices (Source: CIRIA 2006)



For hotels, research has identified a significant correlation between the star rating of the hotel and water consumption. Another significant factor is whether the hotel facilities include a swimming pool.

4.2.3 Demand for grey water

As shown in Figure 4-1, 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. However, the way people use water and the amount of grey water produced in a building can vary greatly. 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. Fi shows that in an office setting the water demand for toilet and urinal flushing may be greater than that what could be supplied by grey water sources available from the same building. For this reason mixed use developments where the GWR system is designed in a strategic way can effectively use the excess grey water from domestic sources to contribute to the demand of office buildings.

4.2.4 Perceptions of GWR systems

There is reported concerns over public acceptability of GWR (the 'yuck' factor) (Policy Connect, 2018). However, several studies have been conducted to assess public perception towards water reuse in different parts of the world many of which have identified clear support for the concept of GWR. Public support for GWR is often greater in areas which are water stressed and areas with unreliable water supply.

A recent Waterwise study in the UK reported 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 not compromised (Waterwise 2019). The generally high level of positivity towards the idea of reuse systems could be interpreted as a reflection of 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.

4.3 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. Table 4-1 characterises the levels and treatment technologies usually implemented for GWR.

Table 4-1: 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

4.3.1 Types of GWR systems

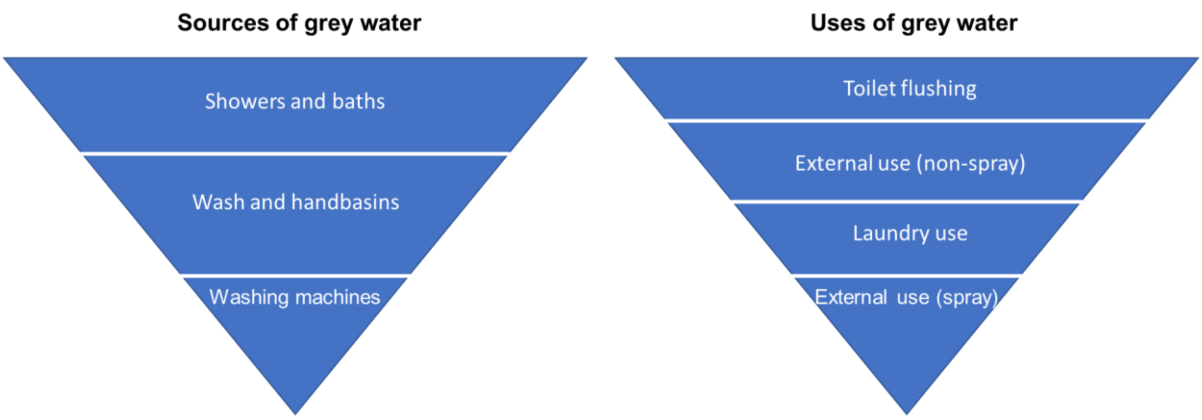
In the UK, GWR systems need to comply with the British Standard (BS) 8525:2010 which groups GWR systems according to the type of filtration or treatment they use (see Table 4-2 below) (British Standards Institute 2010).

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.

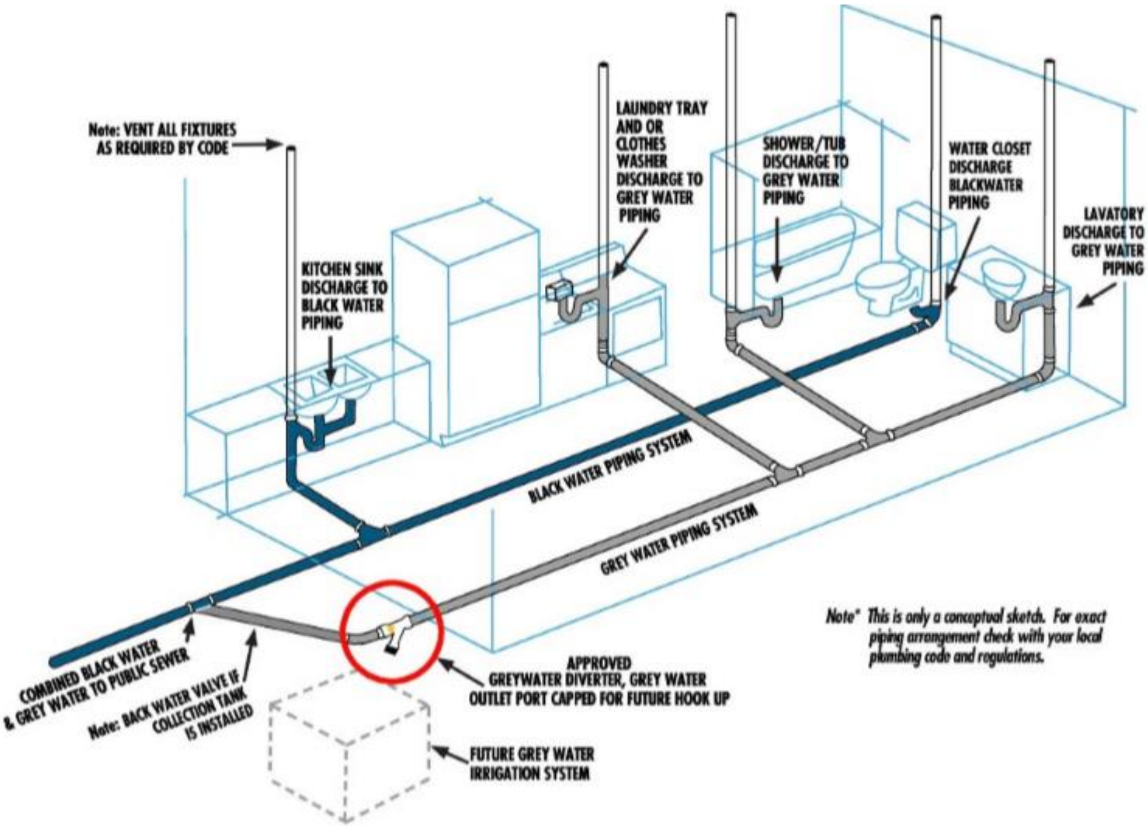
In order to prevent the collection and treatment of water that cannot be used, BS 8525-1:2010 recommends that demand should drive the specification of the GWR system. The code of practice also recommends a hierarchy of sources and uses of grey water so the GWR system can offer the best quality treated water for non‑potable uses without having the additional burden of treating the most heavily contaminated grey water (see Figure 4-3).

