THE
ENVIRONMENT
PARTNERSHIP

International Wastewater Reuse for Non-Potable Uses Review

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PLANNING I DESIGN I ENVIRONMENT

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International Wastewater Reuse for Non-Potable Uses Review

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1.0 Introduction

1.1 Wastewater

'Wastewater' is a broad term describing water resources that are deemed to be surplus to requirements, and either discharged to the environment, or not utilised for further use. This includes water generated from urban and rural drainage systems (such rooftop rainwater, highway runoff, urban drainage, internal drainage board outfalls), discharges from anthropogenic processes (including domestic grey water, final effluent, industrial effluent) and contaminated water in the environment (such polluted groundwater, mine water).

Historically, the UK has underutilised these potential water resources. This due to a lack of demand, a nationally well-connected water supply that has reduced the need for alternative water sources, regulatory reluctance, negative perception and the absence of a co-ordinated national water reuse strategy. However, with increased demand, reduced resources and an increased desire for sustainable solutions, wastewater resources are increasingly being looked at as an alternative water source.

In other countries, wastewater has been more widely utilised, often driven by the necessity of limited or expensive viable alternatives. This has accelerated the adoption of wastewater reuse through research and development, government support, and streamlined legislative processes.

Due to its origin, 'wastewater' often requires additional treatment to ensure its suitability for use. However, depending on the type of wastewater and it's end use, this level of treatment can vary. For non-potable uses (not for direct human consumption) such as agriculture, industrial cooling and cleaning, recreation and some domestic use, the level of treatment required can potentially be less stringent based on specific criteria. This can ensure that a lower quality of water is used in situations where it is appropriate to do so, reducing demand on potable sources of water. This process has successfully been used in many other countries as well as some localised examples in the UK.

1.2 Purpose of this Report

This report has been produced on behalf of Anglian Water to act as a stimulus for the Non-potable Water Reuse Workshop being hosted by DEFRA on 29th November 2024. It introduces the concept of using wastewater resources for non-potable purposes and provides guidance on relevant literature, standards, policies, and global case studies. The report highlights ten different sources of wastewater, detailing their origins, common challenges, treatment methods, potential applications, and the barriers that have been overcome to facilitate their use. It is important to note that this report is not intended to be an exhaustive review of academic literature or national water resource policies.

Image (Source: Arno-Senoner Unsplash

2.1 Rainwater from Roofs

Source: expedia

What is it?

Rainwater falling on roofs is generally captured and channelled into piped drainage systems. Rainwater harvesting is the act of capturing and storing this water for reuse. This can be on a domestic scale (c. 0.1-10m^3), large building (c. 10-1,000m^3), or neighbourhood level (c. 1,000m^3 +). Water can also be diverted into ground aquifer recharge systems.

Where and how is it used

Rainwater harvesting has been used globally for millennia and provides the simplest form of non-potable wastewater reuse. In many developing countries, it continues to serve as a primary source of both potable and non-potable water, such as irrigation and greywater systems[1]. It is commonly used in the UK, particularly on large buildings seeking BREEAM credits. In urban environments, drainage systems often incorporate Sustainable Urban Drainage Systems (SuDS) to slow and manage flows of surface water. In some instances, rainwater harvesting is a component of SuDS (see section 2.2).

Water Quality

Water quality is heavily dependent on the type and condition of the harvesting surface, and length of storage. Issues include:

- Suspended solids from roof surface including hard surface roofing materials and debris;
- Nutrients (nitrates and phosphates) from bird faeces;
- Microbial pathogens from animal contamination or long-term storage;
- Discolouration from organic matter (green roofs or vegetation);
- pH changes due to roofing material or acid rain; and
- Heavy metals from drainage system or PV installations (copper, zinc, iron, aluminium).

Barriers and Solutions

Key barriers to large scale uptake of rainwater harvesting include:

- Initial upfront construction costs vs long financial payback, primarily due to ready access to cheap alternative water sources;
- Ongoing maintenance and energy costs of installed systems;
- Size of roof area determining viability;
- Reliability and or unpredictability of rainwater supply;
- Requirement for large storage volume to make systems effective during periods of low rainfall. Costs associated with underground storage tanks, particularly when retrofit; and
- Ownership disputes for shared buildings.

Large scale rainwater retrofits can be achieved with focused government support. The Australian government has a history of providing generous rebates to install rainwater harvesting systems. This has included grants of between £250-750 to install rainwater tanks, with larger grants available for plumbed tanks larger than 2m^3[2]. It is estimated that up to 26% of Australian houses have some form of rainwater harvesting system[3]. Australia launched its National Rainwater Harvesting Strategy in 2024, designed to provide tangible goals and actionable practices at a national scale[4], with rainwater harvesting tanks mandated on new builds in some Australian States[5]. Other countries with similar national rainwater harvesting policies and guidance include France[6], Ghana[7], South Africa [8], Kenya[9], Rwanda[10] and Grenda[11].

A stormwater utility levy is paid in Germany. This is dependent on the impermeable surface area of a property, with funds directed into a central pot of money to fund sustainable water management which may be used to fund innovation water reuse schemes. Typical values in Germany range from 0.5-2.0 € per m^2 per annum of impermeable area[12]. In the US, rebates on water bills are offered in multiple locations to increase financial viability of rainwater harvesting projects[13].

Smart water control systems can also help alleviate some of the inefficiencies with storing large volumes of water. These can be programmed to release or use water in advance of storm events, freeing up capacity to store subsequent rainfall[14].

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[1] Daud et al. 2021 Issues And Challenges In Rainwater Harvesting For Potential Potable And Non-Potable Water Production. iTECH MAG Vol3 page 55-58

[2] Australian Government Water Tank Rebate Information

[3] Rainwater Harvesting Australia

[4] Australia National Rainwater Harvesting Policy

[5] Chubaka et al. 2018 A Review of Roof Harvested Rainwater in Australia. Journal of Environmental health.

[6] Decree No. 2023-835 Use of Rainwater and Treated Wastewater France

[7] Ghana National Rainwater Harvesting Strategy

[8] South Africa Rainwater Harvesting Strategy

[9] Kenya National Rainwater Harvesting Strategy

[10] Rwanda Rainwater Harvesting Strategy

[11] Grenada National Rainwater Harvesting Programme

[12] Intereg Central Programme – Rainwater Fees for a Fair and Sustainable Rainwater Management DC2.4

[13] Waterreuse.org – stormwater reuse

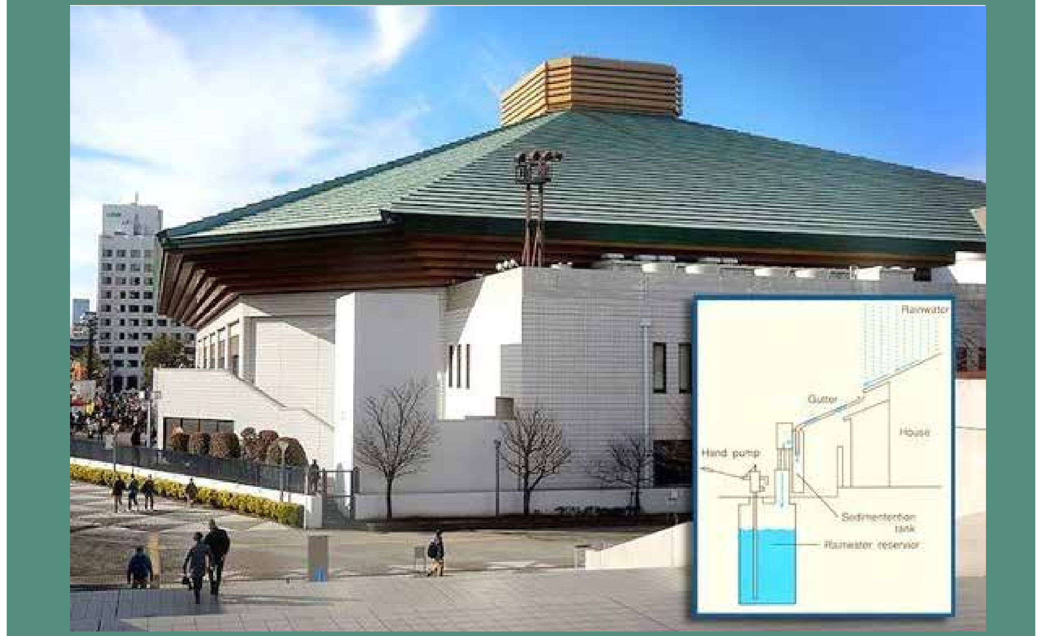
Case Studies

Credit : Tom Young

1. Singapore - 4 Pillars Water Supply Strategy

The 4 Pillars of Water or 'National Taps' Strategy (Rainwater, NeWater, Import and Seawater) was first developed in the 1970s, through which Singapore planned to be fully self-sufficient in water. It has reuse and integrated management at its centre. The development of an island wide water capture system has been key, with water channelled into a series of lagoons and estuary storage areas for later reuse. On a local level, most buildings also have some form of rainwater harvesting.

The 4 Pillars Water Project is centrally planned and controlled by the Singapore Government, allowing the long-term vision to be realised. The government owned Public Utilities Board (PUB) is tasked with implementation, with support from private companies where needed. The development of technology by PUB was facilitated by the co-evolution of knowledge between public and private sectors, with technology now being exported across the world.



