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Water Reuse in the Context of the Circular Economy

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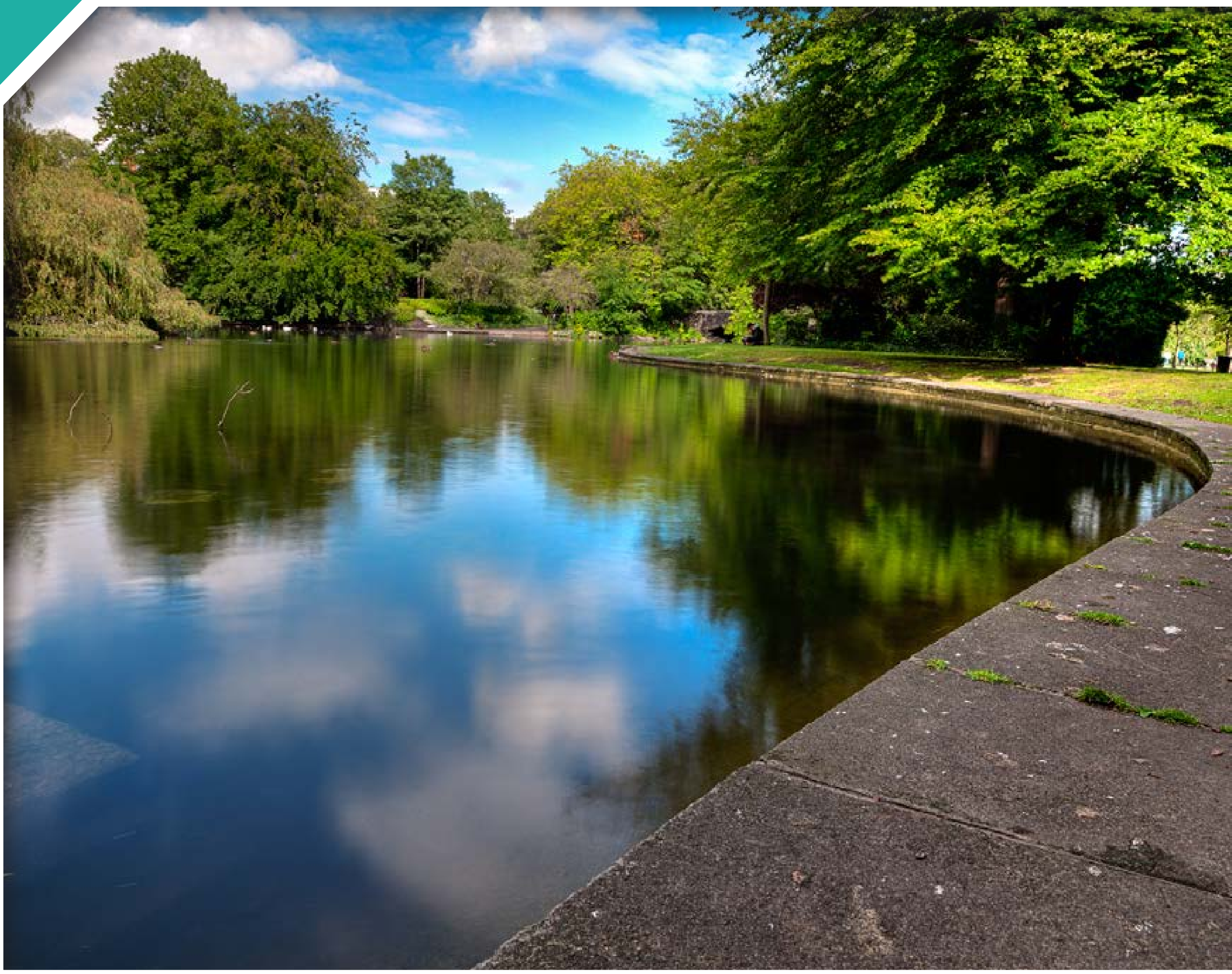

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EPA RESEARCH PROGRAMME 2014–2020

Water Reuse in the Context of the Circular Economy

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EPA Research Report

Prepared for the Environmental Protection Agency

by

Cork Institute of Technology

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

The circular economy approach seeks to recover and reuse as much as possible of the resources used in the economy to reduce pressure on finite resources, protect the environment and improve long-term sustainability. It is being pursued with greater policy focus, in Europe and elsewhere, including for water. “Water reuse” is taken to mean “water which is generated from wastewater or any other marginal water and treated to a standard that is appropriate for its intended use”. The main potential sources for recovery of “wastewater”, based on the volumes involved, are industries using large volumes of water, for reuse on-site, and municipal wastewater treatment plants (WWTPs), the water from which can be reused in the broader economy. Internationally, many countries and regions recover and reuse water in these ways, for a wide variety of purposes. Typically, recovered wastewater must be treated to a standard that is suitable for its intended purpose and the standards are different depending on the type of reuse that is proposed.

This project addresses water reuse in the context of the circular economy in Ireland. This study has reviewed the policy background for water reuse; assessed the international practices in water reuse, including how public engagement is carried out when projects are being planned; examined the main technologies that are used for water recovery and their suitability; and conducted significant stakeholder engagement, including the first national public survey on attitudes to water reuse in Ireland. In particular, the public survey yielded new insights into the attitudes of Irish people towards water reuse, which can serve as a reference point for future work in this area.

The main outcomes are as follows:

- There is increasing interest internationally in water reuse, as an integral part of the circular economy, for water-stressed regions to address the effects of climate change and water scarcity. Water scarcity and cost are the two main drivers of water reuse practices. The key barriers to water reuse include the risk to human health and the environment, as well as public perception, regulatory challenges and market failures relating to the cost of reused water.
- Although Ireland is a country renowned for frequent rainfall and flooding, the actual security of the supply of water services is delicate. There are increasing pressures on freshwater supplies and demand for water. Cost is not a driving factor for the domestic sector as a result of the absence of water charges. Cost may become a future driver for increased water reuse in industry in Ireland with the harmonisation of non-domestic water tariffs and possible water abstraction charges. Sustainability is another driver for industry and agriculture in Ireland.
- There are no municipal water reuse projects or measures in Ireland at the time of writing.
- Some heavy water-using industries in Ireland are pursuing water reuse for their own reasons of cost and corporate social responsibility, but there are few publicly available data on the extent and nature of such measures.
- Many people are open to the idea of water reuse in Ireland and a recognition of its potential benefits for most purposes, with the exception of drinking water and perhaps food production. There is a strong attitude in favour of upgrading the existing water supply network to address potential shortages of water, rather than investing in water reuse projects. Internationally, it has been shown that meaningful public engagement is critical to ensuring that any water reuse measures are accepted and successful.
- The key drivers for water reuse in industry in Ireland are companies’ organisational goals regarding sustainability or environmental protection, wastewater effluent limits for sites and technological advancements. The important challenges for industry are the risk of products becoming contaminated by reused water, the need to meet regulatory or required water quality standards and the high capital expenditure cost of investment.
- The technology assessment shows that higher grade water reuses require higher levels of treatment prior to reuse, with associated higher

energy (and cost) input. Appropriate technologies and treatment trains must be assessed in relation to the intended application of the recovered water.

Our recommendations are as follows:

- In the short term, it appears that water reuse applications for Ireland should focus on internal recycling in industry (e.g. cooling water, process water, washing) and agricultural uses (e.g. milk production), where water reuse is already occurring. The "low-hanging fruit" for water reuse projects is in heavy water-using industries, such as pharmaceutical, food and beverage and wood industries, as these have the strongest drivers for adoption.
- To assess the opportunities for water reuse from municipal WWTPs, an analysis to identify water-stressed regions, potential large-scale users and suitable WWTPs is required. Risk assessment and mitigation methods, both from an environmental and from a human perspective, relative to the specific purposes for which recovered water would be employed, are also required.
- The drought conditions experienced across the country in summer 2018 have highlighted the need to conserve water and to explore alternative sources of water for non-potable urban and industrial purposes. It is recommended that a water reuse feasibility study for a municipal WWTP should be run to investigate (1) the benefits of reusing treated wastewater for specific purposes, (2) potential applications for water reuse, (3) the cost of treatment and conveyance to the end user and (4) the potential associated risks.
- Regarding strategic decisions on future municipal water reuse projects, public engagement should begin at the pre-design stage and involve two-way interaction from the outset, and throughout the process. A meaningful public engagement process that avoids any suggestion of a minimalist approach or a one-way information-giving exercise will need to be designed.
- Numerous treatment technologies are applied globally for water reuse. A selection of current and developing technologies was reviewed for technical and economic feasibility and environmental impact, including UF/MF and RO, modular WWT, SAT, AOP for SAT and GAC technologies, which are recommended for municipal WWTPs, and UV, SAT, modular WWT, MBR and GAC technologies, which are recommended for industry.
- Water quality standards should be adopted for water that has been recovered from waste streams for reuse; the standards should address different purposes of reuse rather than adopt a single standard for all recovered water. The European Union has proposed regulations to lay down minimum requirements for water quality and monitoring for water reuse, which will provide important guidance for water reuse adoption in Ireland.

1 Introduction

The European Union (EU) aims to transition to a circular economy, in which the value of products, materials and resources is maintained in the economy for as long as possible, minimising the generation of waste, to develop a sustainable, low-carbon, resource-efficient and competitive economy (EC, 2015). This project examines one aspect of the circular economy concept as it applies in Ireland: the use of treated wastewater for beneficial purposes (also referred to as “using recycled water” or “water reuse” in this report).

1.1 International Context

There are increasing pressures on traditional water resources on account of a rapidly growing global population, of which an increasing percentage are living in cities, intensifying agricultural practices and expanding industries. The effects of climate change on water supply further compound the strain placed on the world’s water resources. Water supply is a critical issue that impacts people’s welfare and a country’s economy and environment, as well as the functioning of many industries. As stated in the United Nations World Water Assessment Programme:

> In a world where demands for freshwater are ever-growing, and where limited water resources are increasingly stressed by over-abstraction, pollution and climate change, neglecting the opportunities arising from improved wastewater management is nothing less than unthinkable in the context of a circular economy. (WWAP, 2017; p. v)

A country’s or region’s approach to water management, and in particular water reuse, often depends on the degree of water stress that the territory experiences. Thus, countries that experience greater water stress have become leaders in novel water management strategies and practices.

Water scarcity and droughts currently affect many European regions (EC, 2017). Water reuse can help to ensure that there are sufficient quantities of water of suitable quality for the intended purposes. It can also play a part in meeting the objectives of Directive 2000/60/EC (EU, 2000), which establishes a European community framework for action in the field of water policy (EU Water Framework Directive, WFD) by generating sustainable growth, reducing waste and protecting the environment. In 2012, the European Commission (EC) announced its intention to tackle the issue of water scarcity and reuse and supported the need for increasing water reuse in its Communication “A Blueprint to Safeguard Europe’s Water Resources” (EC, 2012a). Furthermore, the United Nations, through its Agenda 2030 for Sustainable Development (UN, 2015), is urging for adoption of wastewater reuse as an essential tool for achieving its Sustainable Development Goals (SDGs). In order to ensure water availability, sustainable resource management and sanitation for all (SDG 6), there must be integrated management of water resources. Internationally, recycled water is used for a wide range of applications. These include, inter alia, agricultural irrigation, landscape irrigation, industrial uses, wetlands remediation, urban uses such as street cleaning, domestic uses such as toilet flushing, and direct potable reuse for drinking water. Globally, recycled water is used mostly for irrigation and environmental and industrial uses; direct potable reuse comprises less than 1.5% of the total. In general, water reuse relieves demand on fresh sources for higher quality drinking water and other more sensitive uses by using recycled water for lower-grade uses.

1.2 Opportunities for Water Reuse in Ireland

Ireland is considered to be a water-abundant country; it has a mild and wet climate and rainfall causes annual flooding in certain river basins. Irrigation is not widely used for agriculture and the direct cost of water to the end user is relatively low compared with other European countries. Therefore, it could be argued that water scarcity is not a strong driver for water reuse in Ireland. Although this may be the case at present, it is important that Ireland treats water as a valuable resource and protects the quantity and quality of water supplies for decades to come. Additionally, water scarcity and cost may become drivers in the future. At present, there are a number of factors causing greater constraints on Ireland's available water, including ageing pipeline infrastructure, increasing demand from urban areas and intensive industry sectors (Irish Water, 2015a), climate change trends to date leading to water shortages in specific regions (EPA, 2011) and future climate change impacts on water supply sources (Gleeson *et al*., 2013). There may be specific regions in Ireland that are more susceptible to water shortages, for example areas with networks reliant on a single source, treatment plant or storage reservoir and those with low available headroom to cater for emergencies, planned maintenance or equipment failures. Irish Water has stated that the Greater Dublin Region has been under increasing water supply pressures and that the existing supply sources and infrastructure do not have the capacity to meet future population and industry growth (Irish Water, 2015b). Domestic water charging does not currently take place in Ireland. In the non-domestic sector, industry and commercial customers pay some of the cheapest water prices in Europe (see section 3.2). However, changes are afoot, with Irish Water and the Commission for Regulation of Utilities (CRU) agreeing on a plan to establish a unified non-domestic tariff to ensure the harmonisation of water charges across all counties. There are currently no charges or penalties in place for water abstraction, although all abstractions greater than 25 m^3/day will need to be registered from 2018 onwards (DHPLG, 2018). For large-scale abstractors, it is probable that a licensing fee will be applied by the Environmental Protection Agency (EPA) to cover the administrative costs of the proposed licensing system. These changes in water charges and the possibility of abstraction charges could lead to increased water charges for industry in the future, which will affect the drivers for water reuse in Ireland.

In addition to water scarcity, there are other factors that either drive or inhibit the adoption of water reuse practices, namely the protection of human health and the environment, public acceptance for water reuse and the cost of such measures relative to the benefits achieved. Key to assessing whether or not water reuse is a viable option for Ireland is taking a risk-based approach. The risk associated with using treated wastewater must be assessed in comparison with the need for water. Wastewater must be treated to the required standard for its intended reuse, whether this be low-grade uses such as industrial cooling or environmental enhancements, or high-grade uses such as potable water reuse and food crop irrigation. It is well documented that contaminants of emerging concern (CECs), such as pharmaceuticals, antibiotic-resistant bacteria and genes, endocrine-disrupting compounds (EDCs), disinfection by-products (DBPs) and pesticides, are susceptible to poor removal during treatment by conventional wastewater treatment plants (WWTPs), which introduce them back to the environment. These risks must be accounted for in any water reuse project or strategies and regulations for Ireland.

Regarding public acceptance, in other jurisdictions, public surveys on water reuse consistently flag up concerns about water quality and health implications – especially overcoming the so-called yuck factor – as key issues that need to be addressed by scheme promoters (Duong and Saphores, 2015; Wester *et al*., 2015). Positive public perceptions and acceptance of water reuse are recognised to be a central feature in the planning and introduction of water reuse schemes (Dolnicar and Hurlimann, 2011; Ross *et al*., 2014). The cost of water reuse schemes is affected by multiple factors: direct construction cost for additional treatment processes, new water distribution networks to the point of intended use and ongoing operation and maintenance costs, including quality assurance testing. In a circular economy approach, in which principles of sustainability are observed, evaluating the benefits of water reuse would ideally include both direct and indirect types. Direct benefits include the avoidance of the capital cost of additional potable water treatment and the (presumably) lower cost of water. Examples of indirect benefits from natural water resource preservation are improved security of supply, the underpinning of economic activity and the impact it has on the carbon footprint via energy used in production. Collectively, these factors inform an estimate of the "true cost of water" (Clere, 2016) for any given scheme being proposed. In the circular economy approach, the "total cost of water" would represent a more suitable basis of evaluation for comparison of alternative water schemes for providing additional water in an area, instead of either a "capital expenditure (CAPEX)-only" or a "CAPEX + operational expenditure (OPEX)" basis.

This report examines the current status of, and opportunities for, water reuse in the context of the circular economy in Ireland. Chapter 2 provides a review of water reuse applications and practices internationally, including drivers, challenges and case studies of progressive countries' water reuse strategies and practices. In Chapter 3, the current level of, and opportunities for, water reuse in Ireland are presented, both within industry and from municipal WWTPs, as well as selected case studies from industry. Chapter 4 presents the stakeholder engagement conducted with the general public, industry, the academic community and policymakers on perceptions of, and barriers to, adoption of water reuse measures, as well as policy, standards and legislative gaps. Chapter 5 discusses the current and emerging water reuse technologies and treatment trains in terms of economic, technical and environmental feasibility. In Chapter 6, the report draws conclusions on the current status of water reuse in Ireland and makes recommendations on how to develop the water reuse sector, the measures required to successfully implement water reuse in the context of the circular economy in Ireland and suitable technologies in an Irish context.

