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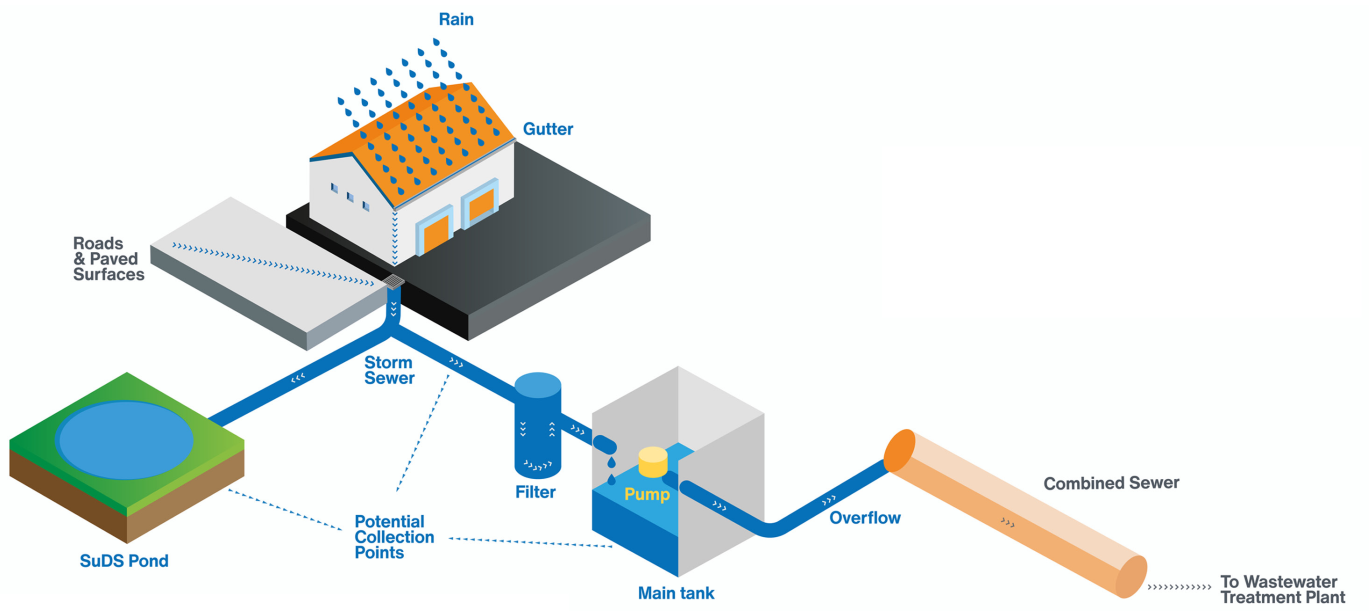
Transitioning Surface Water Collection to Surface Water Reuse Systems

Annex A. Literature Review

Cuthbertson A., Wade R., Black A., Duffy A., Hendry S., Leask F., Ralph E., Sezen E., Varghese A., Ward K.



POTENTIAL REUSES

- GREENSPACE IRRIGATION & WATERING
- INDUSTRIAL PROCESSES (COOLING)
- CONSTRUCTION & FIREFIGHTING
- STREET CLEANING
- CAR WASHING
- TOILET FLUSHING
- GARDEN WATERING

WIDER BENEFITS

- REDUCE SURFACE WATER FLOODING
- REDUCE POTABLE WATER DEMAND
- REDUCE CSO (COMBINED SEWER) SPILLS
- ENHANCE CLIMATE ADAPTATION & RESILIENCE
- ENHANCE BIODIVERSITY & GREENSPACE
- ENHANCE DROUGHT RESILIENCE
- PROMOTE WATER EFFICIENCY

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A1. Background and Scope

Urban expansion and growing urban populations are placing considerable pressure on critical water infrastructure and the urban water cycle. Key factors include increased water demand and the inability of combined sewer networks to cope with increasing volumes of surface water runoff. Urban water demand is expected to increase from present levels of 15-20% to 30% or higher of the total global water demand by 2050 (World Bank, 2021). There is a parallel challenge of multi-sector water scarcity (Environment Agency, 2025), where competing demands from domestic, agricultural, and industrial sectors underscore the importance of exploring alternative sources of water (Halliday *et al*, 2024).

These pressures are compounded by climate change impacts, including increased rainfall intensity, and inadequate or ageing infrastructure. In many countries, use of combined sewers means limited drainage capacity to manage surface runoff, increasing urban flood risk. Combined Sewer Overflows (CSOs) discharge untreated wastewater, increasing risks of habitat degradation and loss of biodiversity. In this context, the literature discusses decentralised and circular approaches to urban water management, including examples of surface water reuse. These techniques and technologies can help mitigate urban flood risk, diversify water sources in urban areas for non-potable uses, reduce wastewater treatment costs and energy use, and provide additional ecosystem services and benefits. Increasingly, these approaches are considered within policy frameworks of resilience, circularity and 'sponge cities' (European Commission, 2025).

From a Scottish perspective, the expectation of warmer and drier summers (SEPA 2025, CREW 2020, 2024), and more frequent extreme rainfall events (Scottish Water 2024), exacerbates the risks of both water scarcity and that urban drainage systems will become increasingly overwhelmed by surface water entering the network. Addressing this is a policy priority (Scottish Government, 2023 and see Annex B). Supporting the transition of Scotland's surface water collection and treatment systems to reduce the overall volume of rainwater entering the combined sewer network (Scottish Water, 2025a), is a key aim of this project. This will enable the reuse of surface runoff in the urban environment and, hence, reduce demand on other treated water sources. Surface runoff represents an untapped opportunity to alleviate growing pressure on Scotland's combined sewer network, whilst reducing overall potable water demand and supporting national net-zero goals (CCC, 2023), including Scottish Water's Net Zero Emissions Routemap (Scottish Water, 2025b).

Scottish Water's Surface Water Policy (Scottish Water, 2017) is to not accept any new surface water connections to existing combined sewer systems. This requires the adoption of new surface water management strategies, including the potential reuse of rainwater that can be collected for non-potable purposes.

This project differentiates between (1) surface water capture and reuse, which may, or may not, involve treatment, but which avoids surface water being disposed to sewers; (2) recirculation of water within an internal piped system, including the use of greywater for toilet flushing, or water recycling within an industrial context; and (3) the reuse of treated urban wastewater.

While options (2) and (3) are outside of the project's scope, they are covered to some extent within the wider water reuse context set out in the literature review, which is separated into the following themes: technologies and techniques; sector applications; economics; and public awareness/perception. A number of practical examples from the UK and internationally are highlighted to demonstrate the breadth of surface water collection and reuse options available. This literature review should be read along with the review of applicable policy and legislation (Annex B).

The literature review explores a wide range of surface water reuse, and some other non-potable water technologies, already adopted to diversify urban water sources (Strang *et al*., 2021). There are multiple overlapping terminologies in the literature. 'Blue-Green Infrastructure' (BGI) and 'Nature-Based Solutions' (NBS) are both used as general terms. Sustainable Drainage Systems (SuDS) and rainwater harvesting (RWH) are also used widely and may each cover a variety of specific techniques and technologies, such as water butts, green roofs, permeable pavements, raingardens, basins, wetlands, ponds, infiltration systems, and underground storage (Jones *et al*., 2023; Scottish Government, 2023). Whilst some of these may be used for either SuDS or RWH, the former are usually focused on drainage, whereas the latter anticipates collection and reuse, which may require additional infrastructure. All of these will reduce runoff pressure on sewer networks and have the potential to reduce the use of potable water, contribute to climate goals, enhance biodiversity and improve public amenity (Scottish Government, 2023).

When properly managed, they can support groundwater infiltration and recharge, reduce pollution, save energy, and urban enhance water resilience by providing a decentralised water supply (EEA, 2021a). These decentralised systems can provide water sources for non-potable uses, offering climate-resilient, relatively low-cost, locally deployable alternatives to potable supplies, and providing multiple ecosystem services benefits (Jose and Wade, 2023). Key challenges include installation and maintenance costs, challenges in retrofitting dense urban areas, water quality concerns, public perceptions, and regulatory frameworks.

The newly published CIRIA report: 'Enabling Development' (Cecil *et al*, 2025) recommends a sustainable discharge hierarchy whereby RWH and surface water reuse must be considered the first option at the outfall with multiple benefits including: carbon footprint reduction of potable water supply network; ensuring adequate drinking water on a site/development; lower water bills; and increases resilience against drought. This is to be implemented in England in the newly published National Standards for sustainable drainage systems, where Standard 1 relates to the collection of surface water for non-potable use (DEFRA, 2025). As noted above, a similar hierarchy is already in place in Scotland under Scottish Water's Surface Water Policy (2017) where for new developments, surface runoff should not go to a combined sewer and the preferred option 1 is that rainwater is stored and reused.