Figure 4-3: Hierarchy of sources and uses of grey water



As shown in Figure 4-4, depending on the how many applications the GWR system supplies in a building and how integrated it is there will be the need for dual plumbing of the drainage system. 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 4-4: 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 4-2, also presents some examples of GWR systems.

Table 4-2: 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. 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. 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. 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.	 Source: The WaterGreen (Droughbuster) Syphon Pump  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.	 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. The Aquaco Aquawiser Domestic Direct Grey Water System[36] collects, filters, disinfects and stores grey water collected from showers, baths and hand basins for supplying water to flush WCs.	 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. The Green Roof Water Recycling System (GROW)[37] 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.	 Source: Water Works UK Ltd.

[36] https://www.aquaco.co.uk/datasheets/
[37] 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 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. An example is the SDS GWOD[38] 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.	 Source: SDS Ltd.
Hybrid systems	These systems use a mix of the system types detailed above. 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. The Aquality[39] 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.	 Source: Aquality

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

4.3.2 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 and have been removed from the market. Similarly the basic physical/chemical systems may not achieve BS 8525:2010 and although capable of treating water quickly have been reported as being unreliable. In terms of biological systems, the group is broad and each of the different 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.

The most significant developments over the last decade 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.

4.3.2.1 Bio-mechanical systems and hybrid systems

Membrane processes can consistently produce high water quality as they are a physical barrier to a wide range of pollutants including microorganisms. They require a small footprint for their implementation. For these reasons, membrane processes have significant potential to be used for GWR applications. 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. Most of the main GWR system suppliers in the UK involve membrane technology in their products.

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 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. The unit has had attention regarding its aesthetics to make it attractive for domestic installations.

4.3.2.2 Nature Based Solutions

Constructed wetlands are well established systems for water treatment. They fall under the 'Biological' treatment type in Table 4-2. They employ an artificial wetland constructed utilising ecological technology to mimic conditions that occur in a natural wetland. Green walls and green 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). 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[40]. NbS is an 'umbrella concept' for other established nature-based approaches which includes green infrastructure.

4.3.3 Integrated GWR and RWH systems

The British Standard (BS8525-1:2010) 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 (British Standards Institute 2010). It highlights important points that need to be addressed before integrating the two systems including:

[40] https://www.naturebasedsolutionsinitiative.org/what-are-nature-based-solutions/

- 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 8525:2010.
- 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 RWH 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.

4.4 Application of GWR systems

4.4.1 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 wastewater from 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 consideration given that most housing stock already exists.

4.4.2 New build residential installations

Generally speaking increasing water efficiency in new build homes is easier and cheaper than retrofit. 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.

4.4.3 Commercial installations

Since the 2011 Environment Agency report 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 and dialogue with manufacturers suggests GWR systems are best suited to the larger commercial market (such as hotels, supermarkets, and multipurpose developments) due to the nature of their water use supply versus demand equilibrium.

Some GWR system companies now focus exclusively on large commercial and new build developments and consider retrofitting GWR systems not to be commercially viable.

4.4.4 Maintenance

Once installed, it is important that users are made aware of the GWR system maintenance requirements. These vary depending on the GWR 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. British Standard (BS8525-1:2010) provides a maintenance schedule for use in the absence of any manufacturer's recommendations.

4.4.4.1 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. Not doing so could lead to either system failure or expose people to increased levels of contamination in the water that is recycled for reuse. It is therefore critical these factors are considered during the design stage when selecting the most suitable alternative water system.

However, 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.

4.4.4.2 Commercial

A combined design, installations and maintenance service is often provided for by the manufacturers/suppliers of GWR systems for commercial settings. For example one manufacturer/supplier highlights that their specialist teams often install and maintain their designed systems which include an integrated non-potable water management strategy utilising RWH, 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.

4.5 Costs and performance

4.5.1 How much water can be saved?

4.5.1.1 Domestic

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[41]). 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[42] each year on the wastewater element of their bills. The average water bill in 2020 is £397[43], therefore a saving of 25% to 50% would represent between ~£100 and ~£200. Note that prices presented throughout this section are as identified in 2020. These relatively small savings are reflective of the low unit price of water in the UK. It should be noted that these values are

[41] Based on average charge of 1.5/m^3
[42] Based on average charge of 0.78/m^3
[43] https://discoverwater.co.uk/annual-bill

based on average household consumption values, greater savings will be achieved where consumption is higher for example in larger houses with more occupants.

4.5.1.2 Commercial

There is limited reported information regarding the savings that can be achieved from commercial GWR systems. Information presented on suppliers' 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 to 86%) and apartment/hotels (51%). 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.

4.5.2 Capital and operational costs

4.5.2.1 Domestic

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 irrigate 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 £3,000.

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. The payback period is influenced by the quantity of grey water recycled and reused and the price of water supply and sewerage charges. Historically the payback period of domestic GWR systems has been relatively long and potentially longer than the operational life of the system. However, with modern GWR designs and sufficient demand for the recycled grey water payback periods can be less than 4 years.