Source: Ecowatch

2. Japan - Ryogoku Kokugikan – Sumo wrestling facility

The facilities' 8,400m^2 roof drains rainwater into a 1,000m^3 tank which is used to supply water to around 70% of the stadium's toilets and air conditioning units. This 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 rainwater harvesting projects.

Source: Star Tribune

3. USA - Allianz Field, Minnesota

Water is captured from the stadium roof and sports field and stored in a 2,500m^3 storage tank. Over the course of a year 7,500m^3 of harvested water is used to irrigate the sports pitch, formal lawns outside the stadium, and 200 mature trees. A smart hub is used to monitor water quality, to clean the water to appropriate standards, and to pump it to the required areas. The system also responds to weather forecasts, thereby predicting rainfall and adjusting water levels in the tank to allow for maximum storage. Part funding was provided by the local Metropolitan Council.

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14 Webber et al. 2022 Moving to a future of smart stormwater management: A review and framework for terminology, research, and future perspectives. Water Research. Volume 218.

2.2 Urban Drainage

Source: Dreisetil consulting

What is it?

In urban areas, where many surfaces are sealed by buildings and paving, natural infiltration is limited. Instead, drainage networks collect and divert surface water to local watercourses. This can lead to the transport of concentrated pollutants, and also increase catchment flood risk through the rapid accumulation of flows. Water from urban drainage is often underutilised for alternative uses[1].

Where and how is it used

Urban drainage systems can be adapted to allow drainage water to be stored for later reuse, rather than being immediately discharged. This requires large storage volumes to be implemented to take advantage of periods of high-water availability.

There is currently a drive to alter traditional urban drainage to include Sustainable Drainage Systems (SuDS). These systems mimic natural drainage regimes, integrating drainage features into the landscape[2]. Water is actively drained into an area of soft landscape, such as a rain garden, swale, infiltration basin, tree pit, or retention pond, with the aim of increasing water treatment prior to discharge, whilst also reducing flow rates. This approach can provide opportunities for reuse of rainwater in situ and encourage localised groundwater infiltration. However, there is often less emphasis placed on capturing large volumes of water for non-potable reuse, despite this approach providing a resilient collection system and UK policy encouraging reuse as a first option for drainage[3]. In Melbourne, extensive Water Sensitive Urban Design (WSUD) planning requirements have seen good success rates in encouraging water reuse as a first option for drainage schemes[4].

Water Quality

Urban runoff contains multiple pollutants which build up on urbans surfaces and are then mobilised during storm events. They include:

- Hydrocarbons (oil, petrol, diesel) from roadways and vehicles;
- Nutrients from amenity areas (fertilisers);
- Heavy metals from drainage gutters and vehicles;
- Suspended solids from construction sites and soil erosion;
- Airbourne pollutants collected during storm events; and
- Cross contamination from foul water drainage pipework systems.
- Pollutants can be successfully reduced when water passes through SuDS.

Barriers and Solutions

Water treatment and storage requires space, which can make retrofitting both expensive and technically challenging in areas where space is at a premium and where existing conventional drainage systems are already in place.

Despite large volume attenuation tanks being present in urban drainage schemes they are not being fully utilised. Tanks are generally large single tanks or a series of tanks that provide capacity to accommodate extremely large storms (100 year return + 40% climate change factor). Many of these tanks stand largely empty for most of the time, and only become partially filled on a few occasions. Therefore, this available volume of water storage is underutilised. Smart control systems allow more active control of these assets by intentionally holding water back, until it is predicted stormwater will enter the tank. The system can release sufficient water to provide capacity to accommodate new drainage water[5]. Therefore, these tanks can remain full for most of the time, meaning the water is available for widespread non-potable uses.

Additional requirements for water reuse in new developments, as well as shared learning/experiences for drainage engineers will improve understanding and encourage better integration and design of drainage schemes. This is especially required as this type of solution may not have an immediate cost return compared to simpler standard 'SuDS' solutions.

Case Study

Source:Ecco Landscapes

1. New Zealand - Kirimoko Park Wanaka

Kirimoko Park is a c.120 unit greenfield housing scheme which put sustainable urban drainage concepts at the forefront of the design[6]. The landform and hydrology influenced the road and plot layout to maximise water conveyance and infiltration and minimise earthworks. Through strategic use of swales, raingardens, and detention/infiltration basins almost all stormwater flows are managed on the surface. This has resulted in a significant 23% cost saving for the project and has allowed stormwater to be an attractive resource visibly showcased on the site.

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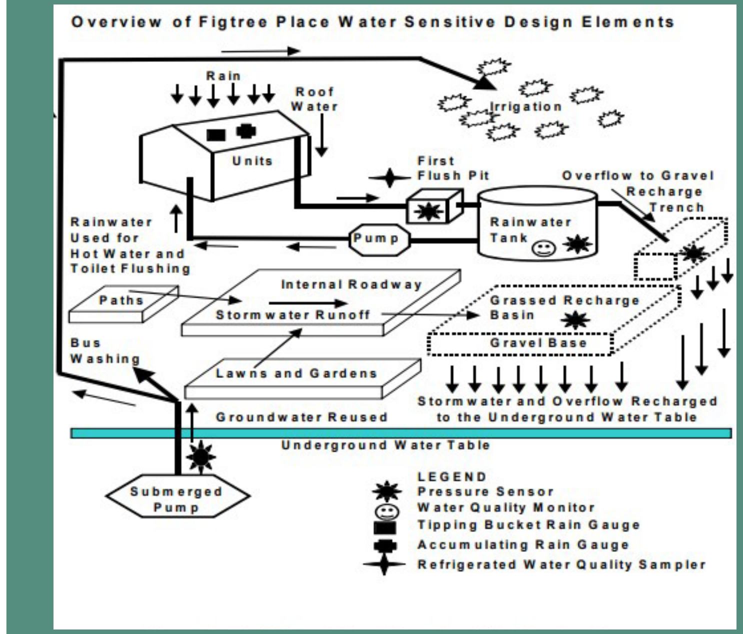
[1] UK Government Blog - Future of the subsurface: urban water management in the UK (annex) October 2024
[2] Susdrain – Urban Drainage
[3] London Plan Policy 5.13 - Drainage Hierarchy
[4] Melbourne's Water Sensitive Urban Design planning requirements
[5] UKGBC – Bruntwood Smart Blue-Green Roof
[6] Archipro – Kirimoko Park AR& Associates
[7] Dreiseitl Consulting – Arkadien Asperg Case Study
[8] Coombes et al. 1999. Figtree Place: A Case Study in Water Sensitive Urban Development (WSUD)

Case Studies

Source: Dreisetil consulting

2. Germany - Arkadien Asperg, Stuttgart

Arkadien Asperg is an urban village where water sensitive design dominates[7]. A watercourse flows through the village, with drainage directed into it via a series of landscape dominated drainage features. Fourteen storage tanks hold up to 60m³ of water, which is then 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.



Source: Urban Water Cycle Solutions

3. Australia - Fig Tree Place, Newcastle

This 27-unit residential development built in 1998 set out to provide 50% of house water demand, 100% of domestic irrigation and 100% of bus washing demand from stormwater harvesting[8]. A series of 9-15m³ storage tanks capture water across the site, with any overflow directed into infiltration basins to recharge ground aquifers. It is estimated that the measures implemented resulted in a water saving of 60% compared to a conventional development.

Source: Vika

4. USA - Washington DC's Canal Park

Located along a section of the city's historic canal system, the drainage system at Canal Park handles up to 9,000m3 a year of stormwater from hard surfaces and buildings[9]. Two 150m³ tanks are used to recycle up to 5,500m³ of water a year for the parks irrigation system, toilets, ice rink and fountains. Water is cleaned through a series of rain gardens, filters and or UV application, depending on its end use.

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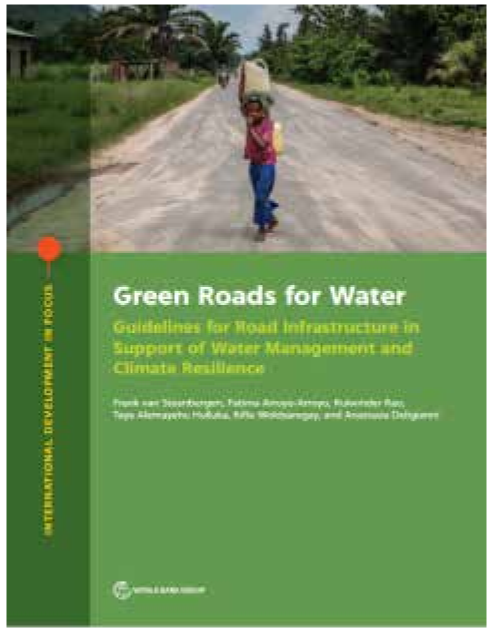
[9] Canal Park, Washington DC EPA Case Study

2.3 Highway Runoff



INTERNATIONAL DEVELOPMENT IN FOCUS

Green Roads for Water

Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience

Source: Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience

What is it?

Highways deal with significant volumes of stormwater runoff. Due to the requirements of road surfaces, this water is rapidly moved away from the highway via conventional drainage systems. Water is discharged into treatment ponds, storage tanks, a combined sewer network or directly into water courses.