2 Water Reuse Practices

2.1 Key Definitions, Terminologies and Scope

A variety of definitions and terminology are used to define water reuse in Europe and globally. Terms such as “water reuse”, “water recycling”, “treated wastewater reuse” and “reclaimed water” are used interchangeably, which has resulted in confusion between and within different countries (US EPA, 2012). This report adopts the definition used in the Common Implementation Strategy (CIS) guidelines on water reuse (EC, 2016a, p.17): “Water reuse is the use of water which is generated from wastewater or any other marginal water and treated to a standard that is appropriate for its intended use.”

Urban wastewater reuse may be planned or unplanned and planned reuse can be direct or indirect. The types of water reuse within and outside the scope of this project are presented in Table 2.1, along with descriptions. The present study covers planned water reuse for potable and non-potable purposes, whether direct or indirect, and does not examine unplanned water reuse. The project considers reuse of urban and industrial wastewater from municipal WWTPs for external applications, as well as internal recycling of wastewater within an industry site. The reuse of rainwater and grey water, or domestic reuse water, are not included under the scope of this report; further information on these topics can be found in a previous EU study (BIO, 2015).

In addition to its reuse potential, wastewater can contain varying levels of nutrients, metals and organic material that can themselves be extracted and reused. These recovered materials offer potential economic value in many industries, including the energy and food industries. For example, several methods have been developed for recovering phosphorus from wastewater, as the recovered product can be used as fertiliser, contributing to the development of a circular economy. However, the broader uses of treated wastewater or sludge for nutrient and energy recovery are outside the scope of this report, which focuses on the application and reuse of the treated wastewater.

Table 2.1. Types of water use/reuse addressed in this project

Type	Description	Included in scope?
Planned reuse	Where systems are developed and controlled specifically for the direct or indirect reuse of water	Yes
Unplanned reuse	Where water reuse happens in an uncontrolled way, such as by abstracting water from a river at some point downstream of an upstream treated water discharge	No
Direct reuse	Wastewater treated at a treatment plant, given further treatment to a suitable standard for its intended use, and piped onwards for a beneficial reuse	Yes
Indirect reuse	Wastewater treated at a treatment plant and discharged to a water body source such as a river, lake or groundwater, for later abstraction and treatment to a suitable standard for its intended use	Yes
Municipal wastewater reuse	The reuse of treated wastewater from a municipal WWTP for direct or indirect reuse	Yes
Industrial wastewater reuse	Wastewater from industry processes (excluding human and domestic-type sewage), generally treated and reused within the same industrial site	Yes
Rainwater harvesting	Collection of rainwater directly into tanks for a beneficial use, generally at the same location as collection takes place	No
Grey water use	Separate collection of certain water wastes (e.g. bathroom sinks, showers) for beneficial reuse at the same location as they are generated (e.g. within a dwelling for toilet flushing)	No
Pollutant or energy recovery	Recovery of pollutants as a by-product or heat energy from wastewater, which can contain valuable resources to be recovered for beneficial reuse	No

2.2 Water Reuse Applications

In the global context, treated wastewater is used for a variety of purposes, which can generally be categorised into urban, agricultural, industrial and environmental reuse applications. These applications can be further simplified into potable and non-potable uses (Table 2.2).

2.2.1 Agriculture

Agricultural applications, such as for crop irrigation (food and non-food crops) and for pastures, is the predominant application type in many countries, largely because of the lower level of treatment required prior to reuse (WWAP, 2017). This offers farmers a reliable source of water even in times of drought and reduces the need for chemical fertiliser as valuable nutrients are recycled in the reused wastewater (Bixio *et al*., 2006).

2.2.2 Industry

Reuse applications in industries vary, from wash-down and rinsing activities with low-quality requirements, to higher quality standards such as those required in silicon wafer manufacturing plants. Specific water-intensive sectors include textile finishing, the pulp and paper sector, the chemical industry and the steel, iron, metallurgy and food industries (Bixio *et al*., 2006).

2.2.3 Urban

There is a wide range of possible urban reuse applications. Examples of non-potable uses include landscape irrigation (public parks, sporting facilities, golf courses, private gardens, etc.), street cleaning, fire protection systems, vehicle washing, toilet flushing, air conditioners and dust control. Direct potable use involves treating wastewater to the required standard and returning it to the water supply system without the use of an environmental buffer (i.e. without discharge to a watercourse, lake, etc.).

2.2.4 Environment

Environmental applications include the restoration of habitats such as marshes, wetlands or fens, which may have been damaged by human intervention, and reforestation projects in dry climates or for recreational benefits (Bixio *et al*., 2006). Groundwater recharge is another application and is specifically aimed at aquifer storage and recovery, and at seawater intrusion control (Crook *et al*., 2005).

Figure 2.1 displays the proportions of global water reuse by application after tertiary treatment (Lautze *et al*., 2014). Globally, agricultural irrigation is the main application for water reuse, consuming 32% of reclaimed water, followed by landscape irrigation (20%) and industrial uses (19%). Only 2% of reclaimed water is used for recharge of groundwater. However, recharge of groundwater and indirect potable reuse were highlighted as applications with important potential (Lautze *et al*., 2014). One noteworthy point is that direct potable reuse is not a major application for water reuse. As the water reuse industry develops, it is expected that a shift in dominance from agricultural applications to municipal applications, such as potable and industrial uses, will be seen (WWAP, 2017).

Table 2.2. Water reuse applications

Categories of use	Uses
Urban uses	Irrigation of public parks, sporting facilities, private gardens, roadsides; street cleaning; fire protection systems; vehicle washing; toilet flushing; air conditioners; dust control
Agricultural uses	Food crops not commercially processed; food crops commercially processed; pasture for milking animals; fodder; fibre; seed crops; ornamental flowers; orchards; hydroponic culture; aquaculture; greenhouses; viticulture
Industrial uses	Processing water; cooling water; recirculating cooling towers; washdown water; washing aggregate; making concrete; soil compaction; dust control
Recreational uses	Golf course irrigation; recreational impoundments with/without public access (e.g. fishing, boating, bathing); aesthetic impoundments without public access; snowmaking
Environmental uses	Aquifer recharge; wetlands; marshes; stream augmentation; wildlife habitat; silviculture
Potable uses	Aquifer recharge for drinking water use; augmentation of surface drinking water supplies; treatment until of drinking water quality

Source: Alcalde Sanz and Gawlik (2014).

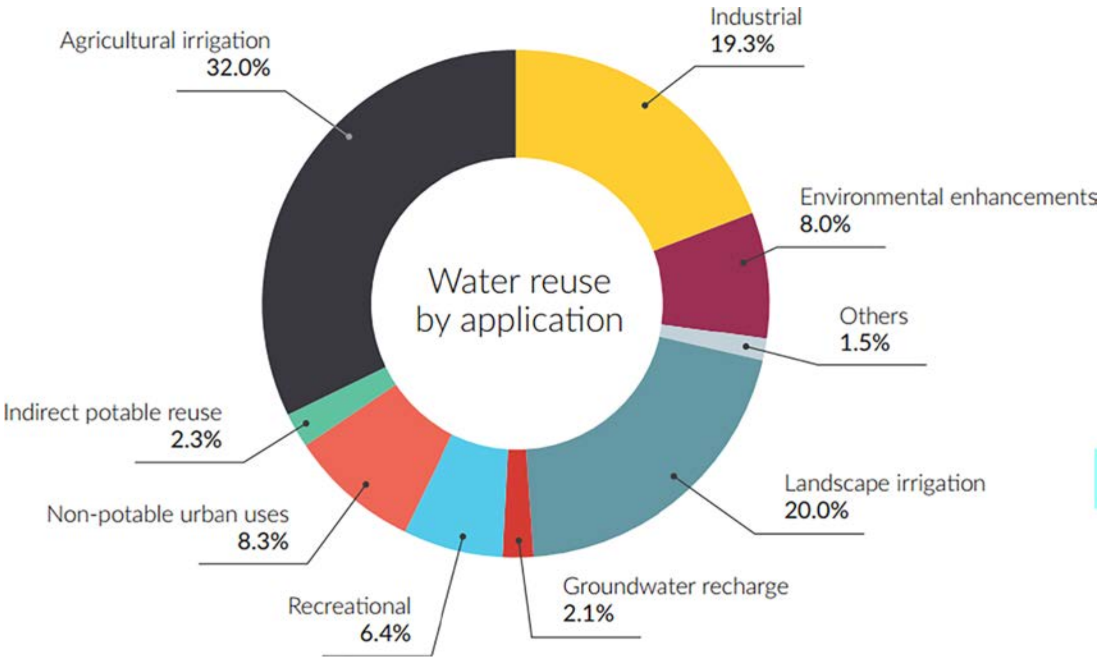


Figure 2.1. Global water reuse after advanced (tertiary) treatment: market share by application. Source: Lautze *et al.* (2014).

Irrespective of the type of reuse application, water quality issues are a principal factor in planning for reuse. Ideally, the wastewater source and type of treatment should be matched to the eventual reuse application (US EPA, 2012). This is known as the “fit-for-purpose” concept; for example, the common standard of secondary treatment of wastewater is often sufficient for many non-potable reuse applications. Determining which applications can and should be provided with treated wastewater is an essential stage in the planning process. Table 2.3 presents the type of reuse requiring increasing levels of treatment. As the level of treatment intensifies so does the acceptable level of human exposure to the treated water and the associated costs. The level of treatment that can be applied depends on the available technology and economic feasibility of such technology.

2.3 Magnitude of Water Reuse

In 2011, an estimated 7 km^3 of treated municipal wastewater was reused worldwide, representing 0.59% of the total water use (EC, 2016b). Data on wastewater collection and treatment are not comprehensive, particularly in developing countries but also in some of the more developed countries (WWAP, 2017). Furthermore, it is difficult to rank the global leaders in terms of water reuse, as countries use different measurements of reuse, e.g. reuse volume or intensity of reuse per inhabitant. China, Mexico and the USA are the countries with the largest quantity of wastewater reuse, but in the first two cases non-treated wastewater is involved. If the reuse per inhabitant is considered, Qatar, Israel and Kuwait are the highest-ranked countries, whereas, when reuse is considered as the percentage of the total water used, Kuwait, Israel and Singapore become the most important (Jiménez and Asano, 2008). Israel, Kuwait and Singapore consistently appear as global leaders in terms of water reuse (Angelakis and Gikas, 2014).

In Europe, much of the development on water reuse has been either on the coastlines and islands of the semi-arid southern countries such as Spain, Italy, Cyprus and Malta, or in the highly urbanised areas of northern countries, such as Belgium, which are increasingly affected by extended periods of drought because of climate change (EC, 2016a). In southern Europe, the primary reuse for treated wastewater is in agricultural irrigation whereas in central and northern Europe urban/residential and industrial uses are more common (AQUAREC, 2006). Although water scarcity has been a driver of water reuse in some European countries, other countries with a similarly high water stress have not developed water reuse capabilities, such as Latvia, Lithuania, Romania, Slovakia, Slovenia and Hungary (BIO, 2015).

Table 2.3. Types of reuse appropriate for increasing levels of treatment

Treatment level	Increasing levels of treatment			
	Primary	Secondary	Filtration and disinfection	Advanced
Processes	Sedimentation	Biological oxidations and disinfection	Chemical coagulation, biological or chemical nutrient removal, filtration and disinfection	Activated carbon, RO, advanced oxidation processes, soil aquifer treatment, etc.
End use	No uses recommended	Surface irrigation of orchards and vineyards Non-food crop irrigation Restricted landscape impoundments Groundwater recharge of non-potable aquifer Wetlands, wildlife habitat, stream augmentation Industrial cooling processes	Landscape and golf course irrigation Toilet flushing Vehicle washing Food crop irrigation Unrestricted recreational impoundment Industrial systems	Indirect potable reuse including groundwater recharge of potable aquifer and surface water reservoir augmentation, and potable reuse
Human exposure	Increasingly acceptable levels of human exposure →			
Cost	Increasing cost of treatment →			

RO, reverse osmosis.
Source: US EPA (2012).

Up-to-date, reliable data on water reuse for European countries are not available (BIO, 2015; EC, 2016b), even though EU Member States are required to report volumes of reused urban treated wastewater. The most recent estimate of treated urban wastewater reused annually in the EU is about 1 billion m^3, which accounts for approximately 2.4% of the treated urban wastewater effluents, which is less than 0.5% of annual EU freshwater withdrawals (Wintgens and Hochstrat, 2006). The reuse potential for Europe by 2025 was estimated between 2134 Mm^3/year and 5670 Mm^3/year. Presently, Spain and Italy rank highest as the reuse leaders in terms of volume, reusing 347 Mm^3/year and 233 Mm^3/year, respectively; Cyprus and Malta, on the other hand, reuse the greatest percentage of treated wastewater, at 89% and 60%, respectively (EC, 2016b).

2.4 Regulation and Policy

In terms of regulation, government policies and legislation are increasingly incorporating water reuse requirements. The USA (state dependent), Canada, China, Israel, Japan, Jordan, Mexico, South Africa, Tunisia and Turkey all have some level of water reuse criteria or requirements. Guideline documents have provided a basis for the development of regulations for countries and are a reference in the absence of regulations. Such guidelines include the US Environmental Protection Agency (US EPA) *Guidelines for Water Reuse* (US EPA, 2012); the World Health Organization *Guidelines for the Safe Use of Wastewater, Excreta and Grey Water* (WHO, 2006), *Guidelines for Drinking-water Quality* (WHO, 2017a) and *Potable Reuse: Guidance for Producing Safe Drinking-Water* (WHO 2017b); and ISO standards for water reuse for irrigation projects (ISO, 2015), with standards on water reuse in urban areas and industrial water reuse being developed.

In Europe, although water reuse requirements are not directly stated in legislation, the Water Framework Directive (WFD) suggests reuse as a supplementary measure (Council Directive 2000/60/EC; EU, 2000). The Urban Wastewater Treatment Directive (UWWTD) encourages the reuse of treated water "whenever appropriate", although there is no definition as to what is appropriate (Council Directive 91/271/EEC; EU, 1991). Appropriateness can be related to the costs and benefits of a reuse application or within the boundary conditions set by relevant legislation and water policy principles. Compliance with the UWWTD facilitates water reuse as the treatment specified in the legislation is an absolute minimum for any reuse applications. At least six EU Member States have developed guidelines and regulations for water reuse: Cyprus, Spain, Italy, France, Greece and Portugal. EU countries with water reuse standards are found to have higher levels of water reuse (BIO, 2015). In Spain, the Royal Decree-Law 1620/2007 of Purified Water Reuse (Spanish Association for the Sustainable Use of Water, 2011) specifies 24 permitted uses for reclaimed water under five broad categories: urban, agricultural, industrial, recreational and environmental. The legislation prohibits reclaimed water from being used for certain purposes, such as human consumption, in hospitals or for aquaculture facilities for bivalve molluscs (Spanish Association for the Sustainable use of Water, 2011). See Appendix 1 for quality criteria for water reuse for urban and agriculture uses. The TYPSA (2013) report, which aims to gather the precise state of the art on water reuse for each country that comprises the EU, provides an overview of the sectors in which reclaimed water is currently applied by country and regulation/guidelines, if any. At present, the EC is working to develop minimum quality requirements for water reuse in the EU. An EU report on minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge makes recommendations as an input to the design of a legal instrument on water reuse in Europe (Alcalde-Sanz and Gawlik, 2014). It is envisaged that the new rules will help farmers make the best use of non-potable wastewater, alleviating water scarcity while protecting the environment and consumers. In 2018, the EU proposed a regulation to lay down minimum requirements for water quality and monitoring, and the obligation to carry out specified key risk management tasks, for the safe reuse of treated urban waste water in the context of integrated water management (EC, 2018). The proposal covers obligations of reclamation plant operators, risk management, permits to supply treated wastewater, information for the public and monitoring of the implementation. Setting harmonised minimum requirements, notably key parameters on reference pathogens and on the quality of treated wastewater and monitoring together with harmonised risk management tasks, would ensure a level playing field for those engaged in water reuse and those affected, prevent potential obstacles to the free movement of agricultural products irrigated with reclaimed water and ensure that health and the environment are protected, thereby also increasing confidence in the practice of water reuse. The annexes to the water reuse regulations proposed by the EU outline the reclaimed water quality requirements for agricultural irrigation for *Escherichia coli* (cfu/100 ml), biochemical oxygen demand (BOD) (mg/l), total suspended solids (TSS) (mg/l) and nephelometric turbidity units (NTUs), as well as minimum monitoring frequencies (see Appendix 1).