Section 6 provides the cost benefit analysis based on the data provided by suppliers for this study. Although this is limited to commercial buildings or large multi-dwelling apartment blocks. The cost of installing GWR in a single house will therefore be smaller than the lower boundary provided in cost benefit analysis in Section 4.6.

4.5.2.2 Commercial

The capital and operational costs of commercial GWR systems can be significant, however, these systems are considered to present high system efficiency. 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. Further details and explanation is presented in Section 6, which provides the cost benefit analysis based on the data provided by suppliers for this study. Payback periods of 3 and 5 years are also being reported by some manufacturers. Carbon and energy impacts

Energy requirements and carbon emissions will vary depending on type of GWR system, installation arrangements and level of the demand. The carbon emissions of a GWR 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 and other past research (Memnon et al, 2016) identified that, apart from short retention systems, more carbon is generally emitted 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, 2017, Hyde et al, 2018, 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 et al, 2017).

4.5.3 Wider environmental benefits

GWR systems can have beneficial effects to society and the environment in terms of sustainable water resource management. There are benefits regarding increased resilience to climate change and future water scarcity. Wider benefits also relate to the environmental and social benefits associated with reduced 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 also presents benefits with respect to water supply and wastewater network capacity and the requirement for infrastructure improvements. 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). 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.

4.6 Modelling of the costs and benefits of GWR systems

This section considers the modelling of the costs and benefits of GWR. It sets out the data and assumptions that are used to evaluate GWR systems. The output of the section presents the costs, alongside the direct and indirect benefits[44] of a GWR system over an expected 20 year lifetime. Unlike the analysis of RWH, the type of GWR system implemented is only dependent on a single factor, the expected yield. This is primarily due to the linear relationship between demand for water in a GWR system and the water produced (both being a function on the number of people using the system, however it is also influenced by the availability of data of GWR systems).

The section shares a number of similarities with the modelling approach for RWH (Section 3.6) in terms of methodology and data. However, as they are separate systems and can be installed in isolation of one another, they are presented separately.

Finally, this section focuses solely on modelling the costs and benefits of installing GWR in new buildings and developments. This is primarily due to the data available, the modelling is based on real world data provided by suppliers, the majority of which was for installations in new developments. There was therefore insufficient data to assess the costs and benefits of retrofitting a GWH installation in an existing building. Despite this, a few brief points on retrofitting GWH systems can be made here. Retrofitting the type of systems discussed here can be prohibitively expensive given the invasive nature of the work involved (particularly for large developments) and the requirement for significant additional plumbing to be carried out. There are however less invasive GWH techniques that can be retrofitted, these typically involve smaller tanks that can be installed on the side of a property and can be feed either out of a bathroom window or through a small hole in the wall. While they are often not suitable for larger buildings, they do offer a less invasive way to capture some grey water in small household. Data on these types of installations has not been provided and therefore the potential costs and benefits of them have not been modelled.

[44] Sometimes referred to as private and social costs

4.6.1 Data sources / data used

The primary data source underpinning the CBA is a survey sent out to the suppliers GWR systems to collect data on the type of installations and the buildings they were installing in. Key data collected from this survey is presented in Table 4-3 below:

Table 4-3: Key data extracted from supplier surveys

Grey water recycling systems
Building type
Building occupancy
Was it installed in a new building or retrofitted
System type
Treatment type
Capital cost
Operating costs
Estimated annual grey water used (M^3)
Annual mains water usage (M^3)

An overview of the other key data sources used in the analysis are included in Table 4-4. More detail on the exact data and how it is used is discussed in the methodology section.

Table 4-4: Additional data sources

Name	Source	Explanation
Water and wastewater prices	Water company websites	Information on the price of water supply and wastewater was collected for the 11 companies that provide both water and waste in England and Wales. Collection was limited to these companies as they provided a good coverage and a representative sample of the country. An average of these numbers was used to determine a baseline water price for residential and non-residential buildings.
Water supply infrastructure costs	(Morales-Pinzón et al, 2012)	Provides data on the social and private cost and building additional water infrastructure based on £ per m^3 of additional water capacity
Amount of carbon in mains	(DeBusk et al, 2013)	One of the indirect impacts assessed is how reducing mains water consumption can also reduce a household's carbon footprint

4.6.1.1 Grouping GWR system data

Data underpinning the type and size of GWR systems was provided by supplier companies. In total information on 22 different GWR installations that took place in England and Wales since 2012 was received from 3 different suppliers. The dataset is not expected to be an exhaustive list of all GWR systems installed and the limited number of installations does increase the exposure of outliers in the data. However, it does allow an estimate of the costs associated with installing a GWR system and the potential water savings that can be made to be established.

Based on the 22 data points, an initial assessment was carried out to group the installations based on solely on yield. The number of data points for GWR systems required installations to be grouped in to a smaller number of bands and only based on one factor, however this was not considered to be a significant problem as the size of the system is primarily a function of GW yield and the relationship between demand and yield is linear.

Installations were assigned a yield category based on information provided on the number of inhabitants in a buildings (or the number of people that used the building for commercial buildings) where this information was not provided by the supplier, an estimation was made based on the type and size of the building. The final yield classifications were:

- Low (1) = 1-500m^3 (individual household),
- Small (2) = 500-1500m^3 (commercial, public space, industrial building),
- Medium (3) = 1500-4000m^3 (office block)
- High (4) = 4000-10,000m^3 (residential development)
- Significant (5) =10,000+m^3 (large scale community or residential development)

The exact grouping bands differ slightly from the demand bands for RWH to better reflect the yield in different building types and to reflect the spread of installations for which data was received.