Where and how is it used

Highway drainage has historically been concerned with removing water from road surfaces as quickly as possible to maintain road safety. As such, highway drainage is underutilised globally for reuse. SuDS on smaller roads are becoming more widespread and allow the reuse of water in local landscape and amenity areas (section 2.2). However, the current role of SuDS in highway drainage is largely to improve water quality before discharge to the environment.

Water Quality

Currently National Highways and other highway authorities in the UK do not have permits attached to many outfalls. Therefore, treatment of this water is variable, and often minimal. Highway runoff therefore has the potential to be heavily polluted with numerous sources of pollution[1,2].

- Hydrocarbons from oil, petrol and fuel;
- Heavy metals from exhaust fumes and brake/clutch components;
- Microplastics and rubber particles from tyres;
- Salt spread via road management operations;
- Herbicides from roadside vegetation management; and
- Nutrients and other suspended solids.

Barriers and Solutions

The lack of guidance and standards of surface water for highways prevents significant efforts to a) reduce pollution in runoff and b) reuse water. The reuse of water could act as an incentive to treat water to an acceptable standard for the proposed use, with many treatment solutions widely available. Minimum water quality treatment standards for highway runoff do exist in many other countries, for example Austria focuses on collecting and treating small quantities of water locally, whereas Switzerland builds large treatment areas taking high volumes of runoff [2]. The variability in highway treatment methods impacts the ability to reuse highway runoff water for local uses without additional treatment.

Treatment options include[1,2]

- Initial sediment and oil removal – filter drains, forebays, grit and oil separators;
- Settlement and storage – ponds, basins and constructed wetlands; and
- Water filtration and treatment media.

Image: Algae bloom (Source: Stormwater)

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[1] Stormwater Shepherds Highway Runoff and the Water Environment May 2024

[2] Mooselu et al. Current European approaches in highway runoff management: A review. Environmental Challenges, Vol 7

Case Studies

Source: Gediminas Rudokas

1. Denmark - Brondby Golf Course

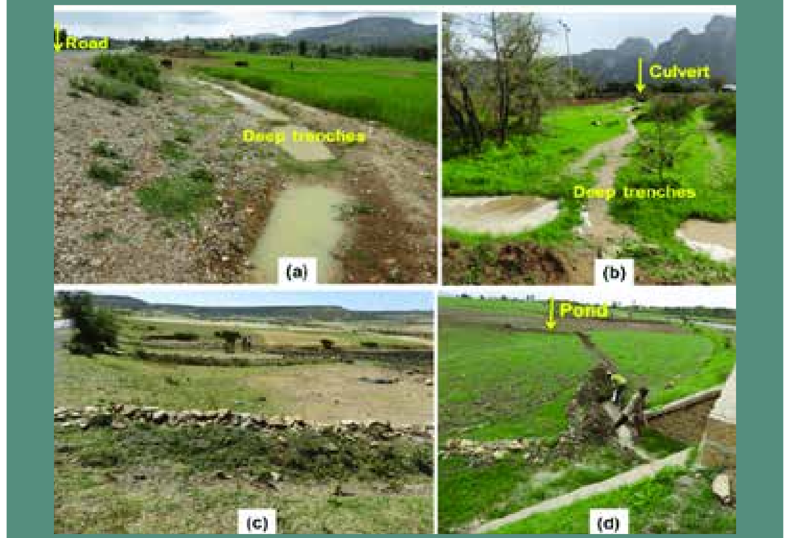
The original drainage design of the golf course includes three large storage lakes, into which land drainage is directed providing up to 5,000m^3 a year of irrigation water. In recent years, a major government funded lightweight railway and cycle path has been constructed on the Club's western boundary. The project engineer was proposing to build a small holding reservoir to temporarily store drainage water, before discharging to the Baltic Sea.

An alternative option however has been to direct water into the golf course for reuse. This involved state and local municipality involvement, with ecological and hydrological surveys conducted and paid for by local government. Approximately 3,500m^3 a year of drainage water is now directed into drainage lakes via a pipe network design to reduce flow rate impact on the lakes' ecosystem. Although the harvesting project was more expensive than the conventional system, the golf club supported the project for its wider environmental benefits. The process took 2.5 years from conception to completion.

Source: Design Lab

2. Australia - Gladstone Park Sports Field Wicking System

Stormwater is captured from adjacent roads and fed into sand based underground storage below the sports field[3]. Water is held in this zone and passively wicked up into the rootzone by the natural ability of water to move from an area of high concentration to low, allowing natural replenishment of soil water when needed. An overflow system ensures that the turf layer and soil above will not be submerged during rainfall events and facilitates enhanced drainage of the sports field. The system is completely passive, requires no pumping, treats and stores highway runoff, reduces the need for fertiliser and eliminates the use of potable water for irrigation.



Source: Kebede Manjur

3. Roads for Water Consortium

The Roads for Water Consortium is a global alliance of organisations organised by Metameta aiming to promote road water harvesting[4]. The consortium focuses activities in areas with severe poverty including Ethiopia, Kenya, Uganda, Tanzania, Malawi, Zambia, Mozambique, Bangladesh, Nepal, Tajikistan, Pakistan and Bolivia. With 20% of the worlds land surface within 1km of a road, the consortium aims to provide advice and guidance on how best to construct and adapt roads for water harvesting and reducing runoff pollution and erosion[5].

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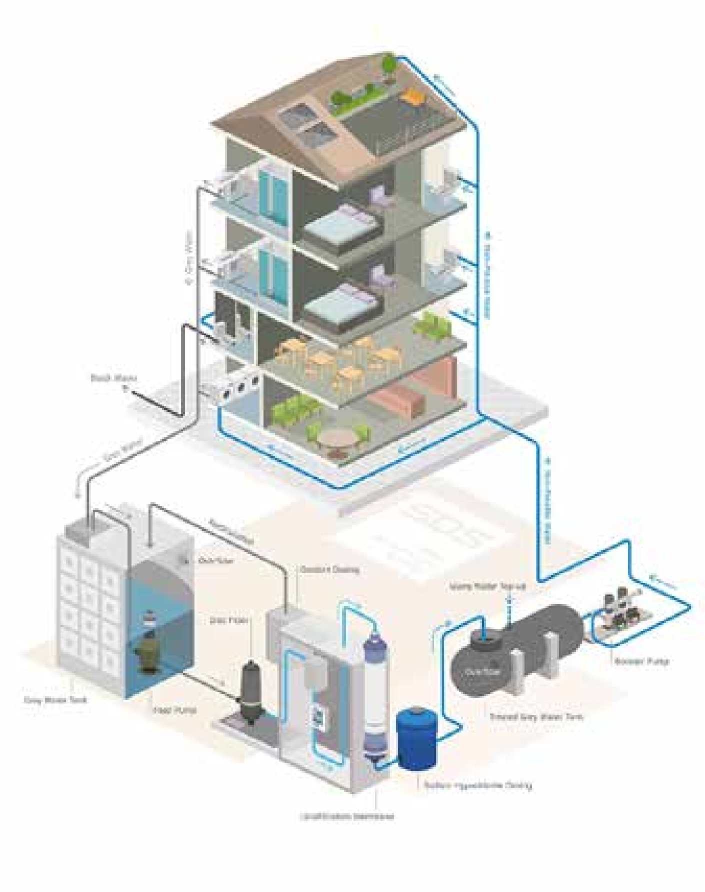
[3] E2DesignLab – Gladstone Park Sports Field Wicking System

[4] Roads for Water Consortium

[5] Borgen Project Blog – Roads for Water Benefits Infrastructure

2.4 Domestic Greywater



source: Envirotec magazine.

What is it?

Greywater includes all non-blackwater[1] domestic wastewater. This includes wastewater from washing machines, basins, dishwashers, showers and baths, as illustrated in the diagram above. In developed countries greywater production per household is in the range of 60–200 litres per day^{-1}, accounting for 75–90% of the total domestic wastewater flow[2].

Where and how is it used

Greywater can be collected and treated on site through small treatment systems consisting of a collection unit, filtration, settlement area and UV treatment prior to reuse in building's toilets or for clothes washing. Biological systems consisting of constructed wetlands can also be used. Storage tanks can range from 0.1-1,000m^3 depending on demand, and systems can cost in the region of £4,000 for domestic and £40,000-150,000 for commercial[3]. Any water that leaves site and enters a large scale drainage system can be considered as centralised treated sewage effluent (see section 2.8).

Water Quality

As greywater does not include any 'blackwater' elements, it generally contains low concentrations of microbial, organics and nutrients. Common contaminants include:

- Ionic species from washing powders, cleaning products and personal care products;
- Raised salinity from use of cleaning products;
- Some microbial content from faecal contamination and washing of contaminated foods;
- Xenobiotic organic compounds (XOCs) like surfactants used in washing detergents;
- Raised temperatures – can be as much as 60-70°C; and
- Microplastics.

Studies have shown that non-potable domestic reuse of greywater does not lead to any public health implications, specifically conditions associated with gastroenteritis[4].

Barriers and Solutions

Payback period: due to cheap mains water prices, payback periods are long. This improves as systems increase in size and become more efficient i.e. for an office block, but there is no primary driver to retrofit treatment systems[2,3].