2.5 Barriers to Expanding Water Reuse

From a technical perspective, water reuse is a valid solution to water stress issues and forms part of an integrated water supply and resource management system. However, planned water reuse practices have not been widely adopted globally (see section 2.3). Water reuse projects that are technically feasible are often not implemented as a result of non-technical barriers such as institutional, public perception and economic barriers (Lautze *et al*., 2014). Also of key importance to any water reuse scheme is the risk to human health and the environment. CECs in wastewater and the environment is an area that has received increased public attention and which could affect water reuse standards and regulation for certain applications. An EC report identified challenges to water reuse as information failures, market failures and regulatory failures (EC, 2016b).

2.5.1 Information failure

Lack of information about actual risks and limited understanding of the benefits relate to the public perception of water reuse. There are a number of hazards (physical, chemical, microbial) associated with water reuse, which, if not properly managed, pose significant risks to human and environmental health. Although guidelines and standards are in place to mitigate against these risks, consumer acceptance is required for the widespread adoption of water reuse applications. The degree of resistance to water reuse generally correlates with the proximity of its application to humans, e.g. there tends to be greater acceptance of distant environmental applications as opposed to agricultural produce irrigated with treated water (BIO, 2015). Studies have found that public acceptance of potable water reuse depends on the level of trust in the institutional forces, such as water and wastewater utilities, academics and regulators driving the reuse plan (Ormerod and Scott, 2013; Ross *et al.*, 2014; Brouwer *et al.*, 2015). Programmes for engaging the public and increasing awareness are imperative for the success of water reuse projects. Education on water supply concerns is also key because the public needs to be aware of water supply problems before they will accept reuse for most applications (Frijns *et al.*, 2016). Perceptions of reused water have been significantly improved in, for example, Singapore and California through public outreach programmes and stakeholder engagement (Alcalde Sans and Gawlic, 2014).

2.5.2 Regulatory failure

Regulatory failures are caused by a number of legislative and institutional issues. With regard to legislation as a barrier to water reuse, there are two forces at play: there are either unclear or complex legal frameworks for reuse or overly stringent water quality standards. There is no single European standard on wastewater quality requirements for specific reuse applications; furthermore, key legislative documents such as the WFD and UWWTD do not set out water reuse requirements or define what is appropriate. Although some countries have developed national standards and regulations, others, where there is little or no reuse, have not. This may result in agricultural products that have been irrigated using treated wastewater in one region accessing the single market. A lack of regulation can hinder the implementation of water reuse plans; without defined quality standards, the level of treatment required cannot be determined (EC, 2016b). “Over-engineering” water treatments could result in unnecessary costs and environmental degradation, whereas the opposite could result in unacceptable water quality. Additionally, the approach to regulation has an impact: fragmentation of the management of the various stages of the water cycle, i.e. different organisations tasked with water supply and wastewater treatment (WWT), can pose challenges in the production of reliable institutional or legal frameworks for water reuse (Alcalde Sans and Gawlic, 2014).

2.5.3 Market failures

Market failures relate to the cost of reused water, the investment environment for water reuse projects and the technical limitations of water reuse technologies. From a consumer perspective, the cost of reused water may be greater than than that of traditional water resources on account of the cost of WWT and the infrastructure investment required to implement water reuse applications. This provides no incentive to switch to reused water for consumers (EC, 2016b). Subsidies to reduce costs are common in regions where water reuse implementations have been successful, such as in Cyprus and Spain (EC, 2016b), although this is counter-intuitive to the WFD requirement for full cost recovery. From the supplier perspective, the high upfront investment required for WWTPs and reuse infrastructure, as well as the perceived low financial returns, can be prohibitive. This combined with the regulatory failure, where the level of treatment and the technological investment required is unknown, creates a significant barrier to investment.

2.5.4 Contaminants of emerging concern

Contaminants of emerging concern, such as pharmaceuticals and personal care products (PPCPs), EDCs, flame retardants (FRs), DBPs, pesticides and artificial sweeteners (ASWs), remain a major challenge to the environment and human health. These CECs are increasingly being detected at low levels in surface water and there is concern that these compounds may have an impact on aquatic life. For example, EDCs are compounds that alter the normal functions of hormones, resulting in a variety of health effects, including reproductive effects in aquatic organisms. A previous EPA-funded study reported the presence of pharmaceuticals in municipal effluents in Ireland (Lacey, 2008) and a more recent study investigated pharmaceuticals as environmental CECs and their presence in, and potential impact on, the Irish aquatic environment (McEneff *et al.*, 2014; Quinn *et al.*, 2015). Another concern is the by-products from the treatment process. *N*-Nitrosodimethylamine (NDMA) is a DBP of concern. It is a semi-volatile organic chemical and a member of a family of potent carcinogens. NDMA is an unintended by-product of the chlorination of wastewater and drinking water at treatment plants that use chloramines for disinfection (Mitch *et al.*, 2003).

It is well documented that CECs are susceptible to poor removal at conventional WWTPs, which results in their introduction back to the environment in concentrations ranging from nanograms per litre up to milligrams per litre (Salimi *et al.*, 2017). Disinfection processes at WWTPs cannot completely inactivate local microorganisms, which are able to regrow post treatment when they find favourable conditions (Li *et al.*, 2013; Fiorentino *et al.*, 2015; Giannakis *et al.*, 2016). Furthermore, there is a lack of research on the fate of antibiotic-resistant bacteria and antibiotic resistance genes in soil after irrigation with wastewater, and some research has found that some antibiotic resistance genes can be transferred from wastewater bacteria to soil or plant bacteria (Becerra-Castro *et al.*, 2015; Deloitte, 2016). CECs are reduced or immobilised in the natural environment as a result of dilution with other source waters or natural degradation processes, such as biodegradation, photolysis and sorption (Guo *et al.*, 2010). Although studies have demonstrated adverse effects on fish and other animals in the environment, the potential effects on human health remain to be addressed fully.

For pharmaceuticals, the concentrations detected in the environment are minute compared with prescribed therapeutic doses; a person would have to consume or be exposed to contaminated water for thousands, and in some cases millions, of years to consume the equivalent of one therapeutic dose, e.g. one pill, of a drug (Raghav, 2013). The WHO (2017) *Guidelines for Drinking-water Quality* recommended against requiring health-based guidelines for pharmaceuticals at this time; the working group of experts concluded that the currently detected concentrations and predicted exposure levels do not pose a serious risk to human health.

Removal of all CECs to below current detection limits is possible using a combination of advanced water treatment technologies, but this could result in an expensive, energy-intensive process. It is currently difficult to assess whether or not the expense would necessarily provide any significant improvement in human and ecosystem health without knowing the long-term health impacts of these CECs. Many wastewater utilities have set objectives to both reduce the energy consumption of treatment and improve the removal of potentially harmful substances (CECs). Achieving one objective may significantly hamper the other and thus wastewater utilities are somewhat reluctant to take decisions to move forward in either direction (STOWA, 2018). Therefore, further research is required on understanding the long-term health and environmental effects of these CECs in order to allow assessment of the real risks and employ the appropriate treatment technologies and processes for water reuse projects. Other limitations include the lack of real-time monitoring techniques for CECs in WWTPs that are reliable and cost-effective (BIO, 2015).

2.6 Case Studies

The following case studies on water reuse in the UK, Spain and Singapore review the drivers and challenges, technologies used, end uses and best practices of specific regions. The UK has a similar economic, social and environmental situation to Ireland; Spain is a progressive water reuse country within Europe; and Singapore is one of the leading and most progressive water reuse countries globally. The case studies offer insights to inform policy and aid development of solutions in an Irish context. Numerous additional case studies have been published (e.g. US EPA, 2012; WHO, 2017b).

United Kingdom

Water scarcity is becoming increasingly pronounced in the UK on a periodic basis and competition for limited supply during peak periods has resulted in a growing interest in alternative water sources. These periods of water scarcity have been caused by the increasing occurrence of drought and consequently there is public, political and climatic pressure to use water wisely. Water reuse projects have been developed for both direct applications, such as golf course irrigation, fish farming and car washing, and indirect potable use (TYPSA, 2013; BIO, 2015;). Industry-driven developments in water reuse are more common, particularly in the dairy industry and in poultry and vegetable production (Gaines, 2014).

Water reuse projects

- The first large-scale planned indirect reuse of water in the UK is the Langford recycling scheme, which takes wastewater that would usually be returned to the sea and treats it further before releasing it upstream to be used for drinking water. The success of the project was attributed to years of data demonstrating water quality improvement as well as early engagement and clear communication with key stakeholders.
- The Old Ford Factory, operated by Thames Water, is a 500 m^3/day plant in East London where water is abstracted from a sewer and treated, using a membrane bioreactor (MBR) and granular activated carbon (GAC), to produce non-potable water for irrigation and toilet flushing in the Olympic Park. Most of the venues in the Olympic Park are supplied with non-potable water (Thames Water, 2013) and the wastewater is also used for cooling towers of a combined cooling, heat and power (CCHP) energy centre.
- Deephams pilot plant is a purpose-built, 600 m^3/day facility used to research indirect potable reuse. The pilot plant comprises pre-filtration, microfiltration (MF), reverse osmosis (RO) and advanced oxidation. During research trials other technologies have been evaluated such as replacement of RO membranes with NF (nanofiltration) membranes.

Challenges and recommendations

Lack of clear guidelines on ownership of wastewater and quality issues have been significant barriers for water reuse projects in the UK, although such guidelines are cited as being under preparation (TYPSA, 2013). The administration load and time required to progress through all relevant agencies and regulatory bodies was cited as a specific barrier in the development of the London Olympic Park water reuse scheme (BIO, 2015). The Chartered Institution of Water and Environmental Management UK (CIWEM) has made a number of suggestions (CIWEM, 2016) to address water reuse challenges:

- promote large-scale water reuse schemes to reclaim water resources;
- a coherent government policy and guidelines on water reuse, with well-founded water reuse quality standards for the protection of public health and the environment, are needed;
- wastewater needs to be treated to an appropriate standard for the permitted use.

Spain

Spain is classified as a water-stressed region; it has a water stress index (WEI) score of greater than 20%. Thus, the country is a leading region in Europe for water reuse and provides a best practice example of water reuse strategies, policy and regulation, technologies and projects.

On a national level, the Royal Decree-Law 1620/2007 of Purified Water Reuse (Spanish Association for the Sustainable Use of Water, 2011) specifies 24 permitted uses for reclaimed water under five broad categories: urban, agricultural, industrial, recreational and environmental. The Royal Decree also prohibits reclaimed water from being used for certain purposes, such as human consumption, in hospitals or for aquaculture facilities for bivalve molluscs (Spanish Association for the Sustainable use of Water, 2011).

Water reuse projects

- Valencia, the Balearic Islands, Murcia and the Canary Islands reuse the greatest volume of water per person per day in Spain and the primary application for water reuse is agricultural irrigation (Molinos-Senante *et al.*, 2011).
- Agriculture: in the Andalucía region, urban reclaimed water is being reused for agricultural irrigation. Wastewater from the city of Almeria is treated through rapid sand filtration before being pumped to a tertiary treatment plant 10 km away. An ozonation system is used for tertiary treatment of the water before gravity distribution to farmers for irrigation. The economic benefits of this project include a turnover of €80 million in horticulture activity in the region, job security and control of the price of water, which is estimated at €0.65/m^3 (Thomas and Durham, 2003).
- Environment: the Empuriabrava, a constructed wetland system in Costa Brava, in the Catalonia region, benefits from water reuse. Nitrified effluent from a WWTP is further treated to reduce the concentration of nutrients in the water, which is then reused for the restoration of aquatic ecosystems. Wastewater is first treated by extended aeration and nitrogen is removed through constructed wetlands. The secondary treated water is piped to Parc Natural dels Aiguamolls de l'Empordà to restore the man-made Cortalet lagoon, which loses water in the summer months.
- Industry: Camp de Tarragona Water Reclamation Plant has successfully addressed water scarcity issues for industries in the Tarragona province, which require high water quality. A pretreatment process is applied to the wastewater to remove TSS and organic compounds before it is passed through a double RO system to reduce the final ammonia concentration to less than 0.8 mg/l, as required by industrial end users. A final ultraviolet (UV) disinfection step is applied before distribution. The treated wastewater is used in cooling towers in the local Petrochemical Complex Industrial Zone (Veolia Water Technologies, 2013). The project has addressed water scarcity issues by freeing up municipal tap water for public use.
- Industry: Life Wire is an EU-funded demonstration project, run from the Baix Llobregat wastewater reclamation plant, the aim of which is to demonstrate the feasibility of one or more technological configurations based on the combination of leading-edge technologies [ultrafiltration (UF), carbon nanostructured material filtration and RO] to polish and reuse reclaimed municipal wastewater in the chemical, liquid waste disposal and electrocoating industries

Singapore

Although Singapore experiences abundant annual rainfall, it has a limited land area and, therefore, limited water catchment areas. This, coupled with a population of 5.6 million, contributes to the classification of Singapore as a water-scarce country. Strategies by the Singapore Government to guarantee its water security have included improved catchment capabilities, conservation policies, enforcement measures, access to alternative supplies through diplomacy and advancing technologies.

Political driver

Historically, water demand in Singapore was met by water trade deals with Malaysia, which was part of the Separation Agreement that the two countries reached when Singapore gained independence in 1965. This ultimately resulted in Singapore becoming dependent on Malaysia for provision of up to 40% of its water demands. This dependency has resulted in political tensions and disagreements between Singapore and Malaysia on water pricing, in turn causing Singapore to intensify efforts to become self-sufficient before the expiration of the import agreement in 2061.

NEWater

Presently, Singapore has a robust water management plan incorporating water reuse technology managed by the Public Utilities Board (PUB), which is Singapore's national water agency. Known as the "four taps", this includes water from local catchments, imported water, desalinated water and highly purified reclaimed water. This highly purified reclaimed water, known as NEWater, is considered to be the pillar of Singapore's water sustainability (PUB, 2017a). NEWater takes treated water that is safe to be discharged into nature and applies further treatments, namely MF, RO and UV disinfection as well as the addition of alkaline chemicals (PUB, 2017b). The result is ultra-clean reclaimed water, which is predominantly used for industrial and air-conditioning cooling purposes at silicon wafer fabrication plants, industrial estates and commercial buildings. The key information is as follows:

- As of 2016, there are five NEWater factories, accounting for 40% of water supplied in Singapore.
- The target is that NEWater will be supplying 55% of Singapore's water demands by 2050.
- NEWater is purer than potable water and is also cheaper (S\$1/m^3) than potable water (S\$1.52/m^3).
- Provision of ultra-clean water is attractive to industries in Singapore, as previously they would treat publicly supplied water to remove organic compounds before use.
- In dry weather NEWater is combined with raw water that is treated before being supplied to the consumer for consumption.
- In order to gain public acceptance of NEWater, PUB has delivered an intensive public education programme on NEWater along with advertisements, posters and leaflets.

Success

Although NEWater is a success story, the overall water management programme in Singapore also depends on the other three "taps". Singapore's success has been attributed to the holistic approach taken, which included political will, institutional integration, integrated land use planning, enforcement of legislation, public education and application of advanced technology (Xie, 2006). Further to the successes achieved to date in the journey towards water self-sustainability, Singapore has become known as a "Global Hydrohub" with significant opportunities in the export of knowledge and technologies.

2.6.4. Summary of case studies

The review of these and other case studies highlights common aspects in water reuse programmes. Water stress is a common driver among all countries considering or implementing water reuse, although water stress can be due to an assortment of factors depending on the region. The challenges to water reuse practices at the early stages of development are primarily a lack of legislation and regulation, which hampers the development of water reuse projects if there is no clear guidance on treatment standards and applications. Moreover, limited data on water reuse practices delay the evaluation of the current scenario and potential opportunities for water reuse in the region. As water reuse practices and policies develop and mature, further challenges relating to infrastructure, technologies and public perception arise. The variability of water reuse practices is highly contingent on the experience and stage of development of the region with regard to WWT and reuse. The above case studies of regions at different stages of advancement and in different contexts illustrate how these factors combine and influence the successful deployment of water reuse in specific regions and address the obstacles described in section 2.5.