Discharge Hierarchy	Scottish Water (2017) Surface Water Policy	CIRIA Report C823F (2025) Outfall Option
Must be considered first	Option 1: Rainwater is stored and reused, such as RWH and/or water butts	RWH and reuse
	Option 2: Surface water is drained into the soil through the use of a soakaway	Infiltration into ground
↓	Option 3: Surface water is drained to a watercourse (open or piped), canal, loch or existing /proposed SUDS	Attenuation and discharge to a waterbody, ordinary watercourse or main river
	Option 4: Surface water is drained to a surface water sewer	Attenuation and discharge to public surface water sewer
Only if all options are unavailable	Option 5: Surface water is drained to a combined sewer	Attenuation and discharge to public combined sewer

Figure A1: Surface water discharge hierarchy for new developments. Adapted from SW (2017) and Cecil *et al*. (2025)

A2. Technologies and Techniques

A wide variety of technologies and techniques are discussed in the literature, some of which are well established in practice. Some are accessible at household level at relatively low cost, such as rain barrels in gardens, whereas others use smart technology, may require considerable infrastructure, and are more appropriate for new developments or business and commercial premises. Retrofit is always possible but for any infrastructure is more expensive than the same technology in new-build. The costs and benefits of green infrastructure are more difficult to determine than for grey infrastructure (WWAP, 2018).

A2.1 Open and closed-loop water systems

Water reuse systems can be categorised as either open-loop or closed-loop. Closed-loop systems are generally considered more efficient, as water is recirculated within the system, reducing the need for abstraction and minimising both water loss and environmental exposure (Environment Agency, 2025).

While rainwater reuse is typically associated with open-loop systems, such as irrigation, there are scenarios where non-potable rainwater can support or initiate closed-loop configurations. These are most commonly found in industrial processes requiring heating or cooling, but there is growing interest in applying closed-loop principles to other sectors, including agriculture, and SuDS-integrated reuse systems.

A2.2 Sustainable Drainage Systems

The capacity of the sewage infrastructure is often limited during extreme weather, making source control and alternative reuse systems essential. Sustainable Drainage Systems (SuDS) are increasingly recognised as complementary strategies for sustainable water management, and can support groundwater recharge, reduce pollution, save energy, and enhance urban water resilience and urban aesthetics.

SuDS take a decentralised approach, managing rainwater close to where it falls, preventing it from entering grey infrastructure. Features such as raingardens, ponds, basins, wetlands, and greenspaces not only reduce runoff but can also enhance biodiversity and improve public amenity (Scottish Government, 2023). SuDS can also collect and store runoff for reuse or controlled release. In contrast, groundwater infiltration focuses on allowing surface runoff to percolate into the ground, directly replenishing aquifers. However, this requires additional treatment for contaminants and removal of sediment to prevent clogging of infiltration basins (National Academies of Sciences, 2016).

While SuDS primarily aim to manage water quantity and quality, the incorporation of rainwater reuse technologies represents a shift toward more resource-efficient and resilient urban water systems.

A2.3 Rainwater Harvesting

Rainwater harvesting (RWH) is a foundational approach that enables both water reuse and flood mitigation in urban and industrial contexts, forming part of a broader surface water strategy. RWH includes accessible technologies at household level such as water butts, but any storage system, or recirculation of captured water for use inside associated buildings or elsewhere, requires both infrastructure and treatment. In Scotland, any system enabling the reuse of captured surface water within a building would need consent under Scottish Water's Byelaws (Scottish Water 2014 and see Annex B).

'Smart' water butts are now available and are deployed as both a rainwater reuse and flood protection mechanism in residential and commercial settings. In the commercial sector, Rheinmetall BAE Systems installed a 10,000-litre smart water tank at its Telford site to support rainwater reuse and flood mitigation, using wireless technology to release water ahead of storm events (River Severn Partnership, 2025).

In the residential sector, a pilot study for Anglian Water trialled smart water butts in an urban setting in Newmarket, England, to assess their effectiveness in flood mitigation and rainwater reuse. The system developed by SDS Ltd used weather-based predictive controls to release water ahead of storms, resulting in significantly improved stormwater attenuation compared to traditional systems (SDS Ltd, 2019). By contrast, a pilot project in Craigleith, Edinburgh, deployed conventional water butts and planters for flood mitigation, without smart control features (Scottish Water, 2025).

A2.4 Infrastructure efficiency and water reuse technologies

Water reuse technologies are increasingly being leveraged to extend the life of existing infrastructure and reduce the need for costly upgrades to centralised systems. Plumbing systems play a critical role in enabling sustainable water management across both urban and industrial environments, and require appropriate regulation (see Annex B). Dual water supply systems, which combine public potable networks with on-site sources like rainwater harvesting, exemplify this approach. These systems rely on dedicated and clearly labelled plumbing infrastructure to keep potable and non-potable streams separate, enabling applications such as toilet flushing, irrigation, and other building services. This requires appropriate regulation through building standards and regulations on water fittings. Greywater reuse refers to the reuse of water within buildings, for example from sinks and showers, especially for toilet flushing. Whilst these can significantly reduce the volume of potable water used in buildings, these systems are outwith the scope of this project.

Due to the maintenance requirements and regulatory barriers of dual systems to ensure public health, this approach is generally better suited to multi-residential or commercial buildings than individual households (National Academies of Sciences, 2016). For example, Frankfurt Airport in Germany supports non-potable reuse of water for building services with six 26,000-gallon (100-m^3) cisterns installed to capture rooftop runoff for toilets and outdoor irrigation, saving 98 million litres per year (Pitt *et al.,* 2011 cited in National Academies of Sciences, 2016).

In New York City, a $2.4 billion investment in green infrastructure, including stormwater capture and greywater reuse, is projected to save $1.4 billion over 20 years by avoiding costly upgrades to conventional sewer systems (NYSDEC, 2013, cited in National Academies of Sciences, 2016).

While most cost-effective when integrated into new construction, existing infrastructure can also be successfully retrofitted. Burszta-Adamiak and Spychalski (2021) demonstrate how existing infrastructure, like sports stadiums, can be retrofitted to support dual systems, resulting in improved water efficiency and economic savings.

A2.5 Pollution prevention

In addition to managing the volume of surface runoff, SuDS solutions such as rain gardens and permeable surfaces contribute to water quality by filtering out contaminants at the source. Permeable surfaces - materials that allow water to pass through them rather than running off – help reduce discharge of harmful pollutants into water bodies by mimicking natural infiltration processes (Monachese *et al.,* 2025).

A2.6 Water quality risk management

In general, rooftop collection surfaces are comparatively cleaner than the impermeable surfaces around a building or on roads, such as paving or car parks. However, rooftop runoff can contain varying amounts of heavy metals and nutrients. A number of contributory factors have been reported (Bañas *et al*, 2023), including:

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

Roof design, RWH systems and materials selection can affect the microbial quality of the harvested rainwater. RWH system components should therefore be constructed from non-toxic, and/or inert materials. In the UK there are currently no regulatory requirements for water quality for rainwater re-use for non-potable water use. Once water is harvested and stored the quality may deteriorate from a microbiological perspective which can present potential health risks (Ward *et al.,* 2017). Harvested rainwater does have quality parameters (i.e. pH, total chlorine concentration, electric conductivity, total dissolved solids, oxygen saturation and total hardness). Guidelines for bacteriological and general systems monitoring are provided in the British Standard BS 8515:2009 + A1:2013 (BSI, 2013).

There are several other factors when assessing the potential risks of reusing stormwater, including how the water will be used, exposure to the water, and the environment where the water will be reused. Risk assessment is based on human exposure which is a factor of chemical or microbial concentrations with communication a beneficial strategy to help the public understand any appropriate safeguards. Pathogens present a risk even for low human exposure such as toilet flushing, with disinfection necessary (National Academies of Sciences, 2016). Watering domestic gardens and washing domestic cars are uses that take place without any treatment, but that is less likely to be true for any other applications.

A3. Sector Applications

Water reuse can play a key role in agriculture and industry, which both demand large volumes of water. In farming, reclaimed water aids irrigation, easing pressure on freshwater and boosting crop resilience during droughts. Industries may rely on recycled water for cooling, processing, and production needs, helping cut overall water use and reduce wastewater output (Brears, 2025a).

Reliance on public water supply may not be guaranteed for certain sectors, as public utilities are primarily expected to ensure water resilience for residential and essential public services. With catchments in England closing to new abstractions and applications from new sectors for direct abstraction being refused, industries are increasingly forced to identify alternative water supply options (Environment Agency, 2025).

Data collection technologies play a critical role in enabling long-term planning and identifying cross-sector collaboration opportunities. Without robust data, it is challenging to model and forecast future [non-potable] water demands effectively (Environment Agency, 2025). The Market Operator Services Limited (MOSL) operates the central data platform for England's non-household water market, supporting transparency, benchmarking, and strategic planning (MOSL, n.d.).