Change in user behaviour: having access to a 'sustainable' water source has been shown to increase water consumption as homeowners use water for a greater variety of purposes when they have greywater available[5].

No national standard or guidance: this makes adaptation difficult in many countries. Examples are becoming more common, such as Los Angeles indoor water reuse guidelines[6] and EU standards for water reuse[7]. Guidance helps to standardise sources of greywater, improve public perception/education and reduce the 'yuck factor'. Long term droughts or sustained water restrictions help drive public uptake and acceptance of these water sources, for example The Millennium Drought in Australia[8].

Enabling Water Smart Communities (EWSC) is a UK based innovative project exploring the relationship between integrated water management, community engagement and practices and housing development to unlock new opportunities for cross-sector delivery and stewardship.

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[1] Black water defined as foul or sewage water

[2] Walle et al. 2023 Greywater reuse as a key enabler for improving urban wastewater management. Environmental Science and Ecotechnology. Vol 16.

[3] Waterwise 2020. Independent review of the costs and benefits of rainwater harvesting and grey water recycling options in the UK. WEStrategy002.

[4] Busgang et al. 2015 Epidemiological study for the assessment of health risks associated with greywater reuse for irrigation in arid regions. Science of the Total Environment. Volume 538.Pages 230-239

[5] Colorado State University Briefing note. Greywater Reuse: A New Strategy for Drought-Stressed Cities

[6] Los Angeles County Department of Public Health Guidelines for Alternate Water Sources: Indoor and Outdoor Non-Potable Uses

[7] Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse

Case Studies

Source: Sydneywater

1. Australia - Grey Water Reuse - Rouse Hill Water Resource Recovery Facility and Sunset Ridge Retirement Community

Most major Australian water recycling projects were implemented in response to The Millennium drought (2001-2009)[8], as well as due to restraints placed on discharge from wastewater treatment plants[9]. Australia's largest residential recycling scheme is the 32,000 home Rouse Hill development in northwest Sydney which supplies toilet flushing, clothes washing, garden watering and car washing, reducing potable water demand by 40%[10]. Use was approved on irrigating fruits and vegetables in 2012. The effluent undergoes tertiary treatment, supplying 200,000m^3 of recycled water a year, with excess quantities discharging to wetlands.

At Sunset Ridge Retirement Community, 25m^3 of greywater is treated a day, captured from showers, bathtubs, and hand basins and used for all toilet flushing and landscape irrigation[11].

Source: ecopeace middleeast

2. Jordan Valley Environmental Education Centre

At the Jordan Valley Environmental Education Centre, a greywater reuse system treats wastewater from sinks and showers to irrigate trees in the grounds[12]. With funding from the U.S. Agency for International Development (USAID), the system consists of a series of constructed wetlands which filter the water in 10 stages, with water then used to irrigate the Centre's landscaped grounds through a drip irrigation system. At full capacity the system can treat 30m^3 of water a day. Training courses and workshops are held at the Centre to ensure the project's learning is shared and utilised elsewhere.

Source: Envirotec managzine

3. London - Kensington 80 Holland Park

25 new homes were completed in West London in October 2020, equipped with a grey water recycling system. Planning and building control regulations had set a limit of 110 litres of mains water per person, per day, on the development[13]. Wastewater from baths and showers are collected in 27 outlets, routed to a holding tank, pumped through a pre-filter system, dosed with low levels of chlorine, before entering ultrafilters. This delivers 2.1m^3 greywater each day, sufficient to flush all 88 toilets on the development[14], and equating to 70% of peak demand.

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[8] Lindsay & Supski 2017 Changing household water consumption practices after drought in three Australian cities. Geoform Volume 84, pages 51-58.
[9] Water reuse and recycling in Australia — history, current situation and future perspectives - ScienceDirect
[10] Rouse Hill Water Resource Recovery Facility
[11] Australian Guidelines for Water Recycling
[12] Queensland Development Code | Business Queensland
[13] EPA 2012 Guidelines for Water Reuse
[14] EPA 2012 Guidelines for Water Reuse
[15] High-tech greywater reuse for exclusive residences | Envirotec
[16] SDS 80 Holland Park Case Study

2.5 Air Conditioning Condensate

What is it?

Air conditioning condensate is the water that forms when warm, humid air passes over the cold evaporator coils in heating, ventilation and air conditioning (HVAC) system. As the air cools, moisture condenses and collects, typically draining away through a condensate line. The byproduct is essentially distilled water.

Condensate is usually removed from the system through a condensate drain line and disposed of via wastewater drains. The extent of how much condensate can be harvested depends on the size of the HVAC equipment, incoming air humidity, and temperature.

Where and how is it used

Most modern buildings now incorporate mechanical air ventilation systems, which will produce predictable volumes of condensate. As the demand for air conditioning increases, so too will the volume of condensate. Water can be used locally with minimal storage needed onsite. Likely non-potable applications include toilet flushing, car washing, irrigation and cooling water[1].

Water Quality

Water quality of the condensate is similar to distilled water (low pH with little to no mineral content). Depending on the type of AC unit and conveyance pipe used, the condensate may contain heavy metals. It may be advisable to mix condensate with other water sources if being used for plant irrigation, to raise pH and or ensure mineral levels are appropriate.

Barriers and Solutions

Payback period – retrofitting reuse systems can be expensive and have long payback periods. Installing condensate reuse at the start of a project helps to reduce the unit price of water and ensures efficient collection and reuse systems.

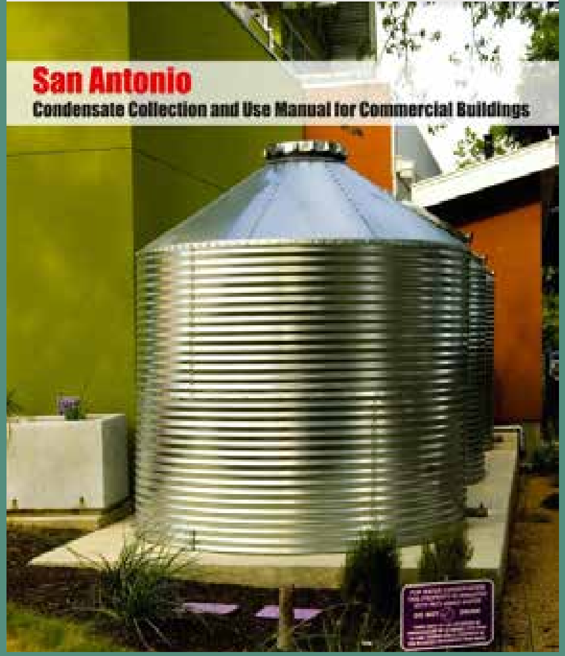
A lack of national legislation, standards or guidance in many countries has made adaptation challenging, however examples are slowly becoming more common, particularly in water stressed regions.

Case Studies

Source:Nick Merrick © Hedrich Blessing

1. Dubai Burj Khalifa

The tallest building in the world incorporates a condensate recovery system. 191m^3 of condensate from the tower's cooling system is recovered, providing an estimated 70,000m^3 of water a year for irrigating surrounding landscape and water features.



San Antonio
Condensate Collection and Use Manual for Commercial Buildings

Source: San Antonio Water System

2. USA San Antonio Condensate Collection Mandate and User Manual

San Antonio (USA) requires all new commercial buildings (with a cooling capacity of 35 kW or more) to incorporate condensate recovery and reuse[3]. A detailed city-wide guide has been produced to assist with the design, installation and management of commercial systems[4].

Source: Aquality Intelligent Water Management

3. London Bloomberg HQ

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[5].

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[1] Algarni, Saleel & Mujeebu 2018. Air-conditioning condensate recovery and applications—Current developments and challenges ahead. Sustainable Cities and Society. Volume 37.
[2] HVACR Nation – Cooling Dubai's Burj Khalifa
[3] Jurga et al. 2023. Condensate as a water source in terrestrial and extra-terrestrial conditions, Water Resource and Industry, 29.
[4] San Antonio Condensate Collection and Use Manual for Commercial Buildings - Source San Antonio Water System
[5] Aquality Bloombery Case Study

2.6 Seawater

What is it?

Seawater covers more than 70% of the earth's surface and is a complex mixture of 96.5-97.5% water and 2.5-3.5% salts (chloride, sodium, sulphate, magnesium, calcium, and potassium). Water containing a lower amount of salt is known as 'brackish' and is found in sea estuaries, inland water bodies and some groundwater aquifers.

Where and how is it used

Seawater is commonly used in water scarce countries and regions and is a provider of both mains potable and non-potable water through desalination.

According to the International Desalination Association (IDA) there are circa 22,000 desalination plants worldwide spread across approximately 177 countries. They generate an estimated 95 million m3 of fresh water/day. The Middle East and North Africa (MENA) region accounts for 70% of the world's desalination capacity, with the US accounting for a significant portion of the rest.

In addition to desalination, there are other novel applications for seawater including:

- Seawater farming using saline water to grow salt tolerant crops (halophytes), such as samphire, quinoa, cosmetic ingredients and bioenergy crops[1];
- Hydrogen production;
- Nuclear power station cooling;
- Passive cooling of greenhouses (typically in coastal locations) with freshwater as a by-product through evaporation; and
- Brackish aquifer water mixed and diluted with other sources of water to increase its usability.