These groupings, and the costs and benefits produced for each group, are not expected to be exact results and they simply present what could be considered a potential benefit based on past examples. Each grouping was estimated using on average 4 data points, making them potentially susceptible to anomalous or unique examples.

Finally, there is a potential self-selection bias of the data underpinning this analysis. The evidence comes from buildings where GWR has already been installed and is therefore considered a 'good' investment. The circumstances which underpin this decision may not be the same as those for a building of similar yield and demand and therefore the resulting costs and benefits may be different.

4.6.1.2 Costs of grey water recycling systems

The costs associated with installing a grey water system were split up in to 3 mains costs:

- The capital expense of installing the system (CAPEX).
- The operating cost of maintaining the system (OPEX).
- The carbon cost including the carbon embedded in the tank and the physical system and the ongoing carbon cost associated with maintenance.

Information on all three costs was aggregated into the classification groups defined above, and an average CAPEX, OPEX and carbon cost was calculated for each grouping (Table 4-5). The system is assumed to be installed in 2020 and have a lifespan of 20 years, the operating cost is assumed to be constant during this period and the final cost is discounted to the year 2020.

Table 4-5: Total costs for GWR broken down by yield

Yield	Example building types	CAPEX	OPEX (annual)	OPEX (total)	CO_2 costs (total)	Total
Low (<500m^3)	Smaller households (such as retired people or young adults), small commercial shops.	£ 19,500	£ 1,600	£24,334	£ 88	**£43,922**
Small (500 – 1,500m^3)	Larger households (potentially families).	£ 54,133	£ 2,950	£44,866	£641	**£99,640**
Medium (1,500 – 4,000m^3)	Retail and commercial stores, leisure centres, some offices.	£ 78,605	£ 2,700	£41,064	£1,376	**£121,045**

Yield	Example building types	CAPEX	OPEX (annual)	OPEX (total)	CO_2 costs (total)	Total
Large (4,000 – 10,000m^3)	Large commercial settings such as shopping centres, multi-unit offices or flats.	£ 107,889	£ 3,967	£60,328	£2,111	**£170,328**
Significant (>10,000m^3)	High rise offices or blocks of flats, hotels, multi-purpose developments.	£ 178,000	£ 5,767	£87,704	£3,667	**£269,371**

The CAPEX and OPEX costs are calculated based on the average costs supplied by suppliers (for new builds) for all installations within each yield band. No information on the amount of embedded carbon was provided by suppliers, information provided in the 2011 Environment Agency report 'Energy and carbon implications of rainwater and grey water harvesting' (Dixon et al, 1999) has been used as a proxy. Examples were provided for a number of different systems in various building sizes. These were allocated a yield category and an average was taken. This provided the amount of CO_2 embedded in the system, across it entire lifetime, a 2020 carbon price was applied to estimate the cost of this embedded CO_2.

Overall the calculations show that as the yield (or demand) for GW increases in a building the overall costs of installing that system will increase, this is due to a larger system (in terms of tank as well as treatment system) being required. Finally, these estimations are all made on the assumption that a system is being installed at the time of building. This is primarily due to only data being available on new builds. Analysis shows that retrofitting these systems can increase the capital costs by up to 50%.

4.6.2 Benefits of GWR

The benefits associated with a GWR system are split up into direct benefits, primarily the water saving that the site makes and indirect benefits, these include CO_2 savings and reducing the need for additional water infrastructure. The benefits are often geography dependent and therefore calculations take in to account the location (region) of the propose site to understand the benefits (where this is not known an average value is used).

4.6.2.1 Direct benefits (mains water and wastewater saving)

The direct benefit of grey water recycling is minimising the amount of water used from the mains and the amount discharged to sewer. All households using a GWR system is assumed to have a metered system and therefore a reduction in water supplied by the mains will reduce the properties' water and wastewater bill.

Installation data provides an estimate for the amount of mains water that the GWR system offsets, an average based on the yield group is then calculated. It is also assumed that the same amount of water will be diverted from going to the sewer network for reuse and therefore there will be a second benefit. The average mains water saving for each group is then multiplied by the average water price to calculate the amount of mains water saved, a second calculation using the average water usage and the cost per m^3 of wastewater is then used to calculate the wastewater savings.

Table 4-6 shows the amount of water saved and the modelled saving on water bills split out by building yield. The expected annual saving is also split by residential and commercials buildings due to the differing water prices. The assumed price (per m^3) for residential water is assumed to be approximately £1.50, whereas the average price for water paid by a commercial client is modelled as approximately £1.44. The wastewater discharge price for residential and commercial buildings is modelled as £1.58

and £1.59 respectively which is the average price of the 11 water companies in England and Wales that provide water and sewage services.

The amount of water offset by the GWR system is assumed to be constant over the 20 year lifespan of the system however the change in water price over this period has been accounted for based on a DEFRA's 2015 water bill projection model (DeBusk and Hunt 2014). The annual change in price is also variable for household and commercial customers.

Table 4-6: Mains water offset by GWR and the cost savings for residential and commercial buildings

Yield	Amount of mains water saved per year (M^3)	Annual mains water cost saving for residential buildings (£)	Annual wastewater cost saving for residential buildings (£)	Annual mains water cost saving for commercial buildings (£)	Annual wastewater cost saving for commercial buildings (£)
Low (<500m^3)	106	£ 160	£ 168	£ 152	£ 168
Small (500 – 1,500m^3)	1,132	£ 1,710	£ 1,790	£ 1,627	£ 1,799
Medium (1,500 – 4,000m^3)	2,496	£ 3, 769	£ 3,947	£ 3,587	£ 3,966
Large (4,000 – 10,000m^3)	3,824	£ 5, 775	£ 6,047	£ 5,496	£ 6,076
Significant (>10,000m^3)	10,900	£ 25,523	£ 26,724	£ 24,288	£ 26,850

4.6.2.2 Indirect benefits

Like the direct benefits, the indirect benefits stem from a reduction in the demand of mains (and sewage) water).