3 Water Reuse in Ireland

3.1 Water Reuse Drivers in Ireland

Ireland is generally considered a water-abundant country in the public perception; it has a mild and wet climate and rainfall causes annual flooding in certain river basins. Irrigation is not widely used for agriculture and the cost of water to the consumer is relatively cheap compared with other European countries. Therefore, it could be argued that water scarcity is not a strong driver for water reuse in Ireland. However, the actual security of supply of water services in Ireland is delicate and under increasing pressure from the demands of the rising population, urbanisation and social demands, and environmental and climate change issues. Environmental flow describes the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems. This “available water” is the amount of water that can be abstracted without causing significant impacts on the environment. A number of factors cause greater constraints on Ireland’s available water, namely:

1. water stress due to ageing pipeline infrastructure, either from widespread leakage or from abrupt localised failure, as has been witnessed in a number of instances in Ireland over the past 5–10 years;
2. increasing demand for water from growing urban areas and water-intensive industries (Irish Water, 2015a);
3. climate change trends to date, which have seen an increase in annual rainfall in northern and western areas with decreases in the south and east, and which have led to water shortages in specific zones (EPA, 2011);
4. future climate change modelling, which predicts Ireland’s winters to become wetter, summers to become drier and changes in precipitation that are likely to have significant impacts on river catchment hydrology (Gleeson *et al*., 2013).

Regarding the cost of water in Ireland, domestic water charging does not currently take place. In the non-domestic sector, industry and commercial customers pay water charges to Irish Water, albeit these are not yet harmonised – a legacy of the divided responsibility for water charging across the local authorities that was in place until 2014. There are currently no charges or penalties in place for water abstraction and the average charge per cubic metre of water supplied in Ireland was €1.15 in 2013 (CSO, 2015). The low cost of non-domestic water in Ireland, in comparison to other EU countries, does not incentivise water recovery (Murray *et al.*, 2010). Irish Water and the CRU have agreed a plan to establish a unified Non-Domestic Tariff Framework, to introduce harmonised non-domestic tariffs for non-domestic water and wastewater customers. The exact level of charging to be applied had not been finalised at the time of writing.

Industry in Ireland must comply with the Industrial Emissions Directive (IED), which is aimed at reducing emissions from industrial production processes and setting conditions, including emission limit values (ELVs), for sites. An industrial emissions licence granted by the EPA is required to refer to the complete environmental performance of an industrial site, including emissions to water. Best Available Techniques (BATs) are used to set permit conditions such as the ELVs for wastewater. ELVs for water depend on the receiving water use, assimilative capacity and taking other sources of discharges to the receiving water into consideration. The assimilative capacity of some receiving waters may put pressure on an industry to reduce its emissions of wastewater, driving water efficiency measures. Additionally, as some sites look to expand production, which may result in an increase in wastewater, their ELVs may not be granted an increase. Thus, sites must explore other opportunities to reduce wastewater, one of which may be water reuse.

Sustainability is another potential driver for water reuse in Ireland. Firms in industry employ sustainability plans and goals. This is driven by external pressures from up the value chain and consumer demand for more sustainable products. This trend is also seen in agriculture, particularly in Ireland, which aims to produce a higher quality food product for export internationally. Programmes such as Bord Bia's Origin Green programme aim to drive improvements and efficiencies in water use and wastewater.

3.2 Reported Water Reuse

Previous reports on wastewater reuse in European countries in 2001 and 2008 found no water reuse projects reported in Ireland (Angelakis and Bountaux, 2001; Angelakis and Durham, 2008). More recently, in a report for the EC, there was no statement of water reuse in Ireland (TYPSA, 2013). It noted that Ireland's mild and wet climate removes the need for irrigation in agriculture and that cooling water tends to be pumped directly from rivers or lakes, apparently suggesting that water scarcity is not a strong driver for water reuse in Ireland.

Regarding water reuse from municipal WWTPs, Irish Water is Ireland's national water utility. It has statutory responsibility to ensure the proper and effective management of public water resources and to ensure that all connected customers have access to a safe and secure drinking water supply. Public water supply schemes currently serve 83% of the population. Irish Water operates 790 water treatment plants, abstracting from some 1173 abstraction points, divided approximately into 70% groundwater and 30% surface water. In terms of volume, approximately 80% of public drinking water comes from surface water sources, with approximately 20% coming from groundwater (EPA, 2016c). Irish Water does not include any specific water reuse goals in its Water Services Strategic Plan (Irish Water, 2015a). It does commit to significantly improving the quality of wastewater discharged to the environment as is currently required by the UWWTD (Irish Water, 2015b). Irish Water's draft National Water Resources Plan (NWRP) is under preparation at time of writing. As part of the drafting process, a Strategic Environmental Assessment Scoping Report has been prepared (Irish Water, 2018); it states that the NWRP will "outline how we move towards a sustainable, secure and reliable drinking water supply for everyone over the next 25 years whilst safeguarding our environment". It explicitly refers to water reuse (or effluent reuse) as one of the options being considered to provide a sustainable, reliable source of water into the future.

Examining water reuse in the industry, Annual Environmental Reports (AERs) require certain information on water use to be submitted to the EPA, namely the quantity of water reused at each site site that is licensed by the EPA under the Industrial Emissions licensing framework. However, the data on water reuse amount to a single annual volume figure, without any further elaboration on either the scale and nature of current reuse or the treatment and management practices employed. Ireland is a hub for large dairy- and meat-processing plants, food and beverage sectors, and chemical and pharmaceutical plants, all of which process large quantities of water and discharge large quantities of wastewater. In 2010, an EPA-funded report found very little evidence of water being recovered and reused within the production process on large industrial sites in Ireland (Murray *et al.*, 2010). The study examined the feasibility of water recovery from industrial waste streams and assessed six facilities from the brewing, dairy ingredients, liquid milk, snack foods and pharmaceutical industries. It aimed to encourage firms to recover water for process use by demonstrating that it was not only technically feasible but also commercially advantageous. It was estimated that 34% of water supplied to all licensed companies is recoverable from individual wastewater streams, equating to 13.9 million Mm^3/year. If mains distribution losses are taken into account, which account for approximately 44%, the gross savings to the water supply network could be as high as 24.8 million Mm^3/year. It was determined that water prices in Ireland do not incentivise water recovery, yet, from the six facilities examined, four sites were judged to have opportunities for wastewater recovery, using membrane filtration, that are financially viable.

Among water professionals in Ireland, water reuse is becoming a more frequent topic of discussion. In May 2017, Engineers Ireland held a seminar on the drivers for, challenges to, and opportunities for water reuse in industry (Engineers Ireland, 2017). Additionally, there are some industry–research collaborations on water reuse. "Dairywater" is an ongoing multi-stakeholder research project, the primary aim of which is to efficiently and effectively treat wastewater effluent from dairy-processing plants using a range of innovative biological, nano-material-based and disinfection technologies. Core to this project is the idea that, in order to remain a leading exporter of dairy products, Ireland needs to address the environmental impacts of this industry in the short term (Dairywater, 2016).

In summary, there is little information available on water reuse in Ireland, either on the scale and nature of current reuse or on the treatment and management practices employed. As there are no formal reporting procedures or previous national studies of water reuse levels in Ireland, from municipal WWTPs or industrial sites, further investigation is required to report more accurate data on water reuse levels and the opportunities for water reuse. Irish Water, as the national water utility, will have knowledge of current and planned water reuse schemes in Ireland. Additionally, the opportunities for water reuse from municipal WWTPs should be examined for water-stressed regions. For water reuse within industrial sites, AERs for industrial emissions-licensed sites can be assessed to estimate internal water recycling in industry. The remaining sections of Chapter 3 address this lack of data on water reuse, from both municipal and industrial sectors.

3.3 Municipal Water Reuse Data

Over 1000 separate WWTPs and sewer networks currently collect and process wastewater in Ireland (Irish Water, 2015a). To assess the level of water reuse from municipal WWTPs and opportunities for water reuse we identified the following: (1) whether or not there are any ongoing or planned water reuse projects in Ireland; (2) which are the particularly water-stressed regions in Ireland; and (3) which are the municipal sites treating large quantities of wastewater in Ireland.

3.3.1 Ongoing or planned municipal water reuse projects in Ireland

As there are no publicly available data on water reuse from municipal WWTPs, the project team made a request to Irish Water for information, from which we received the following information. Treated wastewater is not reused for external use by third parties, outside the WWTP, in Ireland. Most municipal WWTPs recover water for internal use within the WWTP site; however, this is not further treated before reuse and the volume of water is not measured. Typically, 3–5% of water produced is reused for internal use, e.g. for backwashing filters and screenings washings.

The key driver for water reuse is water scarcity; however, these data are not currently available for specific zones in Ireland. Future opportunities for water reuse from municipal WWTPs should look to identify regions suffering from persistent water shortages and match these with suitable municipal WWTPs that could provide wastewater, which, after it has been treated, would be suitable for the intended use.

3.3.2 Particularly water-stressed regions in Ireland

The project team consulted with Irish Water to identify particularly water-stressed regions in Ireland. In 2016, 1,728,522 m^3 of drinking water were supplied to Irish domestic customers by Irish Water (EPA, 2016b). In addition, in 2017, it was reported that 71,000 households are supplied through group water schemes (NFGWS, 2017). In Ireland, approximately 70% of water supplied by Irish Water is used by domestic users and 30% by non-domestic users. However, there is no further breakdown of water used by sector, e.g. industry, households, agriculture. Different regions in Ireland experience water shortages for a variety of reasons, from supply- and demand-side pressures, and these have the potential to become more frequent and severe in the future. There are many areas with networks reliant on a single source, treatment plant or storage reservoir and low available headroom to cater for emergencies, planned maintenance or equipment failures.

The Greater Dublin Area has large water demands on account of the density of the population and industry, and has experienced water shortages and disruptions. For example, there is regularly just 2% headroom available to supply water to the Greater Dublin Area and the vulnerability of this supply was observed in 2013 when water restrictions impacted many areas of Dublin as a result of a production problem at the Ballymore Eustace water treatment plant, which delivers over 50% of the supply to Dublin (Irish Water, 2015a). Over 84% of Dublin's water treatment capacity is now dependent on the River Liffey and this fact illustrates the vulnerability of the service, with negligible headroom, and the need for new long-term sources in planning to manage risks, such as unexpected population growth or migration or economic growth, or risks resulting from climate change and pollution. The existing supply sources and infrastructure in the Greater Dublin Area do not have the capacity or resilience to meet future requirements, as it is estimated that population and industry growth will generate a demand for at least an additional 330 million litres of water per day by 2050 (Irish Water, 2015b). Irish Water has identified the Parteen Basin scheme as the preferred option to address water supply for the eastern and midlands regions. The Parteen Basin scheme comprises the abstraction of water from the lower River Shannon at Parteen Basin in County Tipperary and water treatment nearby at Birdhill. Treated water will then be piped 170 km to a termination point reservoir at Peamount in South County Dublin, connecting into the Greater Dublin network. Supplies of treated water would be made available to midland communities along the route.

In summer 2017, in Mullingar, areas of Donegal and all islands, in particular Aran and Cape Clear, water sources were monitored more closely by Irish Water on account of low rainfall and weather conditions. Furthermore, a number of areas in Ireland experienced water stress during the summer of 2018. It is expected that Irish Water's NWRP, a draft of which is due for publication in 2019, will include information on water-stressed regions in areas under Irish Water control. It is also anticipated that the NWRP will address the data requests made by the project team regarding water production headroom, current water-stressed regions and regions predicted to experience water stress.

3.3.3 Municipal sites treating large quantities of wastewater in Ireland

The EPA's *Urban Waste Water Treatment in 2015* (EPA, 2016a) and *Urban Waste Water Treatment in 2016* (EPA, 2017) reports present municipal WWTP and agglomeration information by county in Ireland. For 2015, the database is presented in Appendix 2 and lists the 157 large WWTPs. Of these, eight plants treat a population equivalent (PE)[1] of over 100,000; these are, in order of size, Ringsend, Dublin; Carrigrennan, County Cork; Limerick City, County Limerick; Galway, County Galway; Shanganagh, Dublin; Leixlip, County Kildare; Ringaskiddy-Crosshaven-Carrigaline, County Cork; and Osberstown, County Kildare. Additionally, the following WWTPs have a treatment capacity of over 100,000 PE: Waterford City; Dundalk, County Louth; and Drogheda, County Louth. These larger agglomerations and their WWTPs present the most likely potential sources for treated wastewater to be recovered in future water reuse programmes.

3.4 Industry Water Reuse Data

Although there are no overall reported data on internal recycling of water in industrial sites in Ireland, the EPA AERs do contain limited data on water reuse, i.e. an annual volume of reused water. The literature review and industry stakeholder consultation confirmed that some industrial sites in Ireland have adopted water reuse projects. The following sections address the lack of reported data on water reuse within industry in Ireland, under the following headings: (1) large water-using and wastewater-treating industry sites in Ireland; (2) large industrial sites' current and planned levels of water reuse; and (3) case studies of industry water reuse projects in Ireland that showcase good practice, to highlight opportunities for water reuse in industry.

3.4.1 Large water-using and wastewater-treating industry sites in Ireland

The first step was to identify the key sectors that are treating and processing large quantities of water and wastewater, i.e. sites with wastewater flow maximum rates of 100 m^3/day, in collaboration with the EPA. These sectors were identified as having the greatest need for reusing treated wastewater. Three sectors identified with significant wastewater to be assessed are the chemical sector, the food and drink sector and the wood sector. To identify sectors with potential opportunities for water reuse, the EPA IED licence database and AERs for industrial sites were utilised to gather information on wastewater volume flows, WWT processes, accredited water conservation programmes, the water used/extracted and water discharge. The information for sites in the three identified sectors was collected in a Microsoft Excel database. The chemical sector includes a wide range of firm activities in manufacturing, from pesticide products to pharmaceuticals.[2] Key information was collected on the 66 site licences. From these, a subset

1 Population equivalent (PE) is a term used to measure the organic biodegradable load generated in an urban area. It takes into account the load generated by the resident population, the non-resident population (e.g. tourists) and industries. A PE of 1 is defined as the organic biodegradable load having a 5-day BOD of 60 g of oxygen per day (EPA, 2015).

2 Chemical sector NACE codes: 1920, 2020, 2011, 2013, 2014, 2030, 2110, 2120, 2442, 2052, 2059 and 3250.

of 40 sites was identified as treating large quantities of wastewater; the majority of these sites manufacture pharmaceutical products or preparations. The food and drink sector includes a wide range of firm activities in the manufacture of meat products, dairy products, animal feeds and beverages.[3] Key information was collected on the 87 site licences. From these, a subset of 71 sites was identified as treating large quantities of wastewater. Key information on industrial sites involved in the manufacture of wood-derived products (boards) was collected on the six site licences. From these, a subset of four sites was identified as treating large quantities of wastewater. In addition to the three sectors identified, it was realised that there may be other sectors treating large quantities of wastewater with the potential for water reuse that do not require an industrial emissions licence. For example, the healthcare sector was recognised as having the potential for water reuse from the Health Service Executive (HSE) Water Workshop in Tullamore on 10 October, where a case study for RO water harvesting in Midlands Regional Hospital Tullamore was discussed.

3.4.2 *Large industrial sites' current and planned level of water reuse*

There is little reported information available on industry water reuse in Ireland, neither on the scale and nature of current reuse nor on the treatment and management practices employed. This is a significant gap in knowledge, as EU Directives (e.g. IED 2010/75/EU; EC, 2010) have come into force that require a greater focus on this topic. To address this information gap, the project sought to survey industrial sites in key sectors treating large quantities of wastewater, to assess wastewater quantities involved and to determine if there are any ongoing, or planned, wastewater reuse projects, as well as assess the technologies used and their applications.

Of the 40 chemical sites identified, the survey was sent to 36 firms, as some decided not to participate or could not be contacted. A total of 19 firms completed the survey, giving a 53% response rate. Of the 71 food and drink sites identified, the survey was sent to 61 firms. Of these, 36 completed the survey, giving a 59% response rate. Of the six wood sites identified, the survey was sent to four firms, as two decided not to participate or could not be contacted. Two wood-processing firms completed the survey. Tables 3.1 and 3.2 present the results of the survey, which examined (1) if the firms participated in a water conservation programme; (2) their wastewater flow rates; (3) if they adopted, or are planning to adopt, a water reuse project; (4) their water reuse flow rate; (5) their capital and operating and maintenance costs; (6) their reused water applications; and (7) their adoption of BATs for water reuse.