Water Quality

Water sources have a salinity rating based on how much dissolved salt (sodium chloride) they contain. The greater the % of salt, the more energy is required to treat the water. Technologies are improving and include:

- Thermally driven technologies: The use of heat to evaporate water, which is then condensed back.
- Electrical Dialysis Reversal (EDR): A membrane process that uses an electric current to separate salt from water.
- Reverse osmosis (RO): The most common technique, which uses high pressure to filter water through membranes that trap salt.

Barriers and Solutions

- The impact of returning concentrated brine from desalination to the ocean has a major impact on the marine environment.
- Intensive use of energy and increased carbon footprint of the desalination process.
- Corrosion of equipment due to saltwater. This significantly reduces longevity of equipment, increases capital costs and reduced viability.
- Significant volumes of seawater and energy are needed for hydrogen production.
- Juvenile nature of seawater farming market and suppliers. In any new market, volatility can quickly disrupt suppliers reducing their ability to expand and become established.
- Lack of research and development into novel crop and cropping techniques using seawater to develop a suite of crops and techniques that have sufficient market viability.
- More research and development required as well as capital support, and diversification options for farmers to allow for growth of new farming industry[2].

Case Studies


Source: Sundrop Farms

1. Australia - Sundrop Farm Port Augusta

Sundrop Farm is one of Australia's leading tomato growers, producing 17,000 tonnes of tomatoes annually (15% of Australia's total crop). The Sundrop greenhouse system uses sunlight and seawater to support the growth of crops[3]. A concentrated solar thermal power plant uses mirrors to heat a central tank to nearly 1,000 degrees. Electricity is produced from the steam, along with desalinated water as a byproduct. The desalinated water is used for irrigation, with tomato plants grown hydroponically, removing the need for soils.


Source: AThe Smart Citizen

2. Qatar - Sahara Forests Project

The Sahara Forests Project is a re-vegetation project which seeks to create green jobs through food, freshwater, biofuel and electricity production. A concentrated solar power plant is sued to produce distilled water, with waste heat used to heat the greenhouse in winter and to recharge desiccant which is utilised to dehumidify the greenhouse. Cool, 'wet' saltwater infused air is passed though the greenhouse to reduce overall irrigation requirements,. A research bay has also been created to investigate halophyte crops (salt loving) that may use saltwater as a water source[4].

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[1] Sea Water Solutions – Seawater farming

[2] Lu et al. 2024. The development of seawater agriculture: Policy options for a changing climate. Environmental Development. Volume 49.

[3] The Index project – Sundrop Farms

[4] Sahara Forest Project

2.7 Internal Drainage Boards

Credit: Tom Young

What is it?

Internal Drainage Boards (IDB) are local public bodies that manage water levels within a specific area. They are an integral part of managing land drainage and flood risk within areas of special drainage need in England and Wales (usually low-lying agricultural land). There are 121 IDBs in existence across England managing over 22,000km of watercourses and over 50% of Grade 1 agricultural land. IDBs are also defined as Risk Management Authorities within the Flood & Water Management Act 2010 alongside the Environment Agency, local authorities and water companies.

The expenses of an IDB are predominantly funded by the local beneficiaries of the water management work they provide. Each IDB sets a budget for its planned work in the forthcoming year, with large capital works often requiring additional government or lottery grant funding.

Where and how is it used

Water from IDB's has historically been viewed as 'problem' drainage water during high winter flows, discharged to main watercourses or marine environments through networks of drainage ditches, sluice gates and high-capacity pumps. However, it is now recognised that the vast volumes of water which leave IDBs each year could be utilised for non-potable uses such as agricultural irrigation, aquifer recharge and sports/leisure irrigation. Water managed by the IDBs is particularly valuable due to its relatively clean nature, presence in a water transport network and management by recognised, experienced and established organisations. However, due to the seasonal nature of IDB drainage water, less water is available for reuse during high demand summer months, thus requiring the storage of winter drainage water.

Water Quality

Most water in IDB networks is from agricultural runoff, with contributions also from urban drainage. Therefore, the main issue with water in these systems is;

- Elevated nutrients (nitrates and phosphates);
- Pesticide and herbicide runoff;
- Suspended solids from soil erosion; and
- Salt, hydrocarbons and heavy metal content from urban areas and roads.

Barriers and Solutions

Managing Conflicts of Interest: There are potential conflicts of interest within districts between various stakeholders, particularly regarding environmental protection measures and downstream water quality. For example, a habitat creation project or a water abstraction scheme may alter downstream flow characteristics.

Scalability and Funding: Infrastructure associated with IDBs is typically large in scale. Installing or modifying infrastructure is often costly and requires input from specialist design teams.

Politics of Organisations: Decisions and management may involve multiple organisations, including statutory, private, and public entities. This can slow down decision-making. However, IDBs provide a stable platform for coordinating multiple stakeholders, making them effective vehicles for implementing integrated water management schemes. By empowering organisations, offering specialist technical support, and providing financial backing, projects can be passed on to bodies with proven management systems already in place.

Case Study

1. California - Department of Water Resources - Flood Managed Aquifer Recharge

Flood-MAR (Flood-Managed Aquifer Recharge) is a management strategy that uses high flood flows from watercourses to spread water onto agricultural land, working landscapes, and managed natural areas to recharge aquifers, sustain riverine and groundwater-dependent ecosystems[1].

In 2018, in response to the Sustainable Groundwater Management Act (2014)[2], which gave local authorities the remit to stabilise groundwater aquifers, the California Department of Water Resources (DWR) formed the Flood-MAR Research Advisory Committee. This contributed to a Development Plan which outlined a wide range of recommendations in thirteen key categories considered essential for Californian Flood-MAR implementation. These recommendations included changes in water governance, water management, groundwater data and analysis, water infrastructure, water rights, water use practices and increased use of interdisciplinary coordination and partnership.

Flood-MAR requires the voluntary participation of landowners, who are compensated for the use of their land. Generally, fallow fields, orchards, recharge basins and flood plains are intentionally flooded during periods of high flow to allow water

Continued opposite ►

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[1] California Flood-MAR Hub – Flood Managed Aquifer Recharge

[2] Sustainable Groundwater Management Act

Case Studies

Source: Paolo-Vescia-scaled

to infiltrate into the ground, and reduce downstream flood risk[3]. This can help landowners to diversify crop and land management techniques and provide alternative markets for water management. Most Flood-MAR projects are funded by local entities with some limited support from the State through grant and loan programs.

Successful large-scale implementation of Flood-MAR strategies will require new governance structures, decision-making processes, and operations agreements to support cooperation. No one-size-fits-all strategy will exist for each site, which requires dynamic working and close cooperation between all stakeholders.

A Climate Vulnerability Study of the Merced Watershed by DWR highlighted that there is likely to be a 7% increase in agricultural water demand, a 20% increase in groundwater abstraction and 600% increase in peak flows in the Merced River. The study highlighted that a watershed wide Flood-MAR could potentially increase groundwater recharge by 75-150 million m^3 a year, and reduce flood peaks by up to 80%.

Credit: Tom Young

2. UK - Felixstowe Hydrocycle Water Reuse

This innovative collaboration[4] between local authorities and farmers was in development for over 10 years and was driven by a supportive local authority (Suffolk County Council). It required significant engagement with multiple stakeholders to, a) define the local issue (water security for farmers and untapped resources), b) decide on a strategy to deal with the problem, c) identify funding mechanisms, and d) implement a solution. The solution is technically simple, with current land drainage water intercepted and pumped to a series of farm reservoirs before it enters the sea. In addition, excess water is pumped to a demonstration Managed Aquifer Recharge (MAR) site. This initiative provides farmers with a year-round water source to fill reservoirs, recharges groundwater, whilst also helping to prevent saltmarsh degradation at the drainage outlet[5].

A large amount of water quality monitoring was needed to ensure that water actively pumped into the aquifer would not result in a reduction in quality. This required close liaison with the Environment Agency, with results showing water entering the aquifer was of a better quality than the aquifer itself.

The funding and governance of the scheme is particularly innovative, with a new company formed by

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[3] A Functional Flows approach to implementing Flood-MAR | California WaterBlog
[4] Felixstowe Hydrocycle
[5] Felixstowe Hydrocycle EA Blog

2.8 Treated Sewage Effluent (TSE)

Credit: Tom Young

What is it?

Wastewater from homes, industries, and businesses is routinely channelled through collection pipes to centralised sewage treatment plants. Here, wastewater undergoes a series of treatments so that it can be released into watercourses (known as Treated Sewage Effluent - TSE). The quality of this water is generally regulated so that minimum standards are set before it can be discharged. The standards vary depending on location and discharge destination.

Where and how is it used

TSE reuse has been used for millennia, with ancient civilizations using it for agricultural irrigation (Romans, Chinese, Greeks and Persians), and has become more prevalent in modern times due to growing water scarcity concerns. Modern sewage treatment systems collect and treat large volumes of water, providing a constant source of treated water ready for reuse[1].

Technological advances and water scarcity issues in arid regions in the 1980's-1990's, particularly in places like the Middle East and southwestern United States, led to increased interest in treated sewage effluent reuse. Countries like Israel and the UAE began implementing large-scale systems for wastewater treatment and reuse, often using treated effluent for agricultural irrigation, with water pumped directly from treatment plants through dedicated supply lines to the point of use.