CO_2 reduction from mains water

The reduction in water from the mains infrastructure assumes a reduction in the CO_2 embedded in that system. Analysis undertaken by the Environment Agency[45] has been used to access the price of carbon embedded in mains water. This is then inflated to reflect the increased carbon price. The amount of carbon in the water is expected to be constant over the 20 year appraisal period however the carbon price increases, the analysis assumes approximately 7 tCO_2/Ml[46]. The breakdown by system size is presented in Table 4-7.

Table 4-7: Annual mains water carbon saving from GWR systems

Yield	Example building types	Annual cost
Low (<500m^3)	Smaller households (such as retired people or young adults), small commercial shops.	£ 35
Small (500 – 1,500m^3)	Larger households (potentially families).	£ 375

[45] Environment Agency (2008) Greenhouse gas emissions of water supply and demand management options
[46] This may not be entirely reflective of what happens in the water sector as there are currently plans to decarbonise the water supply. However this acts as a proxy if no action is taken. Introducing RWH is one (perceived) measure of reducing CO_2 in the grid and therefore it is consistent to access is based on the current CO_2 levels

Yield	Example building types	Annual cost
Medium (1,500 – 4,000m^3)	Retail and commercial stores, leisure centres, some offices.	£ 828
Large (4,000 – 10,000m^3)	Large commercial settings such as shopping centres, multi-unit offices or flats.	£ 1,268
Significant (>10,000m^3)	High rise offices or blocks of flat, hotels, multi- purpose developments.	£ 5,605

Reducing the need for new water infrastructure

Water demand is expected to grow significantly over the next 20 years, particularly in already water stressed areas. One of the key policy reasons for increasing the use of GWR to alleviate some of this demand growth. A further indirect benefit is to capture how the use of these systems reduces the need for new water infrastructure.

The Average Incremental Social Cost (AISC) of water infrastructure, calculated by the National Infrastructure Commission is calculate the benefit in reducing water consumption, through installing GWR, on national infrastructure. The AISC is given in £/m^3 of water[47] and therefore can be used to understand the benefit that an installation would have based on the amount of water it offsets.

A variety of infrastructure options are available and the specific type of infrastructure installed is likely to vary by location, however the specific infrastructure that would be installed in unknown and therefore an average value (£0.63 per m^3) is used.

Reducing flood damage

Reducing the impacts of floods has been considered as a potential benefit for both RWH and GWH installations. Flood damage occurs when the sewer system becomes overwhelmed and cannot transport a sufficient amount of surface water runoff (from storms etc…) during a flood. While GWH does reduce the amount of wastewater sent to the sewage system and therefore allow more capacity for surface water, the impact of this is likely to be minimal and therefore has not been modelled.

4.6.3 Results

Table 4-8 shows the costs and benefits of installing a GWR system broken down by the expected yield of the system. The net impacts are assessed over an assumed 20 year lifetime and all impacts are discounted to 2020 prices.

The results show that for the smallest system types, those typically installed in individual houses or potentially for a small block of flats systems there is a net private cost[48] for all systems, which shows that the cost of installing a GWR system is greater than the financial savings made from the reduced amount of water used. For larger buildings, including larger blocks of flats, large multi house residential developments or community developments the water savings exceed the cost of installing the system.

The exception are buildings (or developments) with very high yields where the introduction of GWR systems becomes cost effective.

[47] The societal cost of water infrastructure expressed per m^3 of water.
[48] A net private cost just looks at the CAPEX and OPEX costs and the mains and waste water savings

Table 4-8: Costs and benefits of installing a GWR system in a building based on the systems yield (greywater produced)

Yield	Example building types	Costs (CAPEX + OPEX; '000 £)	Total water cost savings ('000 £)	Private net benefits ('000 £)	Societal benefits ('000 £)	Total net benefit ('000 £)
Low (<500m^3)	Smaller households (such as retired people or young adults), small commercial shops.	£ 45	£ 5	-£ 40	2	**-£ 37**
Small (500 – 1,500m^3)	Larger households (potentially families).	£ 100	£ 52	-£ 48	£18	**-£ 30**
Medium (1,500 – 4,000m^3)	Retail and commercial stores, leisure centres, some offices.	£ 120	£ 108	-£ 13	£34	**£ 25**
Large (4,000 – 10,000m^3)	Large commercial settings such as shopping centres, multi-unit offices or flats.	£ 170	£ 190	£ 21	£67	**£ 88**
Significant (>10,000m^3)	High rise offices or blocks of flat, hotels, multi-purpose developments.	£ 270	£ 780	£ 510	£275	**£ 787**

Notes: Building types are based on provided examples and an exact costing will depend on the size and scale of the project and different building types may fall in different collection area sizes. Building types/groupings are the same for commercial and residential GWH installations. Water cost savings are the savings made from reduced mains water demand. Private net benefits look at the water and sewage savings vs total cost. Total net benefits also include CO_2 savings and infrastructure costs

A slightly different narrative emerges when the net social impact (this include the CO_2 impacts as well as reduced stress of water infrastructure) are considered. There is a net cost for low and small yield buildings, however for medium and larger buildings, essentially, all buildings or development with more than one dwelling in it, there is a social net benefit.

There are a few key limitations that should be recognised when considering these results. Firstly the analysis is heavily underpinned by the data received from the system suppliers, which for GWR amounted to 22 installations. This is not a large number of installations hence the overall accuracy of the results is uncertain. However, research into GWR systems has shown there are few installed in the UK (compared to RWH) so it is difficult to assess the impact, particularly if they were to be installed at scale.