From the AERs for the chemical and food and drink sectors, the majority of firms reported that they do not participate in an accredited water conservation

Table 3.1. Water reuse in industrial sites

Sector	Chemical		Food and drink		Wood production	
	n	%	*n*	%	*n*	%
Surveys	36	100	61	100	4	100
Responses	19	53	36	59	2	50
Water conservation programme	13	68	32	89	1	50
Average wastewater flow (range), m^3/day	337 (50–1400)		1465 (16–12,500)		(120–1200)	
Water reuse project…	5	26	11	31	0	0
and planning upgrade/expansion	5	26	5	14	0	0
No water reuse…	14	74	25	69	2	100
but plans for future water reuse	2	11	6	17	0	0
Average water reuse flow (range), m^3/day	46 (15–500)		479 (3–1920)		–	
Capital cost of project, €	13k (0–40k)		81.7k (15–250k)		–	
Operating and maintenance cost, €	77.5k (30–175k)		8.6k (0–25k)		–	

3 Food and beverage NACE Codes: 1011, 1013, 1020, 1051, 1082, 1086, 1089, 1091, 1092, 1101 and 1105.

Table 3.2. Water reuse applications in industrial sites

Application	Chemical	Food and drink
Boiler water	2	5
Cleaning	1	7
Cooling	3	5
Irrigation/landscape	1	1
Process input	4	4
Toilets	1	0
Yard/truck washing	1	5
Hydraulic flow	1	0
Cleaning sludge belt press	0	2
Other	0	5

scheme; however, the survey results show that the majority of chemical and food and drink sites operate their own water conservation programme. This is an important first step to reduce water costs and wastewater volumes before adopting a water reuse project. The food and drink sector sites recorded the largest wastewater flow volumes, on average four times higher than those of chemical sites. Over a quarter of chemical and food and drink sites reused treated wastewater on site, and many were planning an upgrade or expansion. The average water reuse project was larger for food and drink sites than chemical sites in terms of water reuse flow and capital cost. Operating and maintenance costs were higher for chemical sites, most likely on account of the higher grade of treated wastewater required for their applications (Table 3.2). BAT conclusions have become mandatory in the permitting/licensing process under Article 14(3) of the IED (2010/75/EU; EC, 2010). The survey asked if industrial sites are addressing the BAT for water reuse in their industry. In the chemical sector just over half of respondents (56%) and in the food and drink sector exactly half of respondents (50%) are addressing the BATs for water reuse in their industry.

3.4.3 *Case studies of industry water reuse projects in Ireland*

Previous studies on water reuse in Ireland have shown a lack of data on water reuse projects and reported that no water reuse takes place. However, the survey of industrial sites undertaken for this project found that there are a number of water reuse projects, of varying sizes, in industry. A lack of awareness of the opportunities for, and benefits of, water reuse is a significant barrier to adoption in industry. Therefore, case studies of best practice water reuse projects in industry were conducted to understand and disseminate the drivers, challenges and processes involved in implementing a water reuse project. Best practice water reuse projects were identified through the industry survey and case studies were developed with companies from the chemical and food and drink sectors.

In the chemical sector, GSK's manufacturing site in Cork operates an MBR system as part of a plant expansion to treat sanitary waste and utility blowdown streams. Analysis of the treated water from the MBR found the water to be of satisfactory quality for use as make-up water for a cooling tower. The project saves GSK 53,000 m^3 of water and €50,000 per annum. In the food and drink sector, Carbery Group invested in RO plants at their headquarters in Ballineen, Co. Cork, to concentrate permeate and to polish water from this process, as well as from various condensate streams on site. The water reuse project led to water savings of 1440 m^3 and cost savings of €365,000 per annum. ABP Food Group is a leading Irish food company regarding environmental sustainability. Its campaign "Doing More with Less" aims to reuse 5% of its water across all sites. ABP has implemented a number of water reuse projects including reuse of treated wastewater in the effluent plant, also used for truck washing and cleaning, at the animal-handling facilities in Waterford and Clones. In ABP Nenagh, the hot water used in the tripe polishing process is reused for the tripe wash; ABP Bandon reuses hot water from the sterilisers in its tripe washing process; ABP Waterford reuses water from the cooling tower to cool the refrigeration compressors; and, at ABP Cahir, rainwater harvesting is used together with treated wastewater for cleaning in the WWTP and chemical make-up. The case studies for these three companies can be found in Appendix 3. Water reuse projects were identified in other sectors; for example, the Green Healthcare project, funded by the EPA and HSE, developed a water efficiency best practice guide for Irish healthcare facilities, which included water reuse case studies for harvesting of RO discharge water in two hospitals (Clean Technology Centre, 2017).

3.5 Opportunities for Water Reuse in Ireland

Although Ireland is a country renowned for frequent rainfall and flooding, the actual security of supply of water services in Ireland is delicate. Water reuse, across both the municipal and industrial sectors, may be a viable option in an integrated water resource management solution for Ireland. Chapter 3 presented the drivers of water reuse in Ireland, in particular pressures on freshwater supplies and increasing demand for water. These drivers are compounded for commercial users, who may face increasing costs and other constraints such as ELVs and sustainability goals.

There are few reported data on water reuse in Ireland, for the municipal or industrial sectors, and previous European studies reported no water reuse for Ireland. As there is an absence of data on water reuse, this may be interpreted to mean that no water reuse practices are employed. Further investigation has found that there is no water reuse from municipal WWTPs in Ireland and that there are no immediate plans to adopt water reuse in the future, as identified in the Irish Water's Water Services Strategic Plan (Irish Water, 2015a) and NWRP (Irish Water, 2017). However, evidence of water reuse was found in water-intensive industries, including the chemical, food and drink, and healthcare sectors.

Looking at the opportunities for water reuse in Ireland in the future, the low-hanging fruit is to expand water reuse schemes in water-intensive industries and sectors. Drivers of water reuse are already evident for industry and the pressures to reuse treated wastewater, such as cost, water scarcity and wastewater ELVs, may increase. However, industrial sites must also take account of the potential impact of water reuse on their wastewater discharge. Reusing wastewater has the effect of concentrating the remaining wastewater not reused, resulting in higher parametric concentrations. These, in turn, can create difficulties for treatment and treatment processes may require upgrading to continue to achieve a defined effluent concentration. It is important to disseminate the ongoing water reuse projects in industry, through case studies and events, as there is little information and few reported data available. This will help raise awareness of water reuse projects in industry and encourage further adoption. No systematic information has been gathered to date on the perceived opportunities and drivers for and barriers to adoption of water reuse in industry in Ireland. This information would improve our understanding from an industry point of view and allow the government to provide the necessary incentives and reduce barriers for companies. This is addressed in Chapter 4, where the results of a survey of drivers of and challenges to the adoption of water reuse in industry are provided.

Water reuse from municipal WWTPs may offer a solution, as part of a wider water management and supply system, for suitable regions some time in the future. Future studies on opportunities for municipal water reuse should consider the following approach. More comprehensive data are required on water-stressed regions in Ireland, which is being addressed by Irish Water. Additionally, regions with a high demand for water and which require alternative water supply sources should be identified. Next, a suitable WWTP that is within relative proximity to areas with high water demands needs to be identified. Larger agglomerations and their WWTPs present the most probable potential sources for treated wastewater to be recovered in future water reuse programmes. For example, areas in the west of Ireland and islands may experience water shortages but these areas may not be suitable for a water reuse project, as there is not a sufficient demand or a suitable WWTP and infrastructure available. Urban areas, which are experiencing water shortages and increasing demand, provide an opportunity for water reuse feasibility studies. Any municipal WWTP water reuse project would need to be investigated in great detail, which is outside the scope of this report. The benefits of reusing treated wastewater must be assessed in relation to the intended application, the cost of treatment and supply, and the potential risk. Additionally, a number of challenges need to be addressed in adopting water reuse, including health concerns, public perception and legislation. Chapter 4 aims to address some of these challenges in the Irish context by engaging with the general public and the key organisations relevant to the potential future adoption of water reuse in Ireland.

4 Stakeholder Engagement

4.1 Introduction

In Ireland, water reuse does take place to a limited extent, mainly within heavy water-using industries; the decision to reuse water within the confines of their site – and managing the issues arising from water reuse – are primarily matters for individual businesses. However, no recycling of water takes place from municipal WWTPs in Ireland, except for small quantities used within the treatment plant site itself, e.g. for filter washing. Wider scale water reuse is an untested concept in Ireland, both in terms of implementation and, perhaps more importantly, in terms of attitudes towards the idea. Therefore, an important aspect of the project was to engage with a wide range of stakeholders, both technical and non-technical, e.g. the general public, the water sector, industry and policymakers. These stakeholders have a role in the possible adoption of water reuse in Ireland and this project aims to gain an in-depth understanding of general public and industry perceptions and attitudes related to water reuse. The project engaged with key stakeholders through (1) a general public survey on attitudes to and awareness of water reuse, (2) an industry survey of drivers of and challenges to the adoption of water reuse in industry and (3) interviews with key organisations and government bodies on the opportunities and challenges, including policy and legislative gaps. The stakeholder engagement with these groups is detailed in the following sections and these provide insights that can be used for future reference, as and when more widespread water reuse may be considered for Ireland.

4.2 Public Survey

4.2.1 Why conduct a public survey?

The circular economy envisages maximum reuse and recycling of natural resources for beneficial use in society. Recycling is a well-accepted concept in Ireland in certain sectors; for example, source separation of domestic waste is now commonplace, including dedicated bins for recyclable products. In water-using industries, there is an increasing level of water reuse (see section 4.3). However, there are no water reuse projects for treated municipal wastewater in Ireland, for any purpose, and there has previously been no significant attempt to understand the acceptability of the idea of water reuse to the Irish public. This is a gap in knowledge that the public survey aims to address.

For successful implementation of reuse schemes, public acceptance is a critical element (Asano, 2001; Po *et al*., 2004; Marks *et al*., 2006). There are ample examples of high-profile water reuse in Australia, the USA and Europe that have failed as a result of severe public opposition (Hartley, 2006; Hurlimann and Dolnicar, 2010). Advertising campaigns with slogans such as "toilet to tap" and "sewage beverage" have obstructed promising projects in a very short period of time. Public acceptance can be elusive and is easily damaged in a long-term process; it is sometimes never achieved in spite of the best plans. Consequently, there is a growing recognition of the importance of more and better community engagement, from the earliest stages, for water reuse projects. The literature contains descriptions of the public engagement that took place for some of those projects. For example, the Monterey County Water Recycling Project took almost 20 years of planning before the project was fully operational in 1998. Every member of the community was told about the value of water by the Irvine Ranch Water District for decades (Crook and Jacques, 2005). As the ultimate beneficiaries (or possibly direct users) of recycled water in the economy, the public must accept the product for the intended purpose before reuse of wastewater can become a reality.

The design of effective public engagement strategies for municipal water reuse projects is outside the scope of this report and, in any event, there are no such planned projects in Ireland, for any purpose, at the time of writing. However, the evidence in the literature highlights the need for such strategies, gives insights into the nature and extent of the processes that would be required, and describes how some processes were flawed. The traditional approach of implementing water reuse by means of a "decide, announce and defend" policy has now been commonly acknowledged as ineffective. The strategy of extensive public education and outreach programmes after the project's conception is also shown to be inadequate (Walesh, 1999; Raab and Susskind, 2009). Another challenge identified is the notion that there is a gap between scientific knowledge and the public understanding of science. This has been coined the information deficit model of public knowledge, as it presupposes that the public has not comprehended the available scientific and technical information. The deficit model has been highly criticised for being overly simplistic and inaccurately characterising the relationship between knowledge, attitudes, beliefs and behaviours, particularly for politically polarised issues such as climate change (Suldovsky, 2017).

Against this background, to gain insights into public knowledge and opinions on this topic, it was decided to conduct the first national public survey on awareness of, and attitudes to, implementing municipal wastewater reuse in Ireland. This is the first such survey in Ireland.

4.2.2 Survey design

Purpose

The overall purpose of the survey was to gain insight into public knowledge and opinions on attitudes and barriers to implementing municipal wastewater reuse in Ireland.

Objectives

The main objectives of the public survey were to:

- assess the level of acceptability of the main water reuse purposes seen internationally;
- gauge opinion on the perceived potential benefits of water reuse in the economy;
- assess the level of concern over commonly perceived barriers to water reuse adoption;
- gauge the level of trust in various bodies regarding water reuse;
- invite open-ended feedback on the overall topic.

Development

A comprehensive literature review was conducted on public perception and previous public engagement exercises in regions developing a water reuse scheme. The findings helped inform the topics to be explored and specific questions asked in the "Water Reuse Public Awareness & Attitudes Survey" (Appendix 4). Preliminary interviews were conducted with small numbers of people to explore the key themes and topics identified and to frame the general level of understanding and key issues on water reuse. From these preliminary interviews and the literature review, a first draft of the survey was developed. A set of demographical questions was included, which correlates with the Central Statistics Office (CSO) database, to enable comparison of the sample in this survey with the Irish population, in order to take account of any potential bias in the respondent group. The survey was iteratively drafted, tested with different small groups and revised, taking feedback into account, to arrive at a final version.

Structure

The survey was structured in three main sections:

1. Background – questions 1–6: age, gender, educational level, location, type of water and wastewater service.
2. Awareness – questions 7 and 8: the level of knowledge of the circular economy and water reuse.
3. Attitudes – questions 9–17: the main questions on attitudes to water reuse: perceived benefits, barriers, concerns and trust.

4.2.3 Survey dissemination

The Water Reuse Public Awareness & Attitudes Survey was conducted between 13 March and 6 April 2018. A structured dissemination and communication campaign took place for the duration of the survey. First, during the first stage of the campaign the project's target audience was defined and sub-target influencer groups were identified. Second, dissemination and communication tools and channels considered to provide the best opportunity for accurately targeting the audience were selected. Third, the chosen methods, which included email marketing, press promotion, website news articles, a social media campaign and other online promotional activities, were implemented.

The survey dissemination objectives were to:

- collect over 1000 completed surveys;
- reach an Ireland-wide demographic;
- engage the general public in the circular economy and water reuse.

The target group was the Irish population aged over 18 years. A range of organisations was identified as appropriate routes for promoting the survey. These included the national and local press, broadcasters, eco-friendly organisations, policymakers, national and local digital influencers, age-friendly organisations, third-level institutions, water-related organisations and agriculture-related organisations. Suitable target messages and social media graphics were designed based on the survey objectives, dissemination media and target market criteria (Appendix 5).

An online survey method was chosen to gain the necessary reach and maximise participation. The survey was distributed through online and offline media, which are detailed in the following sections.

Press release dissemination

A survey press release was sent to contacts at national and local print media.

Nimbus website

The press release was uploaded to the Nimbus website with a link to the survey on 13 March 2018 to coincide with the survey launch. This article was promoted extensively on social media.

Email campaign

A list of target stakeholder groups and influencers was compiled and an email campaign implemented, which included a link to the survey. We included, among other things, all major newspapers, 14 broadcasters, over 30 non-governmental organisations (NGOs), over 50 agriculture-related organisations, over 40 colleges and educational institutions, nationwide IBEC offices, 25 ageing population organisations and over 1300 individual businesses and organisations around the country.

Press and radio coverage

- *Irish Examiner* – 15 March 2018: article by Eoin English publicising the survey.
- *Irish Tech News* – 13 March 2018: article by Ronan Leonard with survey link.
- CRY104fm Radio – 19 March 2018: interview with Dr Eoin Byrne, project researcher.
- CRC1029fm Radio –21 March 2018: interview with Dr Eoin Byrne, project researcher.

Events

- Environ 2018 Conference, Cork Institute of Technology (CIT) campus, 26–28 March 2018: the project team had a stand at the event and spoke in three conference sessions to promote the survey. The event was attended by over 200 people from across Ireland.
- Why Water Matters, Lifetime Lab, Cork, 22 March 2018: this coincided with World Water Day. Project team leader Kevin Fitzgibbon gave a presentation at this event, highlighting the survey.

Social media

The survey was disseminated via social media platforms including Twitter, LinkedIn and Facebook.