TSE sewage effluent is commonly used in agriculture, industry, landscaping and amenity, groundwater recharge and sometimes for non-potable uses within residential developments. In some countries such as Israel, TSE is now the only viable (cost and availability) source of water for agriculture, irrigating over 90% of all crops[2].

Water Quality

TSE quality varies widely depending on the treatment process used. Basic primary and secondary treatments remove some contaminants, but water is still unsuitable for non-potable use. Tertiary treatment significantly improves water quality, making it suitable for non-potable applications. However, some contaminants remain which need to be managed as part of its use[3]:

- Elevated nutrients (nitrates, potassium and phosphates). This can reduce fertiliser requirements, but can cause algae and biofilm issues within distribution networks;
- High salinity and sodium concentration;
- Heavy metals, pharmaceutical products and long-lasting chemicals such as PFAS; and
- Disease-causing pathogens such as E-Coli or Salmonella.

Barriers and Solutions

Despite being the most widespread and historic form of wastewater reuse, TSE still suffers from many barriers for widespread implementation in many countries.

- Designated waste stream in UK -therefore costs associated with obtaining EA permitting for reuse;
- No structure in place to offer long term predictable Service Level Agreement for users;
- Outflows often required to meet EA in waterbody environmental baseline flows;
- Public Perception: Public acceptance of treated wastewater for non-potable reuse has become more common, although public concerns about safety, and the 'yuck' factor remain;
- Long term soil health: Application of TSE can affect long term soil health. Monitoring and research are still needed to understand this and provide mitigating options;
- Lack of relevant regulation and water quality guidelines for crop safety and exportability;
- Lack of regulation and guidance for ownership and maintenance of distribution pipelines;

Several common solutions to overcome barriers have been developed by countries which heavily utilise TSE. For example;

- Dedicated legislation and guidelines: The California Water Recycling Initiative was launched in the U.S in the 1980's to promote the reuse of treated sewage for non-potable uses, such as irrigation and industrial applications. Similar innovative and government projects also emerged in Australia, Jordon, Israel and Singapore. In Jordon, wastewater treatment plants are planned in conjunction with opportunities for water reuse[4].
- Long term strategic planning: TSE is viewed as part of an integrated water management strategy for a country which includes other water resources.
- Attractive pricing structures: TSE is offered at a much lower cost compared to other water sources with assistance of supply network to sites.
- Long term research and development: Solutions to utilise TSE and mange issues are conducted as part of a national strategy. For example, Israel is now a world leader for sub surface irrigation systems using TSE.
- Detailed and long-term engagement with farmers: to understand and alleviate concerns, help co-develop solutions and offer long term support.

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[1] Angelakis et al. 2018 Water Reuse: From Ancient to Modern Times and the Future. front. Environ. Sci.,. Volume 6.

[2] Mishra et al. 2023. Use of treated sewage or wastewater as an irrigation water for agricultural purposes- Environmental, health, and economic impacts. Total Environment Research Themes. Vol 6

[3] Naidoo & Olaniran 2013 Treated Wastewater Effluent as a Source of Microbial Pollution of Surface Water Resources. Int. J. Environ. Res. Public Health 2014, 11(1), 249-270;4

[4] Appendix EPA E 2012 Guidelines for Water Reuse

Case Studies

Credit: Tom Young.

1. Spain - Camiral Golf Course, Barcelona

Camiral Golf Course (and many others in the Mediterranean and USA) using 100% recycled wastewater from the local sewage treatment plant. The golf course paid for a new pipe connection to the plant, which delivers treated wastewater to a 100,000m^3 reservoir onsite. Turf management practices have altered to accommodate water quality parameters, such as regularly flushing of rootzone to prevent salt build up, and thoroughly cleaning of irrigation equipment with acid solution to prevent biofilms.

Credit: Tom Young.

2. Western Wastewater Treatment Plant - Melbourne

The Western Wastewater Treatment Plant in Melbourne has a farm and wetland habitats onsite since its creation in the early 20th Century. The farm is entirely irrigated by treated wastewater from the plant, supporting pasture and livestock fodder[5]. Water is treated with a series of settling lagoons, treatment areas and sterilisation UV prior to water being discharged to the onsite farm. Biogas is collected as part of this process to produce onsite electricity. Surplus water is then provided to the local horticultural industry to supplement groundwater supplies.

Credit: Tom Young.

3. Israel – Use of TSE Across Whole Water Industry

Israel was the first country to fully embrace treated wastewater. This was partly out of necessity in the 1980s, with lakes and aquifers becoming brackish due to over abstraction and sewage discharge. In addition, water resources have historically been viewed as a national security issue, with high priority placed on a long term integrated national water strategy by successive governments. Competitive pricing, volume caps on potable water for non-potable users, and clearly defined water standards for different types of crop were used to quickly move agriculture onto this new supply, with around 80-90% of crops now irrigated with wastewater. A centralised water distribution network allows wastewater to be transported efficiently from source to areas of high demand, and at competitive cost. TSE water is also used in many public parks for irrigation and water features. These features are still accessible to the public but have appropriate warning signs in place to not drink from or enter the features.

An extensive research programme was set up at the same time in Israel's agricultural research centres. These conducted an integrated national research programme to develop new treatment methods, long term soil health studies, breeding programmes for salt resistant crops, novel irrigation techniques and land management techniques. This now means that Israel is one of the leading countries in terms of irrigation technology and use of treated sewage water, with technology and knowledge regularly exported.

This national led approach requires a co-ordinated, long-term strategy to the use of TSE water, with high levels of collaboration between the national water company, utility companies, regulators, local municipalities, developers, private technology providers, and end users. This was summarised in the 2012 National Long-term Master Plan for the Water Sector through 2050, which provided a medium to long term road map defining Israel's vision and goals for a resilient national water supply[6].

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[5] Melbourne Water Western Treatment Plant

[6] Israel Long-Term Masterplan for the National Water Sector – 2012 Version 3.

Case Studies

Source: Unsplash

4. USA – National; Water Reuse Action Plan (WRAP)

The United States' Environmental Protection Agency recently created a Water Reuse Interagency Working Group[7] which is leading the creation and implementation of a National Water Reuse Action Plan[8]. The plan aims to prevent water reuse being viewed as a solution in isolation, but as part of a national strategy on water management at catchment scale. The working group helps to co-ordinate national and state policy, highlight available funding streams for users, as well as driving required research and educational programmes. This includes improving relationships and cross-country learning partnerships through its 2022 research study trip to Israel[9].

Source: Tampa Electric.

5. USA - Tampa Electric Power Plant Cooling

Since 2015, Tampa Electric has utilised recycled wastewater from local treatment plants to cool the Polk Power Station[10]. Supply agreements were created that allowed local municipalities to supply treated wastewater free of charge to the power plant for 30 years. Tampa Electric constructed a 145-mile pipeline and additional treatment plant to clean the water before using it for cooling. The plant is supplied with over 6000m^3 wastewater each day. The process reduces nutrient rich outflows from the treatment plants into Tampa Bay, significantly reducing the environmental impact.

Source: Google.

6. USA – Cooling Water for Data Centres

Data centres in the US are increasingly using TSE water for cooling purposes. Google's data centre in Douglas County, Georgia, now uses up to 30% of TSE from a local treatment plant for 100% of its cooling needs, with additional treatment required onsite before use[11]. Microsoft's Azure Centre in San Antonio uses 100% recycled water, which reduces potable water demand by 220,000m^3 a year, saving over 100,000 a year[12]. Many data companies are now also pledging to produce more water than they use by 2030[13].

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[7] US EPA Water Reuse Interagency Working Group

[8] US EPA Water Reuse Action Plan

[9] EPA Summary of Israel Knowledge Transfer Trip 2022

[10] Tampa Electric Wastewater Reuse Power Mag Article

[11] Google Douglas County Data Centre

[12] Meese et al. Opportunities and Challenges for Industrial Water Treatment and Reuse. ACS ES&T Engineering 2022 2 (3), 465-488

[13] DataCenterDynamics.com – use of reclaimed wastewater for data center cooling

2.9 Industrial Effluent

Source: Basin Business Journal

What is it?

Industrial effluent refers to wastewater generated during industrial processes, typically with a lower quality than the water initially used. Such industrial processes include, machine cooling, food and drink production, chemical manufacturing, heavy industry, swimming pools and leisure centres, vehicle washing, hospitals, laundries and chemical manufacturing.

Where and how is it used

Typically, industrial effluent is treated to a certain level and then discharged back into the environment or to the sewer for further treatment in accordance with the limits set through Trade Effluent Consents, monitored by a water company's Trade Effluent team. An industry will generally use a new source of water as it repeats this process. However, it is becoming increasingly common for wastewater to be treated to a standard sufficient to be reused on-site for the same process, effectively creating a closed-loop system.

Compounds within industrial effluent can be recovered and a proportion of the costs recuperated. This can include soil from beet washings, pectin antioxidants from olive mill wastewater, heavy metals, and liquid slag from steel manufacturing[1]. Potential recovery rates of the compounds determine the financial viability of any such scheme.