A3.1 Urban and municipal uses

There is developing acceptance of the need to increase resilience and circularity in the management of the resource (European Commission 2025, EEA 2021b). At city scale, in Copenhagen, a major flood in 2011 led to the Cloudburst Management Plan intended to create the world's first complete 'sponge city', with projects and technologies at different scales (Interlace, 2023). Hokenos (2025) notes that there is more grey infrastructure than had been anticipated at the start. Some proposed BGI did not work, including 'cloudburst roads' (because of the utilities present); and there are still concerns about water quality where this is discharged back into the water environment. However Copenhagen has been a model for other European cities, and the suggestion is that it has driven positive change in both organisational practice and public acceptance.

Cities are also adopting water reuse as a core part of urban water management. Neighbourhood and regional scale water reuse projects can contribute significantly to urban water supplies (National Academies of Sciences, 2016), with rainwater reuse serving parks, firefighting, and street cleaning, thus conserving drinking water for essential needs. Dual-pipe systems in buildings can distribute recycled and potable water separately, encouraging smarter, more efficient water use across urban areas (Brears, 2025a). At household level, captured rainwater may be used directly for watering gardens as well as washing cars. However recirculation into a building, for toilet flushing for example, is much more complex. In a Scottish context this would need approval under Scottish Water's Byelaws (2014).

A3.1.1 Washing

There are a variety of urban washing applications, at household or commercial scale. These include vehicle cleaning (e.g. car washes and fire engines), equipment maintenance, and the cleaning of paved surfaces and building exteriors (Zhang *et al.,* 2019).

SDS Ltd supplies commercial RWH systems across the UK, primarily for applications such as toilet flushing and vehicle washing, though specific details about individual installations are not publicly disclosed (SDS Ltd, n.d.). A notable example for vehicle washing, is Cardiff Bus, a Welsh public transport company that harvests rainwater for bus cleaning, collecting approximately 447,000 litres in the first six months of operation. RWH has been adopted by fire services sites in England and Wales, including Cheltenham West Community Fire Station, Gloucestershire, where the rainwater is also used for toilets (Rainharvesting Systems Limited, n.d.).

A3.1.2 Fire fighting

Reclaimed water can support firefighting operations in several ways (Martins Vaz et al; FM Global 2010). In Washington DC, stormwater is harvested for the purpose of spray washing of fire engines and refilling of fire truck tanks (National Academies of Sciences, 2016). Firefighting water sources can be implemented with impoundments, reducing reliance on potable supplies and enhancing local resilience during fire events.

A3.1.3 Decorative fountains and water features

Collected rainwater can enhance urban aesthetics by supplying fountains and water features. In Germany, for example, Potsdamer Platz uses underground tanks to collect water, which is then reused not only for decorative features but also for irrigation and toilet flushing. Similarly, at the Cincinnati Zoo, rainwater reuse is used to create a moat-style water feature around an animal enclosure, combining functionality with visual appeal (National Academies of Sciences, 2016).

A3.1.4 Navigation

Although canals are traditionally viewed as infrastructure for waterborne transport, urban drainage, and flood mitigation, there is growing potential to reimagine the role of canals adjacent to urban water infrastructure in supporting rainwater reuse within integrated water management systems (Environment Agency, 2025).

Glasgow's Smart Canal is a modern urban drainage innovation that uses predictive weather technology to proactively lower water levels ahead of rainfall, creating temporary stormwater storage. It does not currently incorporate any mechanisms for rainwater reuse but the potential is there (Duffy *et al.,* 2013.).

A3.2 Agricultural applications

A3.2.1 Agricultural irrigation

Agricultural irrigation is the largest water user globally, with perhaps 70% of total withdrawals, so it is unsurprising that it is also a focus for the use of reclaimed water, falling into open-field systems and glass-house systems (Morris *et al.,* n.d.). When paired with efficient irrigation systems, it can significantly reduce water waste and minimise fertilizer loss, contributing to both resource conservation and pollution prevention (WWAP, 2017). However use of reclaimed water (or any wastewater) for food production requires management of water quality to ensure food safety and the health of agricultural workers (WHO, 2006, and see Annex B). Annex B also analyses the EU Regulation on water reuse for agriculture, not yet implemented in Scotland, which is focused on reuse of treated municipal wastewater. Most crops in Scotland are rain-fed but there is irrigation in the east, where water shortages are most acute and demand is likely to increase. (Bocca *et al.,* 2021; Centre of Expertise for Waters, 2020).

Rainwater reuse in agricultural settings results in cleaner runoff, helping to reduce the entry of nutrient-rich pollutants into surrounding ecosystems (Lepcha *et al.,* 2024). Amos *et al.,* n.d. demonstrated that rainwater harvesting in Nakuru, Kenya could significantly boost vegetable yields and support dietary needs, recommending a multidisciplinary approach for successful implementation.

In response to severe water shortages in Beijing's Huairou peri-urban district, a rainwater harvesting (RWH) project involving local institutions and a vegetable cooperative demonstrated its effectiveness for intensive greenhouse agriculture. A covered storage pond provided irrigation while creating humid conditions ideal for mushroom cultivation, showcasing the economic and ecological benefits of multifunctional farming. The project delivered high-quality irrigation outcomes and economic impact, and was subsequently integrated into policy (Howe *et al.,* 2011).

RWH can significantly support household agriculture, particularly in urban and roadside gardens, a practice growing in popularity across Australia (Rahman, 2021). Water butts that collect rainwater and are used for watering gardens are a simple and accessible technique for Scotland at household level.

A3.2.2 Urban and landscape irrigation

Landscape irrigation using reclaimed water supports the maintenance of greenspaces such as public parks, flower beds, lawns, and urban forests. Beyond aesthetic value, these irrigated areas also contribute to urban biodiversity by supporting wildlife habitats and enhancing ecological resilience (National Academies of Sciences, 2016; WWAP, 2018).

A major turf restoration project for the National Mall in Washington DC developed a stormwater capture and treatment system to serve approximately 68% of the 42 million litres of irrigation water needed annually (National Academies of Sciences, 2016).

The Rory M. Shaw Wetlands Park project is a neighbourhood-scale stormwater capture, treatment and recharge project in Sun Valley, Los Angeles, California that transforms defunct landfill into recreational greenspaces.

Docklands Park in Melbourne, Australia is a large-scale stormwater storage facility with a capacity of 490,000 litres, providing water for irrigation purposes (National Academies of Sciences, 2016).

A3.3 Industrial applications

Industry needs water in a steady supply. If industries recycle and reuse, they increase industrial water supply security and the overall water supply security, as there is more fresh water for other uses such as agriculture and potable supply (Lahnsteiner, 2019). They will reduce their costs for both water supply and wastewater discharge.

Industrial water reuse is commonly applied in cooling systems, boiler feed water, and various manufacturing processes (USEPA, 2012). These applications require careful attention to water quality, particularly in boiler make-up water, where high levels of silica must be removed to prevent scaling and ensure system efficiency. The USEPA provides extensive guidelines for reuse for different purposes.

A3.3.1 Beverages industry

Breweries present multiple opportunities for non-potable water reuse due to their high water consumption across various stages of production. While potable water is essential for the brewing process itself, non-potable water can be effectively repurposed for tasks such as rinsing bottles, cleaning equipment, and other sanitation needs. Some breweries have implemented closed-loop systems that recirculate treated water, significantly reducing overall water waste (Ashraf *et al.,* 2021). There is a local brewery in Dundee where there is potential to model the opportunities.

Although certain manufacturers promote non-potable water reuse technologies that are well-suited for brewery operations, there is currently a lack of publicly documented case studies demonstrating these systems in active use within breweries (Spacedrip, 2024).

Cooling plays a critical role in the brewing process, particularly in regulating the temperature of the wort and fermentation tanks, providing further applications for water-based cooling systems.

Similarly, the whisky industry has high water consumption needs in the form of distilling and cooling. In a first of its kind, whiskey producer Diageo obtained a certification for their management of water resources, the International Water Stewardship Standard (AWS Standard) certification (Diageo, 2021). Dalwhinnie Distillery, part of the Diageo group, relies on surface water sourced from snowmelt and rainfall for processes and cooling (JBA Consulting, n.d.).

A3.3.2 Cooling systems

Cooling towers are key components to cooling systems, providing cooling to industrial, commercial and residential facilities. Surface runoff can provide a supplementary water source for industrial cooling towers that is both technically and economically viable. In the US, policies vary by state, with high water cost areas more likely to benefit and impact adoption for industrial cooling towers (Banboukian *et al.,* 2025).