The data also presents a narrative that GWH is less cost effective than RWH, this is likely due to the fact that installing GWH appears to be more expensive than RWH and GWH does not provide a flood alleviation benefit (which can be a significant social benefit for larger RWH installations). However, the key message is that given the vastly different size difference in the two dataset, the fact that RWH benefits are presented as a range[49] compared to GWH which presents a single indicative cost and that the two systems are grouped by different metrics (size vs yield) means that any comparison between

[49] The range here represents the varying demand of a building but also illustrates that the benefits of RWH are highly depends on external factors, chiefly rainfall.

the two should be undertaken with significant caution. Site specific CBA of both RWH and GWH should be carried out in order to determine what the best option for a specific development is.

Moreover, as may be expected, there were limited examples of the larger community development installation. These installations are (when it comes to costs, set up and approach) highly context dependent. For example, large, multi-high-rise developments in city centres may make use of several smaller tanks to save on space whereas a large residential development may use one large tank. Given that there are very few examples of these to date, it is uncertain how representative those included in this analysis are of similar types of installation.

Furthermore, while the analysis has attempted to take this in to consideration, the relatively small number of sites means that all the variables that influence cost have not been fully accounted for, such as new build vs retrofit, above ground vs below ground or pairing with other systems such as RWH. It was also not possible to split installation costs out by residential and commercial sites as originally intended.

Finally, the relatively small number of installations means that the calculations are susceptive to outliers and situations where costs seem to decrease in larger sites. This is likely due to a specific context in the sites in that category that would make it a special case (such as those set out above). Nevertheless, the overall trends and benefits associated with grey water recycling systems remain clear.

4.7 Water quality

4.7.1 Water quality of grey water

The composition of grey water varies and is a reflection of the lifestyle and the type of chemicals used for cleaning, bathing and laundry (if included as a source of grey water). Grey water can be characterised by high concentrations of easily biodegradable organic materials as well as nutrients (e.g. nitrates and phosphates), xenobiotic organic compounds and biological microbes (e.g. faecal coliforms) and general hydrochemical constituents.

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.

4.7.2 Water quality of recycled grey water

Different GWR systems have different treatment capabilities. The choice of technology for GWR will usually be driven by the water quality to be achieved. Selection of a particular technology will then be determined by several other factors including influent quality, capital and operational cost, available space and its ability to cope with variations in the influent quantity and quality.

Risk to human health is related to the end points or end-uses of the recycled grey water. Considering the scope of this study, water quality and implications regarding risk to human health are considered in the context of using recycled grey water for toilet flushing, irrigation/outside water use and laundry. Section 4.8 below describes the water quality that a well-designed and maintained GWR system is expected to achieve for the majority of these sorts of applications and operating conditions.

4.7.3 Contamination

Sound design, 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 risks to users of mains water arising from potential cross-contamination of mains systems through misconnection or other errors. It also includes 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 backsiphonage, 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 in the British Standard (BS8525:2010) as potentially posing a serious health risk and must not under any circumstances be allowed to come into contact with the wholesome domestic drinking water supplies.

4.8 Regulation and guidance

All GWR systems should be installed in accordance with the following:

- The Buildings Regulations 2010 (amended 2015);
- The Water Supply (Water Fittings) Regulations 1999;
- 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
- The manufacturer or supplier's instructions.

Further advice and information is also provided by the Water Regulations Advisory Scheme (WRAS)[50].

4.8.1 Buildings Regulations 2010 (amended 2015)

The Building Regulations 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 G - Part G1 – Cold water supply signposts relevant information and guidance documentation. This includes the WRAS Information & Guidance Note No. 9-02-05 Marking and identification of pipework for reclaimed (grey water) systems which is discussed further in Section 4.8.4 below.

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 BS 8525:2010) the water efficiency calculation methodology set out in Appendix A of Approved Document G must be followed.

4.8.2 Water quality guidelines and monitoring

British Standard (BS 8525-1:2010) states that it is essential that GWR systems are designed in a way that ensures the water produced is fit for purpose and presents no undue risk to health. The guidelines in BS 8525 have taken the standards included in the Bathing Water Directive[51] and developed values based on detailed research into specific applications where grey water is to be used. The guidance recommends that whilst frequent water sampling is not necessary, it is good practice to observe water quality during maintenance checks.

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 4-9 for parameters relating to health risk, and Table 4-11 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 4-10. The results of general system monitoring should be interpreted with reference to Table 4-11 and Table 4-12.

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[50] https://www.wras.co.uk/
[51] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32006L0007&from=EN

Table 4-9: Guideline values (G) for bacteriological monitoring (British Standards Institute 2010)

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 4-10: Interpretation of results from bacteriological monitoring (British Standards Institute 2010)

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.

Table 4-11: Guideline values (G) for general system monitoring (British Standards Institute 2010)

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 4-12: Interpretation of results from system monitoring[A] (British Standards Institute 2010)

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

The tables provide an indication of the water quality that a well-designed and maintained system is expected to achieve for the majority of operating conditions.

4.8.3 Water quality guidelines and monitoring

The Water Supply (Water Fittings) Regulations 1999[52] 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. These Regulations require that the correct level of backflow prevention is provided to prevent contamination of the public mains water supply. For GWR 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 highlight that all water reuse systems will be inspected recorded and registered.

4.8.4 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 (2015) Information & Guidance Note No. 9-02-05 Marking and identification of pipework for reclaimed (grey water) systems.

The Information & Guidance Note 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 in Figure 4-5.