Water Quality

The quality of the effluent will depend on the industry and the application of the water:

- Cooling water from data centres or industry – minerals, metal salts, metals and microbial growth in the water can become concentrated over time;
- Crop washing – pesticide, suspended solids, colour and odour;
- Metal production – oils, grease, high acidity, salts and heavy metals;
- Machinery and surface washdown – high levels of organic matter, nutrients (nitrates and phosphates), suspended solids, long-chain fatty acids Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD);
- Paper manufacture – high BOD, suspended solids, organic halides (bleach), nitrates and lignin derivatives; and
- Petroleum refining – high BOD, COD, dissolved solids, heavy metals, alkylate, and hydrocarbons.

Barriers and Solutions

- Historically, access to relatively cheap water, versus the high cost of water treatment, has been a major barrier for many industries that operate with narrow margins (e.g. food and drink). However, access to cheap potable water for industrial users is likely to be more limited in the future.
- Many industries rely on legacy equipment that could be difficult to modify, and space may also be limited in some facilities.
- New treatments that recover useful materials from wastewater, require high investment in capital and operating costs.
- Lack of minimum water quality standards for cooling systems, which discourage users from considering alternative water sources.
- Absence of regulatory incentives for industries to reuse more water.

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[1] Meese et al. 2021 Opportunities and Challenges for Industrial Water Treatment and Reuse. ACS ES&T Engineering 2022 2 (3), 465-488

Case Studies

Source: Avery Brewing Co.

1. USA – Avery Brewing, Boulder, Colorado

The brewing process produces a sugar rich water byproduct called 'wort'. Avery Brewing sends this solution to the City of Boulder Water Company treatment plant in return for a reduced wastewater discharge fee. The addition of a sugar rich product encourages the reduction of nitrogen in wastewater, reducing its impact on the environment[2].

Source: CDM Smith.

2. USA - Frito-Lay Snack Food Plant, Arizona

In 2010, Frito-Lay started to operate the first U.S. based food processing plant to produce recycled wastewater at drinking water standards, for reuse in food production. The facility uses a 2,500m3 a day water treatment and recovery system to recycle up to 75 percent of the facility's process water, reducing the plants annual water use by 380,000m^3. The innovative advanced treatment system treats water to drinking water standards and mixes it with standard mains water to ensure it can be safely used to wash and move raw vegetables around the factory[3].

Source: Basin Business Journal.

3. USA – Microsoft Quincy Water Reuse Utility

The City of Quincy hosts many data centres due to the areas' affordable land, cool ambient temperatures, and the availability of renewable electricity from hydropower. Traditionally, groundwater was used to supply data centres, but the mineral rich water generally caused issues with pipe fouling and was unsuitable for cooling purposes. This produced highly concentrated wastewater which was sent to standard treatment plants. Data Centres were charged extra fees to account for the high levels of total dissolved solids and salts due to the difficulties in treating it. As a result, the Quincy Water Reuse Utility (QWRU) was created in 2021 to treat discharge cooling water and recirculate it back to data centres for cooling. The facility saves up to 500,000m^3 potable water a year, and requires significantly reduced volumes of groundwater and irrigation canal water to periodically top up the system[4].

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[2] Meese et al. Opportunities and Challenges for Industrial Water Treatment and Reuse. ACS ES&T Engineering 2022 2 (3), 465-488

[3] WaterTechOnline – Frito-Lay's Casa Grande Water Reuse Facility

[4] Microsoft Quincy Water Reuse Utility

2.10 Mine Water

Source: UK Government.

What is it?

Water is actively pumped from operational mines to prevent flooding and enable continued extraction, even when operations are below the water table. Once mines are closed, pumping ceases, and water levels within the mine recover, effectively flooding the mine. This creates an accessible water resource through the existing mine infrastructure. Due to the size and depth of these mines, the resulting water source can be significant and stable, with additional potential benefits, such as geothermal heat extraction.

Where and how is it used

Currently, due to water quality concerns, most mine water extracted is treated to prevent environmental damage before being discharged. Due to these water quality issues, there has been limited global interest in using mine water for non-potable purposes. However, in some countries, such as the USA, it is becoming more common for active mine sites to reuse water for cooling and cleaning during processing. South Africa is currently assessing the suitability of treated or partially treated mine wastewater for agricultural irrigation.

There is growing interest in extracting geothermal heat from the water, especially from depths greater than 500 meters. In the UK, geothermal potential increases by approximately 27°C per km.

Water Quality

Water quality from mines is often compromised, with a range of pollutants present:

- High levels of suspended solids;
- Heavy metals;
- Acidity;
- Ammonia and nitrates;
- Sulphates, silica and cyanide; and
- Radioactive compounds, in some cases.

As a result, significant treatment is often necessary to make this water suitable for reuse, either on-site for mining operations or for other non-potable uses. Depending on the level of contamination, treatment methods may range from Vertical Flow Ponds, settlement ponds, and constructed reed beds to more advanced methods such as activated carbon adsorption, membrane bioreactors, and lime precipitation.

Barriers and Solutions

The variability in contamination levels and the corresponding treatment requirements (and associated costs) present a significant barrier to the reuse of mine water. For example, a lime dosing and sludge disposal system at the Wheal Jane tin mine in Cornwall, which treats approximately 5.6 million cubic meters of water annually, cost £3.5 million to build and £1 million per year to maintain[1]. Additionally, the remote location of many mines can pose challenges for accessing nearby users who consistently need large volumes of non-potable water, reducing the viability of such schemes.

Many mining sites have also experienced soil contamination, leading to the development of rare and protected plant communities. These are often designated as conservation areas, and care needs to be taken to ensure that any cleanup operations or water extraction do not negatively impact these sensitive environments.

Efforts have been made in South Africa to introduce guidelines for mine owners to investigate and apply for the correct permit to reuse wastewater from mines. The guidance has been put together by the South African Water Research Commission (WRC) and it focuses on gaining the correct regulatory approvals in the current application system[2], and technical guidelines for using this water irrigation[3]. The documents help to highlight current gaps and contradictions in current South African water use regulations, and how best to navigate these. It gives a series of decision trees and priorities when assessing the viability of using mine wastewater for irrigation.

It is likely that the more viable use of mine water will be for geothermal heat extraction in closed-loop systems. This approach requires less treatment, can be more financially favourable, and is more suited to the demand for heating energy, which is often located closer to UK mines.

Case Study

South Africa – Potable and Non Potable Uses

South Africa is a leading authority on the reuse of mine water, with significant efforts made to provide industry guidance and strategy[2,3]. Numerous trials have been conducted with mine water in agriculture, including the successful use of lime treated gypsiferous water (containing high levels of calcium sulphate), successfully used on various field screening trials of over 20 crops at Witbank, Mpumalanga, with no negative impacts on crop yield or leaf burn[4]. Additional trials showed that potassium uptake could be reduced by gypsiferous water, but this can be offset by careful fertiliser planning[4].

A reclamation project in eMalahleni has treated mine water to potable standards which is sold back to the local municipality. The process requires significant treatment of neutralisation, clarification, ultra-filtration and evaporation to produce 20,000m^3 a day[5]. If the quality requirements of the end use were less, the intensity of the treatment process could be reduced and significant quantities of non-potable water produced.

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[1] Wheal Jane mine water treatment scheme - Case study - GOV.UK

[2] WRC 2021 -Guidance for attaining regulatory approval of irrigation as a large-scale, sustainable use of mine-water TT 837/20

[3] WRC 2021 – Technical Guidelines for Irrigation with Mine-Affected Waters TT855/2/21

[4] Grewar 2019 South Africa's options for mine-impacted water re-use: A review. J. S. Afr. Inst. Min. Metall. Vol.119 No.3

[5] Emlahleni (Witbank) Water Reclamation Project

2.11 Polluted Groundwater

Source:World Atlas.

What is it?

Groundwater is a vital source of water for potable and non-potable uses. It can become polluted by a range of contaminants from a point source or across wider catchments. Once a groundwater aquifer is polluted, it is very expensive and time consuming to reduce or remove the contamination. Therefore, a priority for groundwater is to avoid it initially becoming polluted.

Where and how is it used

Depending on the level of contamination, polluted groundwater can be used directly for non-potable uses. This often occurs when no other viable water sources exist. Treatment can occur prior to use but may not be viable depending on the level of contamination. In extreme cases, aquifers have been abandoned where contamination is considered to be too great.

Water Quality

Common pollutants in ground water include:

- Nitrogen, phosphorus and pesticides from agricultural runoff;
- Solvents, petroleum products, volatile organic compounds and heavy metals for industrial activities and landfill leachate;
- Salinity from over abstraction or costal saline intrusion;
- Pathogens from untreated human wastewater;
- Organohalides, hormones and hydrocarbons from pharmaceutical and cosmetic products;
- Emerging pollutants such as PFAS which are not currently regulated; and
- Arsenic and fluoride from natural sources or mine discharge.

Barriers and Solutions

Contaminated groundwater can be partially treated onsite or diluted with cleaner sources of water. Viability for reuse depends on the intended use as well as the type and extent of contamination.

Aquifers can be artificially recharged through intentionally adding water. This is often achieved by using wastewater from other sources (such as treated sewage effluent, flood water, Internal Drainage Boards, urban runoff) and adding into the aquifer through either large infiltration ponds or injecting it into deep wells. This approach can help to dilute or prevent contamination, making water available for reuse. This process is particularly useful in areas where groundwater is experiencing saline intrusion or increased concentration of contaminants from over abstraction[1]. For example, around 25% of the Treated Sewage Effluent produced by the state of Qatar is injected into wells to maintain groundwater levels. The water is then abstracted for agricultural irrigation[2].