It is estimated that about 80,000 cooling towers operate in the UK with 4MW of cooling load approximating to 72m^3 of water per day used to flush the towers to control mineral salt build up from evaporation. This impacts the environment and increases operating costs with designers moving towards different water treatment systems and choice of materials such as stainless steel and plastics that do not easily support bacteria over galvanised steel. The use of ozone treatment instead of chemical biocides has enabled the use of other water supplies such as rainwater instead of mains water for cooling towers. Additionally, ozone treated water can be discharged directly to surface drainage networks or rivers. This also means an exemption from sewage/output charges during cooling tower bleed down, offering savings of 40-60p per m^3 on bleed-off water. RWH provides water to cooling towers at a Co-op distribution centre near Newcastle. Collected rainwater will be used at the refrigeration plant using an ozone treatment system and cyclone filtration to remove any suspended matter (National Academies of Sciences, 2016; MBS, 2009).

A3.3.3 Data centres

Data centres rely on cooling systems to dissipate heat and maintain optimal operating conditions for server hardware, including high-performance chips. The UK's interest in attracting investment in data centres for cloud-based computing and AI has seen data centres classified as Critical National Infrastructure (Department for Science, IT and Medicine and Kyle, 2024). Rising AI adoption is driving increased investment.

With some catchments closed to new water abstractions, data centres may be restricted to public supply sources, prompting a search for alternative solutions. Closed-loop cooling systems, already adopted in Italy and the Netherlands, offer one such resilient approach (Environment Agency, 2025). The market operator for England's non-household water sector, MOSL, is collaborating with the Water Research Centre (WRc), supporting efforts to improve water efficiency in data centres (MOSL, n.d.).

With a policy shift by the UK Government to officially designate data centres to boost business confidence, attract investment and ensure support for recovery from critical incidents, it is anticipated that data centres may face fewer restrictions on water access, even in water-stressed areas. However, a recent report (Kenny, 2025) states that the operational resilience of these centres must be sustainable, not a liability, particularly in the case of water infrastructure. Advancements in cooling technologies offer potential for reducing water consumption. Liquid cooling solutions, such as Direct to Chip (DTC) cooling and some forms of immersion cooling, offer superior heat transfer capabilities, capturing much of the heat produced (McCarthy *et al.,* 2025).

Many data centres are recycling cooling system water to reduce environmental impact and promote sustainability. This includes the use of closed-loop systems that minimise freshwater use by reusing the same water multiple times. Leading companies like Microsoft have developed "zero-water evaporation cooling designs" that can save significant water volumes annually. Data centres can reduce reliance on potable water by utilising alternative sources. Rainwater harvesting and greywater recycling offer environmentally friendly and renewable solutions for cooling and facility maintenance (Heymann, 2025). Recognition that cooling systems water “does not need to be drinking water quality” (UK Parliament 2025) is a crucial and can inform policy on promoting non-potable water sources.

According to a research data centre tool directory, (DCM, n.d.), Scotland has 20 data centres, primarily located in the central belt including a cluster around Aberdeen. A recent BBC Scotland interview highlighting a FOI request to Scottish Water (BBC Scotland & Hayes, 2025), indicates that the volume of tap water usage for data centres has quadrupled since 2021. The operations manager said that “tap water used by data centres as significant – although it still only amounts to about 0.005% of the water supply”. They are promoting the use of alternative solutions, particularly as more data centres are expected in the near future, including a large AI industrial park near Irvine.

Ideally, new data centres, and other new industrial applications, should be located close to wastewater treatment plant that could supply a predictable quantity and quality of water to such developments, and this could be facilitated at the planning stage and in the consideration of the next generation of urban wastewater treatment plant. However the option of reusing surface runoff could also be explored.

The interview also discusses the use of closed versus open loop systems where open loop systems require a constant supply of water and closed loop that recirculates fixed volumes of water, often reducing water use by 90%. However, there are energy costs associated with closed loop systems as they require chillers, pumps, heat exchangers to achieve equivalent cooling performance (TechUK & Environment Agency, 2025).

A3.4 Energy sector

A3.4.1 Nuclear energy

Small Modular Reactors (SMRs) are an emerging energy technology designed to be more water-efficient than traditional large-scale nuclear reactors (ARUP, 2025). Water-cooled SMR system designs, particularly those using light water coolant (U.S. Department of Energy, n.d.), lend themselves to abstracting water from non-potable sources. Their compact size and modular nature allow SMRs to be deployed on smaller sites, which opens up opportunities for co-location with other industrial operations (ARUP, 2025) and potentially, integration with non-potable reuse systems.

In the UK, Generation III water-cooled SMRs are a central part of the government’s Advanced Nuclear Technologies (ANT) strategy, with a plan announced for the government’s intention to deploy a First-of-a-Kind SMR by the early 2030s (Department for Energy Security & Net Zero, 2024). However current policy in Scotland does not support new nuclear development, including SMRs (Scottish Government, n.d.).

A3.4.2 Hydrogen production

Green hydrogen is an emerging energy solution, with water electrolysis being the most common method of production. While rainwater is not typically used in industrial hydrogen systems, it can be a suitable for green hydrogen production if properly treated. This makes it particularly viable for off-grid or decentralized systems, where access to purified water may be limited. A notable example comes from researchers at Tunku Abdul Rahman University in Malaysia, who proposed a system that combines rainwater harvesting with solar-powered electrolysis to produce hydrogen for domestic energy use (Long and Yap, 2024).

A comparable approach was implemented in the Sahel region of Africa, where electrolysis powered by photovoltaic (PV) energy was used to convert harvested rainwater into hydrogen, effectively addressing both local energy and water needs (Waterloo *et al.,* 2025).

The Scottish Government is supporting green hydrogen (Scottish Government, 2024), and there are initiatives from Scottish Water Horizons, the innovation arm of Scottish Water (Scottish Water Horizons, n.d.) Again, as with data centres, whilst surface runoff may be a feasible source of water for green hydrogen, co-location with wastewater treatment plant would seem desirable. The Forth Ports is using wastewater from Seafield wastewater treatment plant to produce their green hydrogen (Hydrogen Scotland 2024).

A3.5 Environmental and recreational applications

A3.5.1 Wildlife habitats

Water cycling can be used to create and maintain wildlife habitats and sustaining stream flows for aquatic ecosystems especially in places with limited availability of surface water. Neighbourhood scale wetlands have the ability to absorb nutrients and filter sediments, provide recreational features, community amenities, educational opportunities and urban habitats (WWAP, 2018; EEA, 2021b). However, design of urban wetlands needs to consider how to manage contaminants, by controlling sedimentation rates and periodic dredging.

A3.5.2 Recreational use

There are opportunities to switch to adopt water reuse approaches that do not require high-quality potable drinking water for recreational use.

Recreational facilities such as golf courses, horse racing tracks, and sports fields play a vital role in supporting the economy and promoting active lifestyles, contributing to both physical and mental health within the community. Water for these uses is typically abstracted from the local environment or supplied via mains from water companies (Environment Agency, 2025).

A4. Economics

According to the Anglian Water review: 'Re-using Water for Potable Purposes' (2025), most 'use journeys' in the UK will experience financial barriers as initial investment can be significant, and lack of clear funding mechanisms/financial incentives can hinder adoption. Traditionally, reuse is seen as an expensive solution but as traditional sources of water become less available (CREW, 2020) economic appraisals should consider scarcity. In future, economic incentives could also consider and quantify additional benefits such as biodiversity net gain, nutrient neutrality, or carbon credits. The case for non-potable re-use could be strengthened by developing pilot case studies.

San Francisco Public Utilities Commission (SFPUC, n.d. b) operates a Water Reuse Grant Program as an initiative to reduce reliance on potable water supply by encouraging the collection and treatment of alternate water sources such as rainwater/storm-water for non-potable uses (e.g., toilet flushing and irrigation. Grant funding is available for three types of project: voluntary (onsite - non mandatory) with up to USD $200,000 if replacing at least 450,000 gallons; 'above and beyond ordinance' (on site – surpassing local by-laws) with up to USD $500,000 if replacing at least 1,000,000 gallons; brewery process water (on-site treatment and reuse of brewery process water) with up to USD $1,000,000 if replacing at least 3,000,000 gallons. Funded activities include the installation of collection and treatment systems and storage of the treated water (Brears, 2025b).

Water scarcity is a major barrier to housing development, especially in the East and Southeast of England. Without intervention, it will prevent the delivery of 61,600 homes over the next five years (PUBLICFIRST, n.d.) This housing shortfall could cost the UK economy £25 billion due to lost construction (£18.3bn), land uplift (£6.3bn) and reduced agglomeration benefits (£344m).

- Implementing water smart housing – with 30% higher water efficiency – could recoup £20 billion of this value, enabling the construction of 49,000 of those 61,600 'lost' homes.
- Areas most affected (i.e. Cambridge, St Albans, and Worthing) are also areas of high productivity, so housing constraints here have disproportionate economic impact.

In rainwater capture and use, infiltration projects are significantly lower in cost than tank capture projects (National Academies of Sciences, 2016).

An independent review for Waterwise (Fredenham *et al.,* 2020) assessed the costs and benefits of rainwater harvesting and grey water recycling options in the UK. The tables below are indicative of their findings.