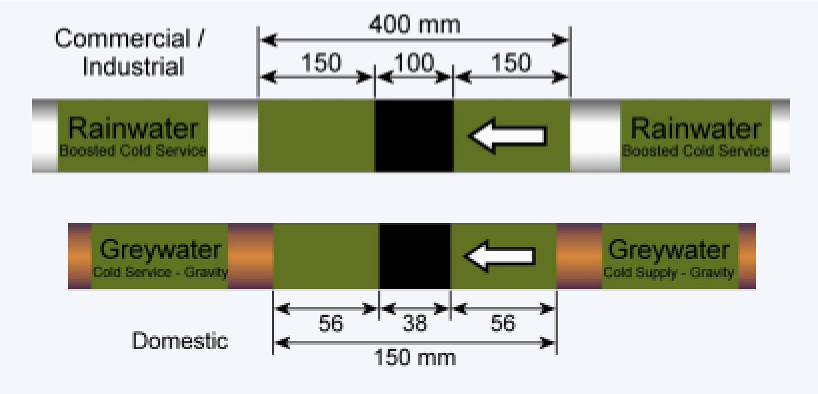
In accordance with BS 1710[53] 'Specification for identification of pipelines and services' pipes that distribute reused water should be colour coded with a green-black-green banding (British Standards Institute 2014):

- 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.

[52] 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).
[53] Currently under review (08/07/2020)

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

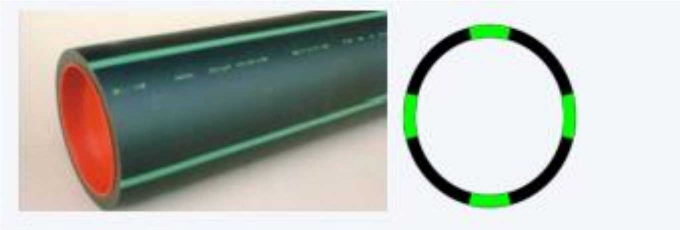
Figure 4-5: Suggested labelling of internal pipes containing reclaimed water for both nondomestic and domestic properties (extract from WRAS Information & Guidance Note No. 9-02-05)



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.

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 (see Figure 4.6).

Figure 4-6: 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 4.7 is taken from the WRAS Information & Guidance Note.

Figure 4-7: 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 4.8 is taken from the WRAS Information & Guidance Note.

Figure 4-8: 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.

4.8.5 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[54] 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.

4.9 The use of GWR systems in other countries

In contrast to experience in the UK the prevalence of GWR systems in some other countries is much higher. 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. In 2005 there were an estimated 400 GWR systems in operation and now there are thousands (Grant, 2016). 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 (Grey Water for UK Housing 2013).

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 (Thames Water, 2017).

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 ((Juan et al, 2016). In Tokyo, it is mandatory to install a GWR system for a building with an area of over

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

30,000m^2 or with potential non-potable demand of 100m^3 per day (The College for Estate Management, 2013).

In the US there are currently no national guidelines in place regarding grey water reuse and individual states are responsible for its governance. As of 2013, only around half of the states promoted the safe use of grey water in its regulation. Municipalities and counties in California are offering rebates and incentives for property owners who install grey water systems to irrigate their landscapes.

4.10 Case study examples

4.10.1 Southbank Place, Lambeth, London[55]

The scheme involves a large (2.13ha) development of eight tower blocks (two commercial and six residential) by Canary Wharf Construction. The development incorporates the largest non-potable water system in London. The drivers for which were BREEAM and CfSH. The development incorporates technologies such as low flow devices, GWR, RWH, cooling tower bleed-off recycling.

An innovative water strategy resulted in the design of an efficient integrated GWR system. The residential buildings produce an excess of grey water, but the offices do not produce enough. Therefore the GWR systems in the residential buildings were designed to deal with the excess grey water which is transferred on demand to the commercial buildings when thy run out of treated water.

The GWR at the site involves six systems (two in commercial towers and four in the residential towers. The total capacity is ~100m^3/d. As described above these are interconnected to supply systems with low yield. This set up is estimated to save ~36,000m^3 of mains water per year and reducing flows to the sewer system by the same amount.

Another city mixed use development example is London Kings Cross. The GWR systems employed here currently result in ~16,500m^3 of mains water saved per year and the same amount does not enter the sewer system.

4.10.2 Whitbread Group, Nationwide[56]

Over the last decade Whitbread has been working in partnership with a GWR system manufacturer regarding the challenge they set themselves to deliver significant reductions in water use. Whitbread stated the following:

"Our vision is to lead the hospitality industry to become more sustainable and we want to work with our suppliers who share these key values, have strong environment policies and can help us reduce our water footprint and environmental impact.."

The partnership initially begun with the supply of water bureau services such as on site water audits to establish existing water consumption and costs. This enabled savings to be identified and recommendations provided for future water efficiency. The partnership progressed to building water sustainability into everyday operations with GWR becoming 'design standard' for all new build Premier Inn hotels. Over the last decade 46 GWR systems have been installed across the Premier Inn estate.

The justification for the GWR for Premier Inn included the fact that the yield from showers matched toilet flushing demand, the grey water volumes would meet the water reduction targets and there was a good Payback Period (or return on investment) of 4-5 years.

The initiative enabled consumption to be reduced by up to 30% at each hotel when compared to that of a similar hotel. Other statistics on what the partnership has achieved includes the following:

- Annual (average) consumption saving per hotel of 657m^3.
- 6.6% reduction in water use year on year relative to sales.

[55] CIRIA, Delivering better water management through the planning system, 2019
[56] Waterscan (2020) https://waterscan.com/case-studies/whitbread-sustainable-water-management/

- 21.2% water consumption reduction relative to sales against a 2009 baseline
- 100% toilet flushing requirement in new build hotels from recycled water.