The infiltration process can be used to further clean water in some locations (Israel), although there are strict rules in other locations (California, Arizona) to ensure that ground aquifers are not polluted by source water and require high levels of treatment depending on the source of water (tertiary through to reverse osmosis) prior to infiltration.

Case Study

Credit: Tom Young

Orange County Ground Water Replenishment System (GWRS), California

Due to an over abstracted ground aquifer which was becoming increasingly saline, a GWRS was set up in Orange County, California in 2008[3]. The facility takes treated sewage water and passes it through a series of osmotic membranes to produce ultra-pure water. The water is then pumped into the ground aquifer for later abstraction. Excess storm water from the rivers within the catchment is also stored in additional conventional infiltration ponds to supplement ground recharge.

This helps to reduce reliance on costly imported water from outside the catchment, reduce treated sewage discharge to sea and prevent saltwater intrusion of the aquifer. The facility can produce up to 492,000m^3 a day, and is still being expanded. The system allows Orange County water users to abstract a set volume of water each year, providing each customer uses their allocation sustainably.

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[1] Dillion et al. 2019. Sixty years of global progress in managed aquifer recharge. Hydrogeology Journal. Volume 27, pages 1-30

[2] Darwish et al 2015, Reclaimed wastewater for agricultural irrigation in Qatar. Global journal of agricultural research and Reviews. Vol 3. Pages 106-120

[3] Orange County Water District - GWRS

3.0 Overcoming Universal Barriers

Many common barriers and potential solutions exist for wastewater sources. It is vital that water reuse is viewed within the wider framework of water security and demand. Water reuse is part of the solution but cannot solve the whole problem. An integrated, long term water management strategy is needed with appropriate water sources identified for the various end uses.

The information listed below is a selection of the most common issues and solutions. It is not an exhaustive list.

Risk of New Innovation and Technology

Innovation requires new technology and methods to be implemented. These can be seen as a risk until proven by early adopters. Similarly altering established systems often has unintended consequences for the user, potentially giving new ideas bad reputations, increasing government restrictions, and reducing future uptake. For example, uncertainly on the water quality of wastewater prior to treatment acts a big barrier for reuse. Most users are not prepared to accept a large variability in quality.

Those countries which have embraced water reuse have seen the challenges as opportunities. In Israel and Singapore, research and development programmes have been developed to support a thriving business sector. Issues have been solved, and the knowledge, technology and skills have been exported as a national commodity.

Demonstration and pilot studies are required at an early stage of a new water source. However, clear roadmaps are needed to ensure that learnings from these can be quickly used to drive mass uptake. The Felixstowe Hydrocycle was an extremely successful project but took over 10 years to come to fruition. At least two other similar schemes are now being worked up based on project principles learnt, which should allow quicker project implementation.

Comparison with Existing Sources of Water

The current straightforward access to high quality and 'cheap' water often results in water reuse projects having a poor financial payback period and perceived extra work. Water reuse needs scalability, technology development and a streamlined approval process to allow mass adoption.

Necessity will force current mindset to be altered i.e. increased price point for non-household users, or access to these current sources of water (currently starting to occur in UK). Planning an integrated strategy is needed in advance of this necessity to ensure smooth transition.

Financial Costs

Upfront financial cost of installing new technology, and the short/long-term financial pressure incurred by businesses. This risk can be mitigated by government grants or schemes. However, stipulations and restrictions often accompany these, making them less attractive.

The correct balance of government support is needed for long term stewardship of water reuse schemes. Government financial support is often only for a limited period to install or research new technologies. It is critical that a regulatory regime and framework are put in place to support implemented schemes including the long-term stewardship of assets. For example, rapid and mass agricultural adoption of TSE in Israel was achieved through the construction of a centralised delivery system and price reduction for users.

Guidance and Regulations

Lack of government guidance and minimum standards for adoption. Industry prefers to work with known standards which then allow long term infrastructure decisions to be made. Without these, industries find it a challenge to know what to implement and who to liaise with. In addition, blanket environmental legislation can be a significant barrier for new sources of water which may not be explicitly considered in existing guidelines. Uncertainty also exists for subsequent disposal of the portion of wastewater that isn't reused and the waste from the reuse process.

New national water reuse standards, and an approved system for adoption for a wide range of water sources will allow clarity on what is needed and where. France's new 2023 water plan defines conditions of water reuse, details long term support for projects, simplifies applications and monitoring procedures, and relaxes geographical constraints of water reuse. Australia's mandate for rainwater harvesting for new buildings, and US cities requirement for greywater harvesting have also significantly improved uptake by removing choice for developers.

There is also evidence that existing legislation does not always have to be changed to allow uptake. In South Africa, guidance on how to navigate existing legislation to reuse mine water for agricultural irrigation has been released. This includes technical standards, as well as a decision process to assess viability of a project, and the correct application process within the confines of the existing legislative system.

Long Term and Integrated Nature of Water Planning

Developing long term integrated national water management and sourcing plans is difficult due to large number of stakeholders, political variability and natural human reluctance to plan in 30 to 50-year windows. By its very nature water use and sourcing is a multi-disciplinary endeavour which requires understanding of other disciplines, and the will and ability to develop flexible solutions.

Real concern about national security is the one main driver which empowers true long-term thinking. This has been shown in Singapore and Israel's long term and proactive approach to water sourcing, leading to both countries being world leaders, and major exporters of water knowledge with the USA's EPA regularly visiting both countries for knowledge exchange programmes.

Local ownership of problem. Although a national issue, impacts of water scarcity are experienced at a local level. This is also the level at which solutions make a real impact. Therefore, it makes sense to allow local water groups to take ownership and find solutions that work for them, increasing the chance of successful independent long-term solutions.

Interdisciplinary working. Water resource management requires input from multiple sectors, however, the water sector is still very siloed. Training across all career stages is needed to educate practitioners on the benefits and requirement of adopting an interdisciplinary approach.

4.0 End User Summary Table

Users	How Industry Uses Water	Requirements	Risks from Wastewater Reuse
Agriculture	Irrigation of crops. Application of fertilisers and pesticides. Crop cooling and frost control.	Greatest demand during long dry spells, and at specific periods of crop development stage. Low levels of heavy metals, salt and human pathogens. Water quality required is dependent on crop type. Presence of nutrients in water can be beneficial.	Concerns of water reuse and the associated chemical and human health risk from substances in the water entering the food chain – improved knowledge and regulation required.
Food processing	Water is used for cleaning, to facilitate product movement, sanitation, factory heating and refrigeration.	High quality water required with potable standards often needed to ensure food is not contaminated.	Maintaining food safety whilst utilising reused water. Understanding risk so water is not necessarily treated to extremely high standard when not needed.
Recreation	Irrigation of turf and landscape features including parks, golf courses, sports pitches and domestic gardens Swimming pools, snow/ice creation for indoor slopes/ice rinks, and artificial lakes.	High end sports surfaces require water free from high levels of nutrients and salt. Extremely clean water for internal human recreational uses.	Requirement to store water for irrigation use can be expensive. Human health risk from ingestion.
Brewing	Large volumes used in production as well as washing and cleaning equipment.	Extremely clean water for any products destined for human consumption.	Human health risk from products and equipment cleaning.
Domestic	Greywater used to flush toilets and for laundry	Separate inflow system to domestic uses to differentiate it from potable water supply. Lower requirements on quality, but clear labelling required. Storage required onsite or dedicated inflow pipe.	Human health risk from presence in domestic setting.
Data centres	Large storage facilities require significant volumes of water to cool air and transport excess heat away.	Constant demand due to continual power demand. Increase in computing demand will likely see these requirements increase in the future. Free from mineral content. Cooling process causes minerals to concentrate and degrade pipework.	Presence of undesired contaminants in water affecting cooling systems. Increased treatment requirements of water pre-use
Power Generation and Industry	Coolant in power plants and industry. Purging, cleaning and material movement in industry. Pumped into oil and gas wells to retain pressure and hydrofracking injection.	Free from mineral content. Cooling process causing minerals to concentrate and degrade pipework. Water is frequently purged from system to prevent build up and lower levels of minerals mean this process occurs less frequently.	Presence of undesired contaminants in water affecting cooling system. Increased treatment requirements of water pre-release of water following industry use.
Hydrogen production	Hydrogen fuel is produced from the electrolysis of water using large amounts of energy.	Devices used for electrolysis only work with freshwater, typically they fail using wastewater because of substances found within it. Water must therefore be free from salts and other minerals.	Water must be extremely clean. Discharge of concentrated waste i.e. brine. High energy requirement to clean water before energy intensive electrolysis.
Carbon capture	Carbon dioxide can be absorbed into liquids or made into other beneficial carbon compounds through electrochemical or biochemical reactions.	Electrochemical reaction requires saline wastewater to facilitate the reaction	Uncertainty in market and leading method to use for carbon capture.

5.0 Key References

Water Reuse Organisations

Green Roads for Water

Enabling Water Smart Communities (EWSC)

International Water Association – Water Reuse Specialist Group

Water Reuse Europe Association

Water Reuse Association

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Australian Guidelines for Water Recycling

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