Table A.1: Costs of tanks and incentives for measures.

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

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

A5. Public Awareness and Perception

There are numerous barriers to uptake of water reuse relating to public perceptions, both for householder level initiatives and in terms of wider institutional and commercial measures. In England and Wales, significant work has been done by the Environment Agency (2025). In Scotland, water is often considered abundant and scarcity is not widely perceived to be a problem (Halliday *et al*., 2024; CREW, 2024.)

They identify a lack of incentivisation for adopting water-efficient practices, as water does not constitute a significant operational cost as compared with household customers, with a perceived lack of return on investment. There is also a lack of awareness and misconceptions about water scarcity for non-household customers. More generally, there is fragmented water governance due to a lack of governance and coordination between sectors and local authorities (see also Annex B) and a lack of a common language to address water usage across sectors.

As part of the Ofwat innovation project 'Enabling Water Smart Communities' (EWSC), EWSC worked with the policy, research, opinion and strategy consultant 'PUBLICFIRST' to explore water scarcity impacts on housing and economic growth including public perspectives around water use (PUBLICFIRST, n.d.). Key findings from the report include:

- 69% of the public claim they already take steps to conserve water, primarily for cost-saving reasons rather than environmental concerns.
- Public support for water recycling exists, where:
  - o Rainwater reuse is highly accepted, especially for use in garden watering/car washing etc.
  - o Reuse of water for toilet flushing and outdoor taps is also highly acceptable.
  - o Recycled toilet water would be deeply unpopular, especially for drinking or washing.
  - o Greywater reuse has conditional acceptance, depending on the end use.
- Messaging matters:
  - o Cost-saving arguments are the most persuasive.
  - o Environmental and "common sense" messages also work, with safety messages being less effective.
  - o Negative health messaging is highly convincing to the public and a major risk to public acceptance (75% found health risk messages convincing).
- Despite wide awareness of water conservation, most people do not see water scarcity as affecting housing availability—only 13% link water supply to housing shortages.

Research by the University of East Anglia (Paranage & Hargreaves, n.d). analysed six wide-ranging EWSC case studies. Effective community engagement is crucial for creating sustainable, water-smart communities, especially as climate, regulatory, and social pressures increase. The case studies reflected engagement practices, from industry-led and behaviour change campaigns, to in-depth co-production processes, through to citizen-led activism and governance. The authors report that, to their knowledge, this is the first effort to analyse such a diverse set of water-community relationships through a shared framework. Analysis showed that success depends as much on community involvement as on technical innovation, with five key lessons emerging:

- No single model fits all – approaches must be tailored to local contexts.
- Many communities are already active – they need recognition, resources, and integration into formal systems.
- Communities bring valuable insights – their perspectives on equity, aesthetics, and governance enrich decision-making.
- Co-creation is vital – engaging communities from the outset leads to better outcomes.
- Engagement methods must evolve – beyond basic consultations toward adaptive, collaborative approaches.

The researchers concluded that building communities that are water-smart will require a shift from just delivering solutions to fostering long-term relationships, valuing local knowledge, and treating communities as equal partners to shape sustainable water futures.

Research undertaken by the Urban Water Security Research Alliance in the Systematic Social Analysis Project concentrated on the introduction of a purified recycled water scheme (drinking recycled water) in the South-east (Alexander *et al.,* 2008). The findings include the need to engender trust with information provided by trusted expert sources. Lack of information is a crucial barrier particularly when trying to encourage behaviour changes in relation to water infrastructure.

Water reuse for drinking water is likely to be the most contentious reuse. However, even for less contentious uses, good public communication is essential. Public communication strategies to promote uptake of rainwater reuse solutions and practices for non-potable uses such as toilet flushing and irrigation should focus on positive messages such as the cost benefit to households. They should avoid phrases that reinforce disgust/ concern or the 'yuck' (Smith *et al.,* 2018) or 'ick' factor (Moncrieff, 2025) that relate to 'recycled water/wastewater' such as 'toilet to tap' (Duckett *et al.,* 2024).

Community engagement through urban planning is considered key to integrating sustainable water management and serves as an engagement mechanism for promoting NBS and increasing awareness (Environment Agency, 2025). Collaboration is key to the future of resource management and resource allocation.

Anglian Water (2025) states adverse public reaction is often a challenge to uptake of the solutions. Public perception and social acceptance play a role, with efforts needed to educate and reassure the public about the benefits and safety of re-used water. These issues show the importance of continuously monitoring implementation of the intervention, and stakeholder engagement to sustain success.

A6. Conclusions

There is extensive literature around water reuse, especially in agriculture but also in the urban environment. Much of the latter literature relates to BGI and NBS, and these terms may be used interchangeably.

Many types of BGI have multiple benefits, potentially addressing both water scarcity and flood risk; providing biodiversity and wellbeing gains; and reducing energy costs in different ways. There is a clear policy preference to remove surface runoff from the sewer network where possible; and reuse is preferable to discharge to surface drainage and then to a freshwater body, with SuDS the most frequently used technologies. There is considerable knowledge and understanding of how to design and use these, and in Scotland this has been the expectation for three decades and in law since 2003 (see Annex B). However related technologies to capture and reuse the water are likely to require additional infrastructure (storage and pipes) and treatment.

The literature review, and the practical examples, evidence considerable expertise within the commercial sector, with larger industries in particular capable of working with their water suppliers to install closed loop systems. Large commercial developments may also be likely to have grey water reuse systems for toilets etc., again reducing water bills and wider environmental impacts.

In a domestic context, in terms of internal plumbing and recirculation, regulation (planning and building control) could ensure much greater water efficiency for new build. This is further considered in Annex B. Retrofit remains both expensive, and with regulatory barriers, throughout the UK jurisdictions and is especially problematic in flatted and shared dwellings. External domestic alterations such as water butts for RWH can be relatively simple and affordable. However most innovation in existing properties might need support and incentives, especially in the absence of perceptions of water scarcity as is the case in Scotland.

There is evidence that where there is no public health risk, public perception is positive for water reuse. However, a much wider range of BGI is available and recognized in policy and literature in both urban and rural contexts. Some of these are principally intended to remove runoff from streets, such as permeable paving, but others could be used to capture surface runoff which could then be used for some purposes.

There is potential to use captured runoff directly, for example for watering gardens or washing cars in a domestic context, and possibly for firefighting, commercial vehicle washing or irrigation of public spaces. Most uses would require treatment, which in turn would require appropriate infrastructure. Scale is critical and impacts both the technologies and the costs. The practical examples illustrate numerous projects, some city-wide and/or large-scale, led by governments at different levels, and often where there is, or has been, either significant drought or significant flood risk.

The cost of some technologies is well understood, but the wider benefits of BGI, e.g. in terms of amenity, ecology, or flood prevention, are not always easy to assess and build into decision-making. The infrastructure to collect and treat surface runoff will be more efficient on-site, in new-build and in larger developments.

The roles of different institutions, and the legal frameworks, are considered further in Annex B. In a domestic setting, there are relatively few financial incentives in Scotland, due to the charging mechanisms, and the prevalence of flatted dwellings and other shared buildings. Local authorities have multiple relevant functions including planning, building control, flood protection, housing, roads and transport. In residential areas there is scope for initiatives led by local authorities and Scottish Water, and the same bodies would be able to play a lead role in enabling capture and reuse by businesses. It will be critical to work with communities (whether domestic or commercial users) both in terms of understanding the benefits and in the design and installation of any new infrastructure, stressing the multiple wins from these approaches. Clarity on treatment requirements for different classes of reuse would be beneficial.

Rainwater reuse is a low carbon solution to emerging water and climate challenges and with coordinated regulations, financial support, and public acceptance the techniques can help build a more resilient and adaptive communities. There can be challenges but also numerous solutions and opportunities; most challenges can be overcome by better design, policy, and public awareness.

A7. Surface Water Reuse – Practical Examples

Surface water collection is becoming an essential component of sustainable urban water management, especially in water-stressed regions and densely populated areas. These systems can range from natural solutions to engineered technologies. Especially important in arid regions and areas prone to drought is access to water with many countries now developing water management strategies that include water reuse. The following provides practical examples of rainwater reuse and RWH techniques from the UK, Europe, Asia, Australia and the US. These are grouped by the UK, Europe and globally, as also organised in Table 2.1 in the main report. Many of them have also been considered in the main text of Annex A and reflected in the conclusions in A6.