Twitter

Extensive targeted Twitter campaign harnessing the extensive CIT and Cork community Twitter networks:

- Key stakeholders and influencers were identified and dissemination lists were compiled. These lists included government representatives and organisations, umbrella organisations, environmental groups, journalists, radio stations, bloggers, age-friendly groups, student bodies, TV stations, broadcasters, etc.
- Twenty-seven tweets directly relating to the survey were published via the Nimbus Twitter account during the campaign, resulting in 431,849 impressions overall.
- A promoted tweet campaign was implemented via the CIT Twitter account.
- A Twitter direct messaging campaign was implemented in which key stakeholders were directly mailed with a request to disseminate the survey.

- A #WorldWaterDay Twitter campaign was devised and implemented to exploit the day's international water theme, earning 19,781 Twitter impressions for the day. The campaign gained excellent traction and was picked up by important influencers such as several high-profile media professionals, who then produced their own tweets to promote the survey on the day, greatly expanding the reach of the campaign.

Twitter analytics

- Total potential reach: 431,849 impressions
- Reach from Nimbus tweets: 290,785 impressions
- Reach from external user tweets: 141,064 impressions
- Largest reach from Nimbus: 24 retweets with 60,050 impressions

Survey prize – Cliff House Hotel, Waterford

To incentivise respondents, a prize of an overnight stay at the 5-star Cliff House Hotel which is a member of the Green Hospitality programme, was chosen.

CIT master's degree in international business collaborative dissemination project

The 2018 class of the CIT master's degree in international business were assigned tasks for the water reuse survey as part of their sustainable business module. These tasks included dissemination of the survey (offline) to students and aged citizens. Three teams of three were set this task and each was given 100 printed surveys to distribute to respondents offline. The purpose of this task was to reach respondents who either are computer illiterate or do not have access to the internet. Overall, 300 responses were collected from the students.

4.2.4 Analysis of results

Data analysis approach

The survey data were analysed for insights into the level of awareness of and attitudes towards water reuse among the respondents. The respondent demographic data on gender, age and education level were correlated with CSO census data to extrapolate the survey sample data to the population. This removed sampling bias for over- and underrepresented groups. Various insights have been drawn from the answers and from correlations between different answers. The comments fields were analysed to identify recurring themes. In total, there were 1102 respondents. It should be noted that a significant group of people who responded to the survey appear to be from a technical background, i.e. engineering or environmental science; people with third-level qualifications, including up to PhD level, were strongly represented in the respondents.

Survey section 1: background

Survey section 1 captures demographic data on the age, gender, educational level and location of respondents as well as on the type of water services serving their residence. The location question differentiated between various cities in Ireland, towns with a population of over 1500 and rural areas, including smaller towns. The vast majority of city and town respondents had a public mains water supply, at 85% and 86%, respectively; only 36% of rural dwellers had a public mains water supply, with 19% served by group schemes; and 45% of rural-dwelling respondents' water supplies came from other private sources. For wastewater, the large majority of city and town respondents, 80% and 76%, respectively, reported having connections to a public sewerage scheme from their dwelling; in contrast, septic tanks and other individual treatment systems were used by 80% of rural respondents.

Survey section 2: awareness

Section 2 consisted of two questions aimed at understanding the level of awareness of the main concepts involved in the survey: the "circular economy" and "wastewater reuse". After each question in this section a brief introduction to the concept just asked about was provided, in order to introduce ideas and define the terms being used in the later survey questions (Appendix 4). The main findings of section 2 are described below.

> Q7: How familiar are you with the concept of the circular economy?

Half of the respondents (50%) were “unfamiliar” with the circular economy concept. Only 13% described themselves as “familiar” with the concept and 37% were “somewhat familiar”.

> Q8: How familiar are you with the concept of water reuse from wastewater treatment plants?

A quarter of respondents said that they were “familiar” (25%) with this idea; 27% were “unfamiliar” and 46% were “somewhat familiar”.

Survey section 3: attitudes

Section 3 consisted of eight questions aimed at understanding the attitudes of respondents to water reuse as well as a final open comments field (Q17). The eight questions were mostly structured in a scale format (e.g. “unacceptable” to “acceptable”; “very low” to “very high”; “strongly disagree” to “strongly agree”). The results are as follows.

> Q9: Do you think it is acceptable or unacceptable to use treated wastewater for the following applications?

There were 11 possible uses listed under this question, which was intended to stimulate nuanced answers relating to water reuse purpose. Most uses showed good levels of acceptability (*c*.62%–82%) (Table 4.1). The significant exception was for reuse as drinking water, at just 19.6% “acceptable”, with over 55% selecting “unacceptable” and *c*.25% replying “maybe”. The use of reused water for agricultural irrigation for food production was reported to be “acceptable” by 42.1%, with 39.1% selecting “maybe”, indicating at least some degree of openness to the idea of water reuse for this purpose.

> Q10: There are potential benefits from the reuse of water from treatment plants. Please indicate your level of agreement with the statements below.

There were four possible benefit statements listed for feedback in this question, plus an open field for “other benefits”. The feedback is summarised as follows: for simplicity “strongly agree” and “agree” are grouped, as are “disagree” and “strongly disagree” and “neither” and “don’t know” (Table 4.2). Benefit statements have been summarised. Comments are analysed in the next section of this report. This question shows

Table 4.1. Potential water reuse purpose

Potential water reuse purpose	Acceptable (%)	Maybe (%)	Unacceptable (%)
Car washing	77.0	6.3	16.7
Agricultural irrigation for food production	42.1	39.1	18.5
Agricultural irrigation for non-food production	65.9	18.7	15.6
Landscape irrigation	74.6	9.2	16.4
Fire protection systems (in buildings)	73.9	13.8	12.6
Street cleaning	77.6	6.4	16.1
Toilet flushing	82.0	5.0	13.2
Drinking	19.6	24.7	55.3
Private garden watering	67.1	16.1	16.8
Industrial and commercial usage	61.9	29.7	8.4
Environmental enhancement (wetland restoration)	64.6	26.1	9.4

Table 4.2. Benefits of water reuse

Benefit statement: The reuse of water will/is ...	Agree (%)	Neither (%)	Disagree (%)
Address increasing demand for water	92.2	4.9	3.0
Address climate change impact on water supplies	79.9	16.4	3.8
Good for the environment, reducing reliance on fresh water supplies	95.2	3.6	1.1
More environmentally sustainable than discharging treated wastewater	92.3	6.0	1.6

strong agreement with all benefit statements for water reuse, which is a significant finding. There is a clear recognition of potential positive impacts among respondents.

> Q11: There are potential barriers to acceptance of water reuse in Ireland. Please indicate your level of agreement with the statements below.

There were seven potential barriers listed for feedback in this question, plus an open field for "other barriers". The intention was to understand the degree of perceived obstacle to the deployment of water reuse in Ireland arising from these issues. The feedback is summarised as follows, with answers grouped as in Q10. Barrier statements have been summarised. Comments are analysed in section 4.2.5.

It is notable that there is high disagreement with the suggestion that Ireland has enough rainfall and does not need water reuse (60.0%) (Table 4.3). This suggests a reasonable awareness of water-related issues. Furthermore, there is a nuanced reply to the statement on health concerns; "disagree" (41.3%) was selected by more respondents than "agree" (33.7%), which seems to show a degree of understanding that wastewater can be treated to a standard that is safe for human contact – if not necessarily for drinking. This is supported by the responses to the statement, "No confidence in the standard of treated water for any purpose". Over half of respondents who answered the question (51.9%) disagreed with this statement, which can be interpreted as showing that there is at least some level of confidence in the standard of treated water that can be achieved, to reuse water for at least some suitable purposes.

There is also some nuance in the two statements that relate explicitly to cost. In total, 69.6% "agreed" with the statement, "Investment should be prioritised for repairing existing pipework". However, a high percentage of respondents to the statement "The extra cost of infrastructure would be too high" answered "don't know/neither agree nor disagree" (48.5%) and, in fact, more respondents "disagree" (32.9%) than "agreed" (18.5%) with this statement. This seems to indicate that, although immediate investment should target pipe repairs, in the future there may be a degree of openness to investing in water reuse projects on the part of the public.

Finally, it appears that levels of concern are relatively low around environmental impacts of reused water, with 43.7% disagreeing with the relevant statement, "There may be negative environmental impacts from water reuse for irrigation or wetlands". A significant number (43.3%) indicated that they would need further information if they were to become confident in water reuse.

> Q12: All public mains-supply water is treated to a drinking water standard and is currently used for all purposes. Do you think it is necessary to use drinking water for the following purposes?

There were nine potential uses for recycled water listed in this question, with simple "yes", "maybe" and "no" options. In part, this question served as a cross-check for Q9, with the rationale being that, if respondents considered water reuse acceptable for a particular purpose, then there should be a correlation with answers of "no" to Q12. It also sought to understand the degree of nuanced thinking by respondents regarding how water is used generally, particularly mains-suppy water from treatment plants.

Table 4.3. Barriers to water reuse

Barrier statement	Agree (%)	Neither (%)	Disagree (%)
Ireland gets a lot of rain; we don't need water reuse.	21.1	18.9	60.0
I have health concerns over any human contact with treated water even if treated to a high standard.	33.7	25.0	41.3
I don't know enough about wastewater treatment to be confident in reuse.	43.3	27.4	29.1
The extra cost of infrastructure and treatment would be too high.	18.5	48.5	32.9
I have no confidence in the standard of treated water for any purpose.	18.4	29.7	51.9
There may be negative environmental impacts from water reuse for irrigation or wetlands.	16.5	39.7	43.7
Investment should be prioritised for repairing existing pipework.	69.6	22.8	7.4

There was a comparatively low "no" response (40.0%) for food-producing agricultural irrigation compared with the other water reuse purposes (Table 4.4). This is consistent with the results of Q9, in which water reuse for this purpose was "acceptable" to 42% of respondents who answered the question. On the other hand, 27.6% of respondents answered "yes" to this question, leaving aside the detail that other sources of irrigation may not be up to drinking water standard. In the context of this survey it is clear from this response that there are higher levels of sensitivity around water quality for this purpose than for any other, except drinking. The other main insight is that a majority of respondents would accept that lower grade water, i.e. not drinking water, can be used for most purposes listed.

Questions 13, 14 and 15 are based on the theory of planned behaviour, which identifies precursor variables for behavioural intention to act; this can be used to understand what drives people to show a specific behaviour and can be useful in designing behavioural change interventions. These questions also act as cross-checks on previous answers, such as for Q10. The answers to these three questions are summarised below and in Table 4.5; for simplicity, "strongly agree" and "agree" are grouped as are "disagree" and "strongly disagree" and "neither" and "don't know".

> Q13: Reusing water from wastewater treatment plants is a good idea.

This statement is intended to show the attitude of the respondents; 87.5% replied "agree" or "strongly agree", which indicates a generally positive attitude towards wastewater reuse among most people.

> Q14: Most people whose opinion I value would approve of reusing water from wastewater treatment plants.

This statement is a normative question; 62.5% of respondents answered "agree" or "strongly agree". Role models and normative communication would be expected to influence the behaviour of almost two-thirds of people.

> Q15: Within my household, the choice to reuse water from wastewater treatment plants should be up to me.

This statement aims to assess "perceived behavioural control". It measures the need for personal control over a certain matter or behaviour. The fact that 57.3% answered "agree" and "strongly agree" shows a strong desire among a majority of people to be able to choose if recycled water is reused at home.

Table 4.4. Necessity of using drinking water for the following purposes

Purpose of use: Is drinking water necessary for ...	Yes (%)	Maybe (%)	No (%)
Agricultural irrigation – food production	27.6	32.5	40.0
Agricultural irrigation – non-food production	4.9	18.2	77.0
Landscape irrigation	7.0	9.1	84.0
Fire protection systems	10.6	12.3	77.2
Street cleaning	8.8	5.7	85.7
Toilet flushing	9.3	9.1	81.8
Car washing	9.7	5.3	85.0
Private garden watering	4.8	17.0	78.5
Industrial and commercial use	9.4	29.2	61.6

Table 4.5. Responses to questions 13, 14 and 15

Statement/question:	Agree (%)	Neither (%)	Disagree (%)
Q13: Reusing water ... is a good idea	87.5	9.5	3.2
Q14: Most people whose opinion I value would approve ... of water reuse	62.5	34.2	3.6
Q15: Within my household, the choice to reuse water ... should be up to me	57.3	26.0	17.0

Q16: The future adoption of water reuse in Ireland would involve many stakeholders. Please indicate the level of trust you would have in the following stakeholder groups.

The final question, apart from the open comment field, asked about the level of trust that respondents would have in the main stakeholder types that might become involved in either informing people about, or delivering, any future water reuse programmes. The results are summarised in Table 4.6.

The highest-scoring group is academic experts, with 78.5% of respondents expressing "very high" or "high" levels of trust in this group, followed by the EPA (70.5%) and industry experts (63%). The respondents had the least amount of trust in news and media outlets, with 45.9% in the "low" or very low" category, followed by Irish Water (38.2%) and the government (26%).

4.2.5 Survey comment fields

The public survey contained three open fields for comments, as follows:

- Q10: Potential benefits from the use of water from treatment plants: other benefit (please describe).
- Q11: Potential barriers to acceptance of water reuse in Ireland: other barrier (please describe).
- Q17: Are there any other comments you would like to make?

Summary statistics on comments received are provided in Table 4.7.

Discussion of Q10 "other benefits" comments

There were a number of other potential benefits from water reuse that survey respondents listed. The following are the main themes among the answers received.

- Potential cost reduction in the overall supply of water/economic benefit: 34.9%. Respondents thought that cost reductions might occur for a variety of reasons, from reduced operating costs for treating drinking water to avoiding building new large infrastructure to develop new water sources.
- Greater public knowledge and awareness: 22.2%. The public educational outcome regarding water reuse and resource conservation was viewed as a positive benefit in itself by a number of respondents.
- Reduced stress on natural water resources: 15.6%. Some respondents identified the combined water and nutrient reuse value of recycled water

Table 4.6. Stakeholder level of trust

Stakeholder level of trust	Very high (%)	High (%)	Average (%)	Low (%)	Very low (%)
Government	4.0	21.4	48.4	20.1	5.9
Non-profit environmental organisations	11.7	41.8	39.0	5.2	2.3
Academic experts	25.7	52.8	19.6	1.6	0.5
Local authorities, e.g. county councils	4.0	28.7	43.7	15.8	7.8
Irish Water	7.9	25.3	28.8	19.9	18.3
News and media	1.5	11.8	40.4	30.2	15.7
Industry experts	17.9	45.1	28.0	6.2	2.8
EPA	28.5	42.0	25.7	1.4	2.7

Table 4.7. Summary data for survey comments

Survey section	Number of responses
Survey responses received (total)	1102
Comments to Q10 – "other"	83
Comments to Q11 – "other"	71
Comments to Q17[a]	166

[a]This excludes "no" and "thanks" comments.

for agricultural purposes; others focused on the potential benefits of avoiding higher abstraction from natural resources, reducing the discharge impact from WWTPs or potentially avoiding large new infrastructure projects.

- Water facilities/standards: 4.4%. One benefit suggested was that water reuse would require/drive higher standards in WWT.
- Increased employment: 4.4%. It was suggested by some respondents that water reuse measures could lead to employment opportunities.
- Rainwater harvesting: 5.6%. Some respondents suggested that greater use be made of rainwater harvesting or specific uses for recycled water.

Discussion of Q11 "other barriers" comments

There was a high level of overlap between comments in Q11 and those in Q17. People who gave comments in Q11 also tended to add a comment in Q17; comments to Q11 were generally echoed in Q17, both in content and in themes raised. The main themes raised were:

- lack of public awareness/understanding (29.6%);
- the need to repair existing infrastructure (22.5%);
- recycled water quality concerns (19.7%);
- low confidence in the relevant authorities (9.9%);
- potential cost to implement (8.5%).

Discussion of Q17 comments

There were a number of recurring themes in the comments posted in the final open question, Q17; these are summarised in Table 4.8. Many comments address more than one theme.

Other themes/insights included:

- the suggestion that pilot schemes could/should be used to trial water reuse (1.8%);
- concerns that a dual water mains distribution system (i.e. potable and recycled water pipes) could give rise to cross-connection, i.e. tapping into recycled water instead of potable water pipes in error;
- a suggestion that grey water reuse could be considered at a domestic level.

It appears that at least 15 people (10%) who posted comments were from a related technical background. Some respondents stated this explicitly, whereas the background was inferred from the content of posts or email addresses provided in other cases. However, the actual number may well be higher given the technical detail in certain comments.