Performance data of another, international, example of a Premier Inn Hotel GWR system is provided below in Table 4-13. The hotel of 300 rooms is integrated with Abu Dhabi International airport. The GWR system has been in operation since 2014, grey water from showers supply toilet flushing.

Table 4-13: Case study: Abi Dhabi International Airport – Premier Inn

Month	Potable water consumed	Recycled grey water used	Total water used	Percentage saved
July 2015	2,936m^3	904.6m^3	3,300.6m^3	27.4%
July 2016	1,965m^3	1,019.4m^3	2,984.4m^3	34.2%

4.10.3 College Lane Campus, Lowestoft

Suffolk County Council commisioned construction of a new higher education building (Lowestoft College 6th Form). Combined rain and grey water recycling technology was specified to help achieve an 'excellent' BREEAM rating. The new 6th Form was built to replace multiple locations in Lowestoft.

To increase the recycled water efficiency water from showers, wash hand basins and the roof is used to flush 60 WCs. The new building opened September 2011 and is estimated to save 5,000 litres of potable water per day using the rain and grey water recycling. The system efficiency is estimated at 45%.

German grey water filtration technology is used to remove particles down to 5 microns from the water collected from showers and wash hand basins. Underground, precast concrete storage tanks collect via gravity drains the grey water for treatment. The shower and wash hand basin grey water can then be used for flushing toilets. Additionally, rainwater from the 3,160m^2 roof is collected in a 16,000L precast concrete service water storage tank. The GWR system provider were employed on a supply, install, commission and maintain basis.

4.10.4 Nine Elms, Southbank, London[57]

The major brownfield redevelopment on London's South Bank has an IWM strategy designed into the project to minimise the effect on the sewer system and reduce demand on the public water supply. The development involves 20,000 homes and create 25,000 jobs but without the IWM would increase demand on existing water infrastructure by 800% in an area of existing water stress where the sewers are at or close to capacity. The IWM strategy balances water supply and demand by using measures that include GWR for non-potable uses (toilet flushing, washing machines and landscape irrigation). Other measures include RWH and water efficiency.

Once the strategy is adopted peak mains water demand and foul water discharges will be 32% lower than expected reducing the need for immediate capacity upgrades to the water and wastewater infrastructure.

The Nine Elms IWM strategy was developed by the VNEB Partnership (Wandsworth Council, Lambeth Council, the local authority, Transport for London and local developers), Thames Water and Arup. Thames Water are currently assessing how they can remove more surface water flows from the combined network to create capacity in other high growth development areas in London.

[57] CIRIA, Delivering better water management through the planning system, 2019

4.11 Conclusions

This section has provided an appraisal of GWR systems for non-potable uses in a variety of building types including domestic dwellings and commercial premises. It provides guidance for homeowners, house builders, planners, plumbers, architects and building managers. It has concluded that:

- 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 costs of installing a GWR system can vary between £40,000 and £270,000 depending on the size of the tank and system required, a range that is significantly larger, and more expensive than the costs observed for a RWH system.
- When the private payback that an installer could expect from installing a GWR system is considered in isolation, it is clear that for buildings where the demand is low to medium (for houses, small blocks of flat, single unit commercial spaces such as retail units) there is a net cost of installing the system. This is because water demand in these buildings is not sufficient to make them cost effective. When the social (indirect) benefits are included, medium sized buildings become cost effective but low and small demand buildings still have a net cost.
- For larger buildings, both residential and commercial (such as office blocks, tower blocks with flats in and residential or community developments) both a net private payback (the water savings exceed the cost of installation and maintenance) and even more significant total impacts are observed. For the very largest buildings and developments there are significant benefits.
- 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 also 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.

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Appendices

A1 Appendix 1 – Review of rainwater harvesting (appended separately)

A2 Appendix 2 Review of grey water recycling (appended separately)

A3 Appendix 3: Breakdown of cost and benefits of RWH systems

Table A3-1: Breakdown of costs and benefits of installing rainwater harvesting systems

Collection area	Demand	Water cost savings	Costs	Private net benefit	Net benefit
Small	Low	£ 3,072	£ 12,133	-£ 9,060	**£ 13,275**
Small	Small	£ 28,280	£ 18,930	£ 9,351	**£ 50,663**
Small	Medium	£ 50,501	£ 19,022	£ 31,479	**£ 109,012**
Small	High				
Small	Significant				
Medium	Low	£ 8,700	£25,601	-£ 16,901	**£ 36,848**
Medium	Small	£ 29,182	£ 33,579	-£ 4,397	**£ 48,240**
Medium	Medium	£ 58,749	£ 37,733	£ 21,016	**£ 96,459**
Medium	High	£ 130,293	£ 24,642	£ 105,652	**£ 228,260**
Medium	Significant	£ 195,378	£ 23,514	£ 171,864	**£ 330,941**
Large	Low	£ 6,806	£ 21,687	-£ 14,881	**£ 20,938**
Large	Small	£ 36,050	£ 33,823	£ 2,228	**£ 73,056**
Large	Medium	£ 76,307	£ 34,703	£ 41,604	**£ 138,526**
Large	High	£ 129,966	£ 24,916	£ 105,050	**£ 229,386**
Large	Significant	£ 149,490	£ 31,665	£ 117,824	**£ 453,542**
Very Large	Low	£ 6,823	£ 24,060	-£ 17,238	**£ 13,439**
Very Large	Small				
Very Large	Medium	£ 93,450	£ 28,225	£ 65,225	**£ 209,708**
Very Large	High	£ 113,017	£ 55,511	£ 57,506	**£ 279,381**
Very Large	Significant	£ 933,425	£ 58,669	£ 874,757	**£ 2,223,091**

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