A7.1 United Kingdom

Community Housing Development, Telford, Edinburgh

A RWH system was used to supply water all year round to environmentally friendly affordable homes for toilet flushing and irrigation for a communal garden area. Potential to save 266,000 litres per year, saving 7,410 kgCO_2e. Easy to install combi RWH-water reuse system reduced maintenance requirements with internal components in one unit. The system is currently running at 91% efficiency, using rainwater for 9% of its supply. Rainwater Saving 210,000litres, Potential carbon saving 4,410KgCO_2e, roof area 287m^2, (below ground) for tank size of 10,000L.

https://www.stormsaver.com/case-studies/residential-case-studies/scottish-housing-development

Gooddrop Ltd, Hull

Gooddrop collaborated with University of Nottingham to develop new approaches to growing cotton and mitigate problems of growing cotton. Cotton is an invasive, environmentally harmful commodity crop, with excessive herbicide and pesticide use, large water consumption and contributes to land use degradation. It was found that growing cotton could be achieved in controlled indoor environments within existing or new buildings. The system is designed to balance water recovery, RWH and minimal potable water use (Wardle 2025). The R&D facility produced 50,000 kg lint in year 1 with initial system fill of 308,000 l (mix of potable and rainwater). The annual water balance is 83m^3/yr (Rainwater share: 50m^3, potable share 33m^3). The water efficiency gain compared to conventional cotton is 99%+. The resulting fabric is unbleached, and fully compostable. For centuries, the UK has imported fibre at vast environmental and social cost. Three years of development has proven it can be grown sustainably in the UK "showing what's possible when you reimagine cotton supply chains for the 21st century". The first garment was made in collaboration with sustainable couture label TAMMAM and shown on the runway in London, highlighting how the innovation could influence the fashion supply chain.

https://www.good-drop.com/

Mickley, Tyne Valley, Northumberland

A sustainable Housing development uses a water collection system to catch run-off from its curved structure. With a surface area of 90,000m² the water is collected through a gutter and passed through a series of hoppers to the main storage system.

Aims of the site were to retain and improve tree cover, implement SuDS and reduce surface run-off from to better than existing through retention of trees and further planting, permeable surfaces to roads and parking, green roofs to buildings to slow run-off, RWH for garden irrigation, soakaways for each house, rainmeadows for flood periods.

https://www.newtonarchitects.com/projects/mickley-square-sustainable-housing/

Havenstreet, Isle of Wight

Southern Water conducted a trial on the Isle of Wight, installing over 1,000 slow-drain water butts at no cost to residents, with the aim of mitigating storm overflows. Standard garden water butts hold up to 200 litres of nutrient-rich rainwater at a time, which can then be used to water plant pots and flowerbeds. The scheme is expanding after a successful trial which led to a 70% reduction of spills from the nearby storm overflow site which had previously activated 27 times a year when it rained more than 5mm – during the six-month trial there was only one spill.

https://www.makewaterfamous.com/news/free-water-butts-reducing-storm-overflows

Llys Enfys Care Home, Glamorgan

Medical facility RWH system to support achieving a high BREEAM rating. Given the significant demand for toilet flushing (averaging 7 flushes per WC per day), the system was installed to save water by supplying non-potable water to 76 WCs for use by residents and staff. The system collects water from a 2,300m² catchment area of roof with symphonic drainage, directing it to two 23,000L storage tanks. With abundant rainfall and a large catchment area, the system yields up to 1,850m³ of rainwater annually, operating at an estimated efficiency of 70%. The rainwater is mechanically filtered before entering the rainwater tanks via a 380 micron, stainless steel sieve. Fredenham *et al* (2020).

Community Centric Rainwater Management, London and Cirencester

Location: Waltham Forest and Lambeth, London, Cirencester, UK. This is RWH for regeneration projects in combined sewer catchments with 74 Waterbutt planters in 14 residential streets managing runoff from a combined area of 1800m^2. Benefits include flood risk management, RWH, amenity, increased sewer capacity, climate change adaptation, biodiversity, reduced wastewater pumping and treating, education. Project was part funded by Thames Water and Ofwat and involved an innovative online platform for engagement and sign-up, tapping into community engagement channels (e.g. whatsapp groups) and community champions (e.g. flood action groups) to promote the scheme and help it achieve scale. By using digital technology, the project made measurable impacts in addressing the challenges of a changing climate by deploying the waterbutt planters. The project developed a blueprint by establishing good practices for effective community engagement to achieve SuDS at scale, improving community understanding of surface water flooding, benefits of RWH and engaging communities to take collective action to reducing CSOs. For distributed storage of waterbutts to have an impact rainwater capture must be deployed at scale across a catchment, (hundreds and thousands of devices). However, deployment at scale within communities is a major challenge and this project helped to show that it is possible. (susdrain, 2025; Boorman *et al.,* 2025).

https://www.thameswater.co.uk/about-us/innovation/community-centric-rainwater

Bloomberg HQ, London

Bloomberg's London office building hosts 4,000 employees and has a multi-faceted water reuse system which includes the reuse of air conditioning condensate. Condensate is collected, cleaned and used to supply the building's cooling towers. It is also fed into the building's water recycling system which includes harvested rainwater and recycled greywater. This supplies the water for toilet flushing for the entire building and delivers an overall 73% saving in water consumption.

https://www.bloomberg.com/company/stories/eco-friendly-features-bloombergs-new-european-headquarters/

Tesco Extra, Havant

Second generation food and retail store with 100% mono pitch roof including symphonic drainage for a catchment 800m^2. To meet planning conditions for increased site density, the SUDS plan required RWH. The scheme utilizes an above ground tank due to high density piles used for building columns. The rainwater applications are 14 WCs (public and staff) and 2 home delivery wash down points. The 24hr operation 7 days a week requires a robust design with flexible architecture to allow for operation during maintenance. The rainwater is lifted from the main storage tank with a single pump to the rain manager where it is distributed from a 300L tank by twin booster pumps on demand to the WCs and wash down points. A fine particle filter and UV filter was specified for additional treatment. The rain manager solution provides the most flexible enabling the user to operate on mains water without the main tank being in service and for single person servicing of the whole system. This is especially useful in the event of contaminated water in the main tank and tank servicing. Fredenham *et al* (2020).

Nat Flatman Street, Newmarket

A smart RWH system that addresses water scarcity and flooding as part of Anglian Water's 'Smarter Drop Street' pilot project to research retrofit solutions. East Anglia receives a third less rainfall than the rest of the country. The purpose of the project was to identify practical, cost-effective ways to address climate change impacts and human behaviour on water availability, surface water flooding and environmental pollution. Nat Flatman Street is a typical, terraced street connected to combined sewer network with limited outdoor space. Anglian Water worked with Groundwork, a social enterprise NGO, and SDS to engage with and encourage residents to have a smart rainwater harvesting tank installed. A take-up of 22% was achieved. The system is a standard water tank with a small control box for communication between a rainwater management measuring and reporting platform that calculates the required tank volume based on forecasted rainfall events and releases water until the required capacity level is reached. The tank can attenuate all or part of the ensuing rainfall. The slimline tanks have 270 litre capacity. Across 13 sites, the tanks have a total storage volume of 3.5m^3, attenuating roughly 520m^2 of impermeable area. In total approximately 40m^3 of stormwater was attenuated, or about 25% rainfall; representing more than eleven times the volume of the tanks installed. Over 29m^3 of collected rainwater was pre-emptively released in advance of storms by the automated control process, thereby increasing the volume of stormwater attenuated. Improvements made during the project to the weather-based predictive control algorithm resulted in a 50% increase in the average volume of water discharged. A cost-benefit analysis indicates that the smart rainwater management system significantly outperforms traditional water butts in terms of cost per cubic metre of stormwater attenuation.

https://sdsinfrastructure.com/case-studies/newmarket/

A7.2 Europe

Copenhagen – sponge city

Following a 1:1000 year flood in 2011, Copenhagen developed its Cloudburst Management Plan in 2012. This ambitious city-wide strategy is intended to deliver the first 'whole city' sponge city. The Plan includes a wide range of infrastructure with 300 proposed projects over 20 years and annual prioritisation. Some of this is funded from water and drainage charges as well as contributions from the city administration and private co-financing. Estimated costs were €1.5bn., but the cost of the 2011 flood was €0.8bn. Two Masterplans were developed, one for grey and one for blue-green infrastructure, with most of the solutions adopted being from the latter, but including some tunnels, pipes and tanks. There is considerable variety in the type and scale of projects. Although not yet complete, overall the process has both stimulated activity by organisations and institutions and been a participative mechanism. Flood risk in priority areas has been reduced by between 30%-50%.

https://interlace-hub.com/cloudburst-management-plan-copenhagen

Nuremberg – low energy development ‘Prisma’

Combined commercial, retail and residential complex. All stormwater is managed on site whilst creating a pleasant and comfortable living and working environment. The ground floor has retail facilities (stores and cafe), 2-4th floors are offices and 5-6th floors are residential. All rainwater is collected into underground cistern after passing through raingardens and small ponds for treatment. It is then pumped to two different circulation systems: the 1st is used for irrigating plants and feeds a small watercourse which runs through the complex. The 2nd is used for natural air conditioning where water is pumped to five water walls decorated with coloured glass which pulls air down – in the summer the falling water cools the air and in winter it warms the air (~180C). Howe (2011).