4.2.6 Public survey summary

Section 4.2 has described the background, design, dissemination and analysis of the public survey conducted as part of this project. The idea of water reuse is broadly seen as positive, for several reasons, and there is a high level of openness to many possible uses. The data indicate that drinking water reuse is not acceptable to the public and that many people remain doubtful or negative towards food production reuse.

There is a high level of consistency between the comments in terms of themes raised and opinions given across the three comments sections. There is strong agreement that public education, awareness and acceptance of water reuse will be essential for the success of such programmes. There is also a common thread of concern over the quality of the treated water and its potential impact on human health. Finally, there is a strong theme suggesting that other policy and investment priorities should take precedence, be that rainwater harvesting or, most significantly, repairs to existing infrastructure, such as leaking water mains. These themes in the comments are closely matched by the statistical results in section 4.2.4. For example, for Q11, almost 70% of respondents agreed with the statement "Investment should be prioritised for repairing existing pipework" and this subject was also one of the top five themes in the open comments in Q17. However, regarding the cost–benefit issue, there is also a significant number of comments suggesting that there could be cost savings to be made from reusing water, a question that falls outside the scope of this report. For this project, no analysis has been made of the relative economic case for water reuse versus other investment areas, on either a capital investment or an operational cost basis.

Although no water reuse projects are currently being planned, it is hoped that the results of the survey will serve as a useful reference point for future planning, in that they highlight the key issues around and concerns of the Irish public towards water reuse.

Table 4.8. Themes in Q17 survey comments

No.	Themes	Occurrence, % (*n*)
1	"*Water reuse is a good idea*" Many comments either stated this view explicitly or clearly implied it, for example on the principles of reducing waste, or conserving natural resources. However, a number of the same comments also expressed concerns, as described in the other themes in this table. Therefore, although there is a good level of positive disposition to the idea of water reuse in the comments received, the support is highly qualified	32.5 (54)
2	"*There is/will be a need for public education and good communication for water reuse to be successfully adopted*" If water reuse measures are planned in future, many respondents stressed that strong public engagement programmes will be needed so that people can understand clearly the need for water reuse and the water quality issues arising, and so that they have trust in both the intended uses and the authorities delivering such measures. It was also suggested that education programmes on water reuse in schools would be beneficial in the long term	20.5 (34)
3	"*There are chemical or biological contaminants that might be in reused water even after treatment; I would have concerns about health risks, e.g. if there were human use of or contact with such water*" A range of potential residual contaminants in reused water was mentioned in various comments as being of concern; these included plastics, pharmaceutical residues, various pathogens and other exotic compounds. This arose from a lack of confidence in either the inherent technical capabilities of WWT processes or the operation of them. The detail in such comments implies a level of technical knowledge consistent with the respondents having a technical/water professional background in a number of cases	18.1 (30)
4	"*Other investment priorities are more urgent, particularly leak reduction in water mains*" Comments on this theme explicitly stated the view that water investment should focus on other priorities; the most common suggestion was that reducing leakage in water mains should be the top priority. Some comments flagged the apparent contradiction of suggestions to reuse treated water to reduce waste while the potable water network has the level of leakage that is reported at the time of writing	13.9 (23)
5	"*The cost of the necessary infrastructure for water reuse would be too high and bad value for money*" These comments are related to the theme 4 comments, but more explicitly question the costs involved for additional treatment and for the new treated water distribution infrastructure that would be required for water use measures, relative to the benefits that would be delivered	9.6 (16)
6	"*There should be charges for drinking water provision*" This view was explicitly stated or clearly implied in these comments and included suggestions for incentivising people to make use of recycled water, e.g. a cheaper price or making it free	5.4 (9)
7	"*Rainwater harvesting should be promoted/incentivised*" These comments are related to those under theme 4, namely that rainwater harvesting should receive a higher priority than water reuse and that this should be more widely adopted, particularly for households, either in regulations for new builds or by incentivising retrofit measures	4.8 (8)
8	"*It will be important to adopt water quality standards and guidance for recycling of water*" The respondents making these comments appear to have relevant water sector knowledge – they are aware that standards do not exist at present for water reuse and commented that different standards will apply depending on the application for which the water is intended	4.2 (7)

4.3 Industry Drivers and Challenges

The industry survey (see section 3.4 of this report) also assessed the drivers for and challenges to water reuse projects, and whether or not water reuse is a viable option for sites in the chemical ($n=18$), food and drink ($n=30$) and wood, paper, textiles and leather ($n=1$) sectors.

Figure 4.1 displays the most important drivers for these water-intensive industries, namely (1) organisational goals around sustainability or environmental protection set by companies, followed by (2) wastewater effluent limits for sites and (3) technological advancements, e.g. lower costs of treatment systems. The least important drivers are the availability of grants, loans and incentives and the high cost of water. Companies adopting water reuse seem to be driven by their own organisational goals, primarily because a key driver of water reuse internationally, the cost of water, is not present. Wastewater effluent limits is another important driver, particularly for the food and drink sector, and may limit a site's ability to expand its production; water reuse is a potential solution to reduce wastewater flows to allow

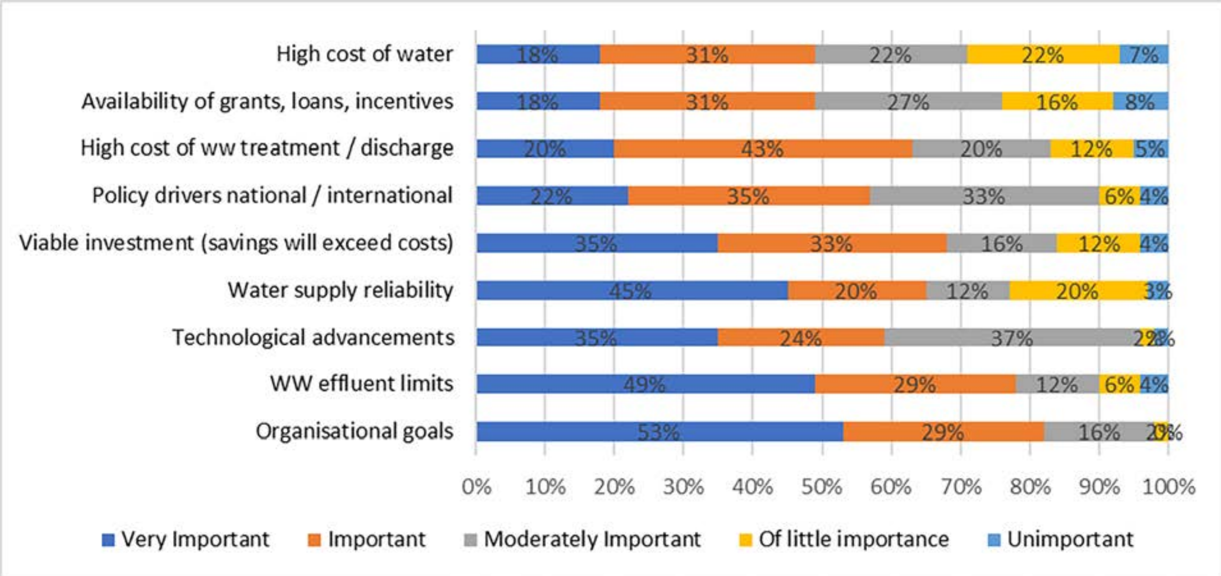


Figure 4.1. Importance of drivers for water reuse in industry. WW, wastewater.

for expansion of production. It is not recommended that the government subsidises water reuse projects in industry, as it is not a key driver for its adoption.

Figure 4.2 displays the most important challenges for industry. These are (1) reputation/health risk (i.e. the risk of product becoming contaminated by reused water), followed by (2) the inability to meet regulatory or required water quality standards and (3) the high capital costs of investing in water reuse projects. The least important barriers for industry are public opinion (i.e. opposition by the public, stakeholders or elected officials) and the availability of water (i.e. water scarcity is not an issue in Ireland). The risk of a product becoming contaminated is of concern to industry, particularly for those sectors that produce products for human consumption, where the quality of product is of upmost importance. However, public opinion and opposition to water reuse projects is not considered a barrier. Companies believe that there is a high CAPEX cost to water reuse projects; conversely, the lack of available funding is not considered a barrier. Promotion of case studies of water reuse projects from different industries documenting the capital investment and payback may address this. Additionally, if the cost of water increases for industry, which is possible in the near future with the harmonisation of water rates across counties, this will reduce the payback time for capital investments in water reuse projects.

Survey respondents were asked about the viability of water reuse for their sector. Forty-four per cent of chemical sector respondents believe that water reuse is a viable option. The key reasons given that it is not a viable option are the strict control of inputs to the processes and the upmost importance of quality. However, water reuse for non-process applications, such as boiler water, cleaning or toilets, may be applicable. Other respondents noted that there is a lack of knowledge on site as well as insufficient standards or guidance. Finally, the availability of water and potential for using rainwater were also noted.

Eighty per cent of respondents in the food and drink sector believe that water reuse is a viable option for water resource management. The key barriers to adopting water reuse practices noted by the respondents relate to the risk of product contamination and the quality restrictions for using treated wastewater in food processes. One respondent called for water reuse standards for the industry: “Until a standard is commonly known it [water reuse] will not be carried out by the majority of companies in the industry due to fears over contamination”. A factor to consider for many sites is the high capital costs versus the return on investment, but this may be related to applications where the water must be treated to a high standard or potable reuse. However, applications other than being directly involved in production were highlighted, such as boiler water, washing and toilets. Finally, one respondent was “unsure of any other case studies in the area”. Therefore, increasing the awareness of water reuse projects in industry may be of benefit.

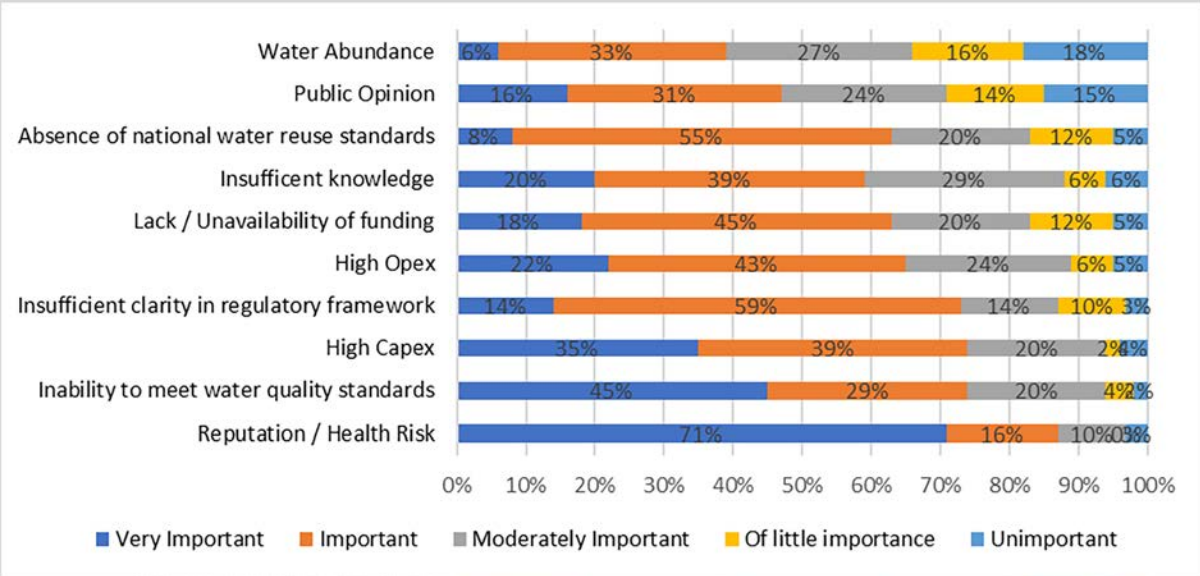


Figure 4.2. Importance of barriers to water reuse in industry.

4.4 Key Organisation Stakeholders

As part of the stakeholder engagement, interviews were conducted with high-level stakeholders to understand the opportunities for and challenges to adopting water reuse in Ireland at present and in the future, if any. Key organisations that have a role in the current, and future, adoption of water reuse in Ireland were identified, including Irish Water, the EPA, the Department of Housing, Planning and Local Government (DHPLG), the Department of Agriculture, Food and the Marine (DAFM), Teagasc, Bord Bia and the Sustainable Water Network (SWAN). Relevant people from these organisations were interviewed to discuss key topics from the literature review of international water reuse practices (Chapter 2) and from examining the current level of, and opportunities for, water reuse in Ireland (Chapter 3). The stakeholders were asked for their opinions on the drivers for and barriers to water reuse, in particular the policy and legislation gaps. They were invited to provide their opinion on the opportunities for water reuse in Ireland, if any, for the most common reuse applications internationally: agricultural irrigation (32%), landscape irrigation (20%), industrial uses (19.3%), non-potable urban uses (8.3%), environmental enhancements (8%), recreational uses (6.4%), indirect potable reuse (2.3%), groundwater recharge (2.1%) and others (including direct potable reuse; 1.5%) (Lautze *et al.*, 2014).

In Ireland, the opportunities for reuse of treated wastewater for irrigation are very limited, as food or non-food crops do not require additional irrigation on account of the high rainfall. There is also very little irrigation of public parks and green areas in Ireland; thus, there is no demand here for water reuse. Crops that do require supplementary irrigation are high-value products, which would not use treated wastewater, as it does not align with a high-quality product. Furthermore, water is an important vehicle for the introduction of hazards (e.g. pathogenic bacteria, viruses and parasitic organisms, such as *Cryptosporidium*). Under current Irish and EU legislation, clean or potable water must be used in the production of horticulture products whenever necessary to ensure that foodstuffs are not contaminated. Where potable water is not used, it must be demonstrated that clean water used does not contain microorganisms, chemical contaminants or other harmful substances that could affect the safety of the produce (EU, 2004; EC, 2015). National guidelines are provided for limits of *E. coli*, as an indicator of faecal contamination, in fresh food produce (FSAI, 2016). Treated wastewater to be reused for horticulture must take account of these regulations and guidelines. The level of risk of contamination from water will depend on the source (treated wastewater), method of application during irrigation (overhead, furrow, drip, etc.), the activity (irrigation, washing, misting, etc.) and the type of crop (ready-to-eat, sometimes eaten raw, always cooked) (Bord Bia, 2017). Bord Bia, the

Irish Food Board, aims to promote, assist and develop the marketing of Irish food, livestock and horticultural produce. It is also under their remit to operate quality assurance schemes to maintain or improve the quality of Irish food and horticulture, such as the Origin Green programme. Bord Bia provides guidance and requirements for water use with fresh horticulture produce through the Sustainable Horticulture Assurance Scheme (Bord Bia, 2017).

Additionally, there is increasing concern regarding the ability of WWT to completely remove CECs, including pharmaceuticals, antibiotic-resistant bacteria and resistance genes (ARB&Gs). Current WWT methods may only partly remove pharmaceuticals, meaning that residues are still present in effluent. This is of particular concern for crops that are eaten raw. Knowledge on the actual effects of water reuse with regard to these aspects is currently not consolidated. Current research is examining the antibiotic resistance in treated wastewater and potential uptake in crops through an EU COST Action, NEREUS (http://www.nereus-cost.eu), of which Teagasc is a member. *Ireland's National Action Plan on Antimicrobial Resistance 2017–2020* (Department of Health, 2017, p. 60) acknowledges that "in agriculture a holistic approach to biosecurity and animal husbandry by stakeholders with a focus on disease prevention and control strategies are integral to addressing the development and spread of AMR [antimicrobial resistance]". A large EPA-funded project by the National University of Ireland (NUI) Galway, AREST, will examine the role that the environment plays in the transmission of antimicrobial resistance.

Forestry, in terms of afforestation and felling, does not entail water use in Ireland and thus water reuse as such. Forestry has the potential to mitigate flooding by regulating water runoff from land, and equally the reverse occurs at times during ground preparation for afforestation or clear felling.

Industrial use of treated wastewater, from municipal WWTPs and internal recycling, is a common application internationally. The stakeholders interviewed stated that internal recycling of wastewater in industry is the most suitable opportunity for water reuse in Ireland, as there are drivers for water reuse in industry, i.e. organisational goals and wastewater effluent limits (section 4.3), and many of the challenges of water reuse from municipal WWTPs are not applicable.