RHW for data centre cooling in the Netherlands

A cost-efficient, sustainable solution for harvesting rainwater for data centre cooling as enough water could not be provided by the municipality for these needs. Rainwater from the industrial roof was reuse for cooling the facility. The challenge demanded delivering a RWH system that would be more cost effective, sustainable and faster to assemble than other options, such as concrete or plastic.

After installation of the first tank, the customer ordered three more. A retention tank, made of spiral corrugated pipes, could serve the purpose more efficiently than the originally planned reinforced concrete slab tank, which was more expensive, had higher production costs and a shorter life span. This solution was an environmentally friendly construction practice that used renewable material, reduced construction time, increased longevity and saved costs including lower maintenance requirements. This ultimately reduced the carbon footprint contributing to the circular economy at end of life.

https://viacon.co.uk/case-studies/harvesting-rainwater-for-a-sustainable-cooling-solution/

Arkadien Asperg, Stuttgart, Germany

Arkadien Asperg is an urban village where water-sensitive design dominates. A watercourse flows through the village, with drainage directed into it via a series of landscaped drainage features. Fourteen storage tanks that collect roof water and ire spread throughout the village hold up to 60m^3 water, which is used for irrigation, toilet flushing, washing and to top up the watercourse. Play spaces are designed to be floodable, providing further capacity for on-site attenuation.

https://www.building.co.uk/focus/our-town/3054588.article

Benicàssim, Valencia, Spain

Innovative ceramic permeable pavement composed of ceramic tiles that allow infiltration, runoff treatment and water reuse as part of a SuDS built as a demonstration project in 2018 and monitored from September 2018 to September 2019. The purpose of the research was to demonstrate the hydraulic performance of the solution by monitoring runoff quantity and quality variables. Monitoring data analysis illustrated positive results: reduced peak runoff rates and downstream flows. Hydrologically the system storage capacity is 100% runoff for rainfall events up to 15–25 mm. This is a very significant as these values represent 81% and 91% percentile thresholds for the study area. System performance was confirmed in terms of runoff management and water infiltration. Monitoring data shows ~ 1,060 m^3 rainfall over 28 events, with 322 mm accumulated rainfall over that period and 86% stored rainfall. Approximately 150 m3 overflowed the system during 5 events, 75% related to a flash flood event on 18th October 2018 where 48.8 mm fell, equivalent to the 97% percentile for the rainfall regime in that area (3% of rainfall exceeded on average). Stored water was either reused or infiltrated. Castillo-Rodríguez et al (2021).

A7.3 Asia

Tokyo, Japan

To promote water reuse on a regional scale, Fukuoka city government and Tokyo metropolitan government required the use of reclaimed water or rainwater for toilet flushing and green belt irrigation in buildings with floor space exceeding 5,000 m^2 (Fukuoka) or 10,000 m^2 (Tokyo). As a result, water reuse on a regional scale was implemented in Tokyo in Shinjuku, Shinagawa, and Tokyo Bay. However, owners in other areas of Tokyo could not access these regional schemes and had to install individual water reuse/RWH systems. Capital and operational costs of small facilities are a financial burden and not as reliable as large scale facilities with users relying on public water supply during drought conditions. Takeuchi & Tanaka (2020).

Huairou, Beijing, China

Confronted with severe water shortages in an already water-scarce region, peri-urban farmers in Beijing developed multifunctional urban farming practices to deal with reduced water for irrigation. As part of the EU funded SWITCH project (Howe *et al.* 2011), a RWH demonstration project was developed that included several institutions and a vegetable cooperative to show that RWH can provide a useful source of water for intensive agriculture in greenhouses. A covered rainwater storage pond had the dual purpose of storing irrigation water for use in the greenhouses as well as generating the humid conditions ideal for growing mushrooms. Farms in Huairou depend on pumped groundwater as there is no access to surface water. Using rainwater reduced pumping costs, increasing the farmers' income and availability of high quality irrigation water.

The higher returns compensated for water fees and enabled farmers to pay for high investment RWH facilities. Local government had participated in the original working group and began supporting further applications for the technology. The results were subsequently integrated into policies and under China's 12th Five Year Plan (2011-2015) with recommendations for RWH continuing into the most recent 14th Five Year Plan (2021-2025) and the "Green Building Creation Action Plan" (WATERTECH, n.d.) The WATERTECH article examined the current state and optimisation paths, challenges, benefits and opportunities for adopting RWH technology including cost benefit ratios for investment 'as the nation advances toward its ambitious sustainability goals, maximizing non-traditional water source utilization will play an increasingly vital role in creating low-carbon, resilient cities'. Howe *et al* (2011); Jefferies and Duffy (2011).

Xuhui Runway Park, China

Located in the Xuhui Riverfront Area, a formal industrial zone, the14.63-hectare site was a runway for Longhua Airport (Shanghai's only civilian airport until 1949). The redevelopment project transformed the Riverfront Area into a mixed-use district, where the historic runway was master planned as a public street and linear park serving as a 'runway of modern life'. The area provides recreation space for nearby communities and respite from the high-density redevelopment. Environmental, social, and economic and sustainable approaches resulted in a project that is leading the city's new lifestyle – reimagining space for pedestrian and road traffic. The layout limits the number of traffic lanes, promoting public mobility and integrated bike lanes. Stormwater from the park and nearby Yunjin Road is managed through a 5,760m^2 rain garden to the north and 8,107m^2 constructed wetland to the south of the site. After rain garden and forebay treatment, stormwater meets the surface water quality standard of China for recreational water. A portion of the treated runoff is collected in a 10,408-gallon underground cistern for park operation and maintenance use when necessary, sufficient for irrigating 4.87 acres of planted areas, or providing water for the park Runway Fountain. Reused rainwater reduces potable water use and saves 19,200 USD annually.

https://www.theplan.it/eng/award-2020-Landscape/xuhui-runway-park-an-innovative-urban-revitalization-project-sasaki-

Ryogoku Kokugikan, Japan

Sumo wrestling facility: Rainwater from roofs is a primary resource with significant reuse potential as it is generally captured and channelled into piped drainage systems. This 8,400m^2 roof drains rainwater into a 1,000m^3 tank, which is used to supply water to ~70% of the stadium's toilets and air conditioning units. The captured water can also be used as an emergency water supply after earthquakes, and to melt snow on the roof. The local municipality now also offers subsidies to help install RWH projects.

https://www.tep.uk.com/non-potable-water-reuse/

A7.4 US

The US National Water Reuse Action Plan (WRAP) was developed in collaboration with partners across the water sector. Actions in the plan support the adoption of potable and non-potable reuse and address local and national barriers across a range of technical, institutional and financial topics. Since 2020, the effort has grown to include over 70 actions and 170 action leaders and partners, including a federal Interagency Working Group, that collaborate to advance reuse across the country. The collaborative strives to ensure that water reuse is accessible and straightforward to implement. The WRAP is to better integrate federal policy and leverage the expertise of both industry and government to ensure the effective use of the nation's water resources. Throughout the WRAP development process, the EPA and its partners have engaged in significant efforts to identify and characterize opportunities to foster the consideration and implementation of water reuse.

https://www.epa.gov/waterreuse/water-reuse-action-plan

Canal Park, Washington D.C.

The site is a former school bus depot that has been transformed into a community park and a model stormwater capture and reuse project that collects an estimated three million gallons of water per year. Stormwater from the site and nearby streets is captured, treated and managed with bioretention, tree planters, and cisterns, then approximately one million gallons are reused to meet the park's water supply demands for landscape irrigation, fountains, and an outdoor ice rink. Canal Park's green spaces have provided the community with social, economic, and environmental benefits while reducing pollution in the Anacostia River.

https://www.epa.gov/system/files/documents/2024-12/canal-park-case-study_508.pdf

EPA Headquarters, Washington D.C.

Continuous monitoring and adaptive control (CMAC) technology for Advanced RWH at the USEPA headquarters in Washington, D.C. The objective was to retain water for on-site irrigation and reduce wet-weather discharge to the combined sewer. The challenge was to upgrade an existing 6,000-gallon RWH system as uncaptured wet-weather flows contributed to the local combined sewer system increasing the potential for combined sewer overflows (CSO) and poor water quality in the Chesapeake Bay. Two competing priorities were addressed: minimise wet-weather discharge and maintain water availability for irrigation on-site. Technology: The existing RWH system was retrofitted with continuous monitoring and adaptive control (CMAC) technology. The cloud-based platform automatically monitors the weather forecast and calculates expected runoff volume from future storms. The system then automatically opens the discharge valve in advance of the storm and releases a predicted volume equal to the potential runoff. As the forecast changes, the system adjusts intelligently. Before the storm begins the system closes the valve, capturing rain to refill the cistern. The valve remains closed until another rain event is forecast, ensuring water for reuse. A solenoid valve allows the CMAC technology which controlled water draining to the combined sewer system and monitor discharge flow, irrigation flow, and air temperature and activate a freeze protection system during cold weather. Along with the existing RWH system, this eliminated the need to install additional storage volume. Since deployment (2014), the advanced RWH system has proven to be a low-cost, high-performance solution for meeting stormwater management goals. The system harvests and store up to 6,000 gallons water for 10,000 ft2 of roof area for a wet weather capture of 1" rain events resulting in 100,000 gallons of wet weather flow prevented annually.

https://www.epa.gov/sites/default/files/2018-08/documents/smart_data_infrastructure_for_wet_weather_control_and_decision_support_-_final_-_august_2018.pdf

San Francisco – online water reuse system project

The Exploratorium - Pier 15.

Size: 333,000 Square Feet. Alternate Water Sources: Rainwater and Bay Water. End Uses: Toilet Flushing and Heating and Cooling. Volume: Up to 2,364,000 Gallons/Year. (RWH System and Bay Water Heating and Cooling System). Potable Water Use Reduction: 30% (Rainwater Harvesting System Only) Driver(S): Project Sustainability Goals, Public Education, Certification, and Mandate (San Francisco Stormwater Management Ordinance).

Whole Foods Mixed-use Development, 38 Dolores Street.

A RWH Project for Non-Spray Irrigation. Size: 195,000 Square Feet. Alternate Water Sources: Rainwater. End Uses: Subsurface Irrigation and Drip Irrigation. Volume: 26,000 Gallons/Year. Potable Water Use Reduction: 26% for Irrigation; 1.3% Total Project Reduction. Driver(S): Sustainable Sites Pilot. Project Certification, and Mandate (San Francisco Stormwater Management Ordinance).

James R. Herman Cruise, Terminal Pier 27

8,000 Square Feet Alternate Water Sources: Rainwater. End Uses: Toilet Flushing and Irrigation. Volume: 370,000 Gallons/Year Potable Water Use Reduction: 50%. Driver(S): Certification and Mandate (San Francisco Stormwater Management Ordinance) System Cost: $930,000 Annual O&M Cost: $38,000.

San Francisco Museum of Modern Art, 151 Third Street

Size: 235,000 Square Feet. Alternate Water Source: Rainwater. End Uses: Toilet/Urinal Flushing, Irrigation and Cooling Tower Make-Up. Volume: 1,000 GPD; 365,000 Gallons/Year Potable Water Use. Reduction: TBD. Drivers: Sustainability Goals, Reduce Potable Water Use, and Compliance with San Francisco Stormwater Management Ordinance. The Stormwater Management Ordinance requires projects 5,000 square feet or more to decrease their post construction stormwater runoff rate and volume by 25% for the 2-year, 24-hour design storm. The captured water is treated by a filter assembly including a 50 micron filtration filter and a 20 micron bag type filter. After treatment, the water is disinfected and distributed for non-potable applications, which includes toilet flushing, make-up water for the cooling towers, and drip irrigation of the gardens and living wall. Overall, the system is saving 365,000 gallons of potable water annually, equating to roughly 1,000 gallons of water per day.

Moscone Center Expansion Project — 747 Howard Street.

Size: 1.5 Million Square Feet. Alternate Water Sources: Rainwater, Foundation Drainage and Steam Condensate. End Uses: Toilet/Urinal Flushing, Irrigation and Street Cleaning. Volume: 15 Million Gallons/Year. Potable Water Use Reduction: Meets 100% of Onsite Non-Potable Demands & Provides Offsite Potable Water Demand Offset. Drivers: Certification, Compliance with San Francisco Mayoral Executive Directive 14-01, and Compliance with San Francisco's Stormwater Management Ordinance. Onsite Water System Cost: $2.5 Million. Has net-positive water usage, as the project intends to export more non-potable water offsite than the amount of potable water consumed onsite. San Francisco Mayoral Executive Directive 14-01 requires San Francisco City and County agencies to develop alternative local water sources.

Energy Center San Francisco-BART Foundation Drainage Project — Powell Street BART Station.

Alternate Water Sources: Foundation Drainage. End Uses: Steam Heating in Downtown San Francisco Steam Loop. Volume: 30 Million Gallons/Year Potable Water. Use Reduction: 30%. Drivers: Reduce Potable Water Use and Sustainability Goals. Onsite Water System Cost: $3.5 Million. Annual O&M Cost of onsite Water System: $200,000. ECSF provides steam for heating, hot water and process steam to hotels and buildings in downtown San Francisco. Driven by their commitment to the sustainable use of energy and water, ECSF partnered with BART to reclaim foundation drainage at the Powell Street BART station and redirect it to their District Energy Plant located nearby for use in the district steam loop. To maintain the structural integrity of its transportation system, BART captures foundation drainage from the Powell Street BART station in a large cistern and pumps it to SFPUC's sewer system. Recognizing an opportunity, ECSF approached BART to divert that water instead for use in the district steam loop. ECSF's innovative approach began with identifying foundation drainage as a resource rather than a nuisance to be discharged to the sewer. By tapping into this constant flow of groundwater, ECSF can reduce their overall water consumption by 30%. Through this joint effort, both BART and ECSF are demonstrating outstanding leadership and modeling the path for successful public-private partnerships in San Francisco.

https://www.sfpuc.gov/programs/water-supply/onsite-water-reuse

A7.5 Australia

Australian Managed Aquifer Recharge (MAR) Systems

Location: Adelaide, Australia. **Function:** MAR is a Water reuse system initiative enabling urban applications. Surface water is collected during high-flow periods, treated, and stored in underground aquifers for reuse. **Features:** The stored water is used for agricultural and urban irrigation; Includes filtration, sedimentation, and nutrient management to ensure water quality.

https://www.waterconnect.sa.gov.au/Content/Publications/DEW/Managed%20Aquifer%20Recharge%20Schemes%20in%20Adelaide_Final.pdf

Sydney Park Water Re-use Project

The city of Sydney's largest water harvesting project was built in partnership with the Australian Government through the National Urban Water and Desalination Plan. The project captures and cleans ~ 240 Olympic-sized swimming pools of water per annum. It is a central element of Sustainable Sydney 2030, targeting 10 % water demand is met through local water capture and re-use in the park. The project's success lies in its unique fusion of design, art, science and ecology – an interwoven network of community infrastructures in transforming a former brick pit and landfill site into a vibrant new urban parkland. The scheme has improved water quality, visual amenity and detention storage by enhancing circulation of water through existing ponds that previously suffered poor water quality with stagnant water during warmer months and low rainfall. Prior to the this, all stormwater flowing through the Munni Channel continued to Alexandra Canal and beyond to Botany Bay untreated. The project pumps ~ 1000L/s stormwater from Munni Channel into the park water re-use scheme. This diverts ~ 840 ML/yr stormwater for treatment and reuse. The treatment train includes a gross pollutant trap, bioretention system (5,000m^2), wetlands and the existing ponds. Water re-used for irrigation is further treated by filtration and UV disinfection. Each year, 30 million litres of harvested water is now recycled for improved circulation of the ponds, irrigation of the Alan Davidson oval and the Village Green, and non-potable water supply for the nursery and truck washing at the City of Sydney Depot. The project strives to create “opportunities to immerse and engage with the landscape and experience different perspectives by conveying a water story through visible processes; the project is educating the community about the importance of urban water management, and the interdependent nature of urban and natural environments. The function and processes of RWH and cleansing is made legible through its visible ebbs and flows in the landscape.

https://www.planning.nsw.gov.au/government-architect-nsw/case-studies-public/sydney-park-water-re-use-project

Hawke’s Brewing Co., Sydney

Hawke’s Brewing Co. is an independent beer company (founded in partnership with former Australian prime minister Bob Hawke, where his share of royalties are donated to Landcare Australia). Collaboration with the research sector, University of Technology Sydney and the Commonwealth Scientific and Industrial Research Organisation was to improve sustainability and reduce the company’s carbon emissions. They designed a system that captures CO_2 from fermentation and reuses it to enhance plant growth within a closed, self-sufficient, AI-enabled hydroponics system. In addition to preventing the release of CO_2, solar electricity generation and large roof that captures rainwater makes the brewery building well-suited for indoor farming. The lettuce produced is used in the on-premises restaurant. Lettuce was chosen as “lifecycle carbon costs are high, with vast resources used to grow, irrigate, transport and refrigerate a product containing very few calories”. Plants grow faster in a CO_2 enriched environment with ~100 lettuces grown per month. The greatest carbon savings are made by not buying traditionally farmed lettuce. The system is integrated with sensors that collect data to train AI to automatically detect and optimise growing conditions. Light spectrum output, pH, nutrient concentration, lighting movement, tank levels and water consumption are remotely controlled. System power draw, air quality, water usage, pH buffer solution usage, nutrient consumption, CO_2 absorption and light intensity are also monitored. The novel system is also a unique draw for the brewery and restaurant.

https://www.csiro.au/en/work-with-us/funding-programs/SME/SME-success-stories/University-Of-Technology-Sydney.

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