Farms that are using large volumes of water, e.g. for dairy, beef, pig and poultry production, present an opportunity for water reuse in Ireland according to some stakeholders. An example is dairy farms, where the water from the plate cooler, i.e. the cooling mechanism for milk, can be reused for drinking and washing. Sustainable Irish food production is of increasing importance for the agriculture sector and the government. Food Wise 2025 sets out a 10-year plan for the agri-food sector and has sustainability as a key driver for Irish agriculture and its plan for future growth (DAFM, 2015). Additionally, Bord Bia's Origin Green programme aims to drive improvements and efficiencies in water use and wastewater.

From a legislation perspective, there is no European, or Irish, directive for water reuse. One stakeholder stated that the option to reuse treated wastewater should be left up to each individual Member State. The European Drinking Water Directive (Council Directive 98/83/EC) is currently being revised, which may be of relevance to future water reuse projects. The Drinking Water Directive, on the quality of water intended for human consumption, is designed specifically to protect people from the adverse effects of drinking contaminated water by ensuring that it is wholesome and clean. In general, the Directive has been relatively well implemented by Member States, but its approach to monitoring quality at the point of consumption uses parameters determined over 20 years ago. This calls for an examination of whether or not the Directive will deal effectively with existing and emerging pressures in the EU for decades to come. The proposal includes the introduction of standards for 10 new chemical parameters, namely beta-oestradiol, bisphenol A, chlorate, chlorite, haloacetic acids, microcystin-LR, nonylphenol, polyfluoroalkyl substances (PFAS) (individual), PFAS (total) and uranium.

The River Basin Management Plan for Ireland 2018–2021, published in 2018, aims to publish legislation to develop a register of water abstractions greater than 25 m^3/day (DHPLG, 2018). This equates to the total daily water usage of approximately 100 households. It will probably affect half of group water schemes, as well as farmers with over 200 dairy cows, golf courses, quarries and those producing concrete products, and industry. Currently, no charging for water abstraction is envisaged. In the case of larger scale abstractors, however, it is likely that a licensing fee will apply to cover the administrative costs of the licensing system.

In the future, this may increase the drivers for water reuse in industry if abstraction charging becomes more onerous.

Another challenge related to water reuse identified by stakeholders was providing a dual piping system if the water is to be treated to different standards for various applications, as the cost of treating wastewater to a drinking water standard is very high. The Minister for Housing, Planning and Local Government, Eoghan Murphy, was asked his views on a matter regarding drinking water and stated that:

> The suggestion of retrofitting a new dual system of distribution pipes for treated and untreated water across the public water network nationally would be economically prohibitive and massively disruptive. Irish water is currently managing 88,000 kilometres of pipe network, which is largely underground and concentrated in densely populated towns and cities, together with some 7,000 water and wastewater assets nationwide. The immediate priority in conservation terms will continue to be the ongoing national Leakage Reduction Programme. This will include investment of some €250 million over the next four years under the Find and Fix repair scheme and the Water Mains Rehabilitation programme. (Murphy, 2018)

This outlines the Irish Government's current position, which is that retrofitting a new dual system of pipes is not seen as economically feasible. The present focus is on fixing leaks, which is also a key concern of the public (section 4.2). Other solutions to employ a dual piping system exist, for example, utilising the existing pipelines to transport water of lower quality to where it needs to be and then treating a small part of it to drinking water standard for domestic use by means of point-of-use, decentralised treatment systems. For households, this could mean that water is sent from the distribution system directly to the toilet, the garden hose and the washing machine, but treated to potable standards before reaching the taps and shower in the house. This would also be disruptive, but there would not be a need to double the public network.

In discussions with key stakeholders, a number of relevant views were expressed; the main points are described here. The first is that, if there are any possibilities for water reuse from municipal WWTPs, it will be in the long term, as there are more pressing water sector priorities at present, such as reducing the number of leakages. In addition, water is a relatively abundant resource, thus reducing the pressure for reuse. Key to assessing whether or not water reuse is a viable option for Ireland is taking a risk-based approach. The risk associated with using treated wastewater must be assessed in comparison with the need for water. In other countries where water reuse is practised, there is a serious need on account of water shortages. If Ireland does not have sufficient water scarcity challenges, there is not a reason to introduce potential risks from contaminants in treated wastewater.

In view of these findings, it would appear that the outcomes from this report will probably form a baseline for future policy development, rather than act as a spur for immediate or short-term policy development.

5 Technology Assessment

5.1 Introduction

Recycling and reuse are central to a circular economy approach and offer a strategy to improve water supply by managing wastewater better. Such a strategy must ensure that the treated wastewater is safe for its intended application. Therefore, the WWT, or combination of treatments, applied for water reuse will depend on the quality and quantity of wastewater, the final quality required for the specific applications, the economic cost and the environmental impact (Alcalde Sans and Gawlic, 2014). Treatment of wastewater for reuse can require additional treatment beyond that required to achieve the minimum quality standards for wastewater (i.e. in addition to the common primary and secondary-stage treatments, depending on the use envisaged), usually to remove pathogens and chemical contaminants. Treatment technologies used for water reuse purposes are embedded in WWT schemes. WWT levels are generally classified as preliminary, primary, secondary, tertiary and advanced, although tertiary and advanced are often combined.

Technologies to treat water to the quality required for reuse are generally focused on secondary treatment through to advanced treatment schemes. Secondary treatment is the biological removal of biodegradable organic matter and suspended solids and includes suspended growth (activated sludge, AS), attached growth (rotating biological contactors, RBC; moving bed biofilm reactor, MBBR), hybrid processes and lagoons (waste stabilisation ponds, WSPs). It can also include nutrient removal (nitrogen and/or phosphorus). Consideration of the range of secondary treatment processes lies beyond the scope of this report; however, their common feature is treatment of wastewater to a similar water quality standard.

Implementation of advanced water treatment technologies is highly dependent on the final application of the treated water. As opposed to secondary treatment, advanced treatment involves the removal of total dissolved solids and/or trace constituents as required for the specific water reuse application. Membrane technologies are therefore used in advanced treatment for the removal of the dissolved solids, which can either be pressure driven, such as MF, UF, nanofiltration (NF) and RO, or electrically driven (electrodialysis, ED). Many factors may affect the choice of water reclamation technology, which include (1) the type of water reuse application; (2) the reclaimed water quality objectives, i.e. wastewater characteristics of the source water; (3) compatibility with existing conditions; (4) process flexibility; (5) operating and maintenance requirements; (6) energy and chemical requirements; (7) personnel and staffing requirements; and (8) residual disposal options and environmental constraints (Asano *et al.*, 2007).

A treatment train is a sequence of WWT techniques that are designed to meet the needs of a particular environment in order to maximise results. A treatment train can include one or multiple treatment technologies in sequence. Choice of treatment train and treatments included in the sequence is highly dependent on a number of the previously defined factors. Figure 5.1 presents typical schemes for treatment trains used in water reuse. Some or all of the numerous steps represented under advanced processes may be employed, depending on the end product water quality desired and on whether or not engineered natural processes are also used. Not all possible combinations are displayed here.

Technologies to facilitate water reuse make up an advancing and innovative sector, with much focus on developing new technologies as well as improving the energy efficiency of existing technologies. Chapter 5 presents the current and developing technologies and treatment for water reuse and makes recommendations that may be applicable in an Irish context.

5.2 Technology Assessment Methodology

Several technologies to enable water reuse are either already commercially available or in development. Biological WWT standards are currently very high and treated wastewater from such facilities is normally up to a high standard with regard to solids, organics and nutrient removal. There may, however,

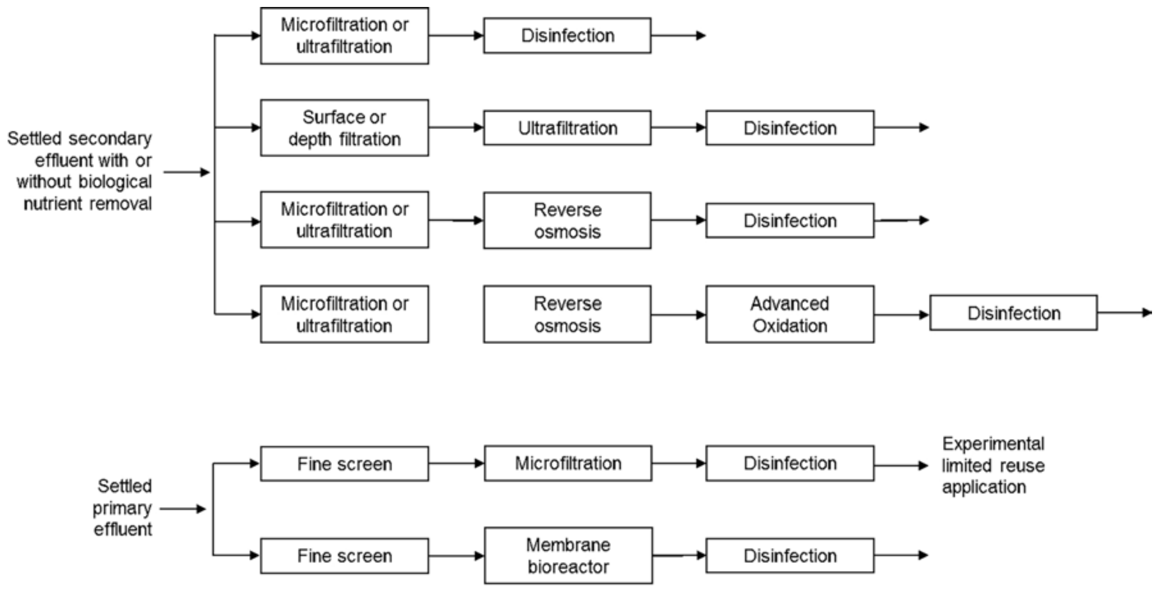


Figure 5.1. Typical schemes for water reuse processes (NRC, 2012).

be issues regarding microbiologicals, inorganics or micropollutants remaining in the treated water. Therefore, enhanced treatment techniques may be required, depending on the reuse application, to remove colloids, dissolved matter and microorganisms. Such techniques include advanced membrane filtration technology systems such as MF, UF, NF and RO (GEA Process Engineering, 2018). These methods aim to treat the water to a very high-quality standard. Others include ion exchange (inorganic compound removal), ozonation (pathogen removal), activated carbon (AC) filtration (hazardous organic compounds removal) and UV disinfection. Section 5.4 aims to investigate current and developing innovative water recycling and reuse technologies. It focuses on innovative and advanced technologies, as there is already an abundance of information on current – and secondary – WWTs that can be applied to water reuse. It identifies and evaluates these innovative technologies in terms of economic and technical feasibility and in terms of their potential environmental impacts. Evidence-based conclusions are presented as to what are suitable technologies in an Irish context, and which technologies are suited to which sector or treatment facility. In order to assess relevant innovative water reuse technologies, the following four steps were taken:

1. The first step was a literature review of the latest scientific articles, theses, magazines and scientific databases on all aspects related to water reuse technologies.
2. During step 2, we selected the most relevant water reuse technologies for further analysis. These eight technologies were assessed on technical, economic and environmental criteria.
3. During step 3, the current water reuse technologies employed in Ireland were identified. There are no water reuse projects in municipal WWTPs. In industry, sites with water reuse projects were surveyed.
4. As part of step 4 we presented the conclusions from the technology review and assessment and recommendations for appropriate technologies applicable for municipal WWTPs and internal recycling in industry.

5.3 Review of Key Documentation

The first step reviewed relevant documents on water reuse technologies. These included European regulations on water reuse processes and BAT reference (BREF) documents for adoption of water reuse in industry (Brinkmann *et al.*, 2016; EC, 2016c). Scientific articles on current and developing water reuse technologies and on the circular economy trends were also reviewed, including Giakoumis and Voulvolis (2018), Hamilton *et al*. (2007), Jasonova *et al*. (2006), and Sharma and Kennedy (2017). PhD and MSc theses on new technologies in water reuse were reviewed from EU countries (the Netherlands – Abel, 2014; Belgium – Marcano, 2012) and non-EU countries (USA – Bird, 2015). Technical references consulted also included texts on water and waste water treatment, such as Davis (2010). Previous studies of water reuse technologies included the Seventh Framework Programme (EU FP7) Demoware project launched in 2016 (Demoware, 2016) and the Fifth Framework Programme (EU FP5) AQUAREC project (Bixio and Wintgens, 2006). After an extensive literature review of water reclamation technologies, more than 15 technologies were identified as being used for water reuse; these are MBRs, anaerobic membrane bioreactor (AnMBR), forward osmosis (FO), struvite crystals treatment, GAC filtration, powdered activated carbon (PAC) filtration, biologically activated carbon (BAC) filtration, metal–organic frameworks (MOFs), media filtration, sand filtration, riverbank filtration, soil aquifer treatment (SAT), aquifer storage and recovery (ASR), direct injection, wetland biological treatment, advanced oxidation process (AOP) and disinfection systems (UV, Cl, O_3, H_2O_2).

5.4 Water Reuse Technologies Assessment

From the list of water reuse technologies found, eight technologies were selected for further assessment based on their efficiency, innovation and relevance to the Irish water sector. These technologies are presented in Box 5.1.

5.4.1 Microfiltration – reverse osmosis/ ultrafiltration – reverse osmosis

There are generally four recognised types of pressure-driven membranes: MF, UF, NF and RO. The hierarchy of the processes selected is dependent on the types of materials rejected, operating pressures and nominal pore sizes on an order-of-magnitude basis.

The combination of RO and membrane filtration technology, whether MF or UF, is a suitable technical solution for WWT and potable water production. RO technology has already been successfully applied for water treatment (municipal and industrial) for many decades, treating a wide range of water sources, such as tap water, groundwater, surface water and wastewater, and it is also used for the treatment of domestic industrial effluents for internal reuse or for compliance with the existing discharge regulations. However, an appropriate pretreatment is the most critical factor to warrant the successful performance of these RO systems. RO and NF are membrane processes that use the differences in permeability of water constituents as a separation technique. The membrane is a synthetic material that is semipermeable, i.e. it is highly permeable to some constituents and less permeable to others. To remove a constituent from the water, the water is pumped against the surface of a membrane, resulting

Box 5.1. Water reuse technologies considered in more detail

MF + RO or UF + RO (see section 5.4.1)

AnMBR (see section 5.4.2)

FO-MBR (see section 5.4.3)

Modular WWT (see section 5.4.4)

SAT (see section 5.4.5)

AOP (see section 5.4.6)

UV disinfection (see section 5.4.7)

AC (see section 5.4.8)

A technical description of each of the technologies is provided in the individual subsections of section 5.4. The technologies are then assessed according to technical, economic and environmental criteria. The technical analysis considers their treatment capacities, pollutant removal rates and technology maturity, and summarises their advantages and limitations. The economic analysis considers capital expenditures and operational expenditures for each technology and the environmental analysis takes account of their energy consumption and, in turn, contribution to CO_2 emissions.

in a separation of product and waste streams (Davis, 2010).

Microfiltration usually uses pore sizes between 0.04 µm and 0.10 µm, although coarser MF pore sizes of 0.2 µm and 0.4 µm can also be used. MF can be implemented in many different water treatment processes when particles with a diameter greater than 0.1 mm need to be removed from a liquid. Usual applications include separation of bacteria from water (biological WWT), effluent treatment and separation of oil/water emulsions or pretreatment of water for NF or RO. The main operating cost of an MF system is related to fouling and includes the power requirement, power cost, membrane life and replacement cost, membrane cleaning cost and scale inhibition cost.

In recent years, hollow fibre UF technology has gained acceptance for the treatment of waters with high contamination levels. This is, among other things, on account of its higher efficiency – compared with other conventional filtration technologies – for the removal of suspended solids, microorganisms and colloidal and organic matter. UF is a pressure-driven purification process in which water and low molecular weight substances permeate a membrane, whereas particles, colloids and macromolecules are rejected. Flow through the semipermeable membrane is achieved by applying a pressure gradient between the inner and the outer walls of the membrane structure. UF membranes typically have pore sizes in the range of 0.01–0.05 µm and have a high removal capability for bacteria, most viruses, colloids and silt, thereby effectively achieving separation and purification. UF applications include potable water, RO pretreatment for seawater desalination applications and wastewater reclamation. Figure 5.2 shows a typical MF scheme.

5.4.2 *Anaerobic MBR for water reuse*

The AnMBR technology is an integrated system combining an anaerobic bioreactor with a low-pressure membrane UF or MF. A typical AnMBR scheme is shown in Figure 5.3. As MF/UF membranes can physically retain suspended solids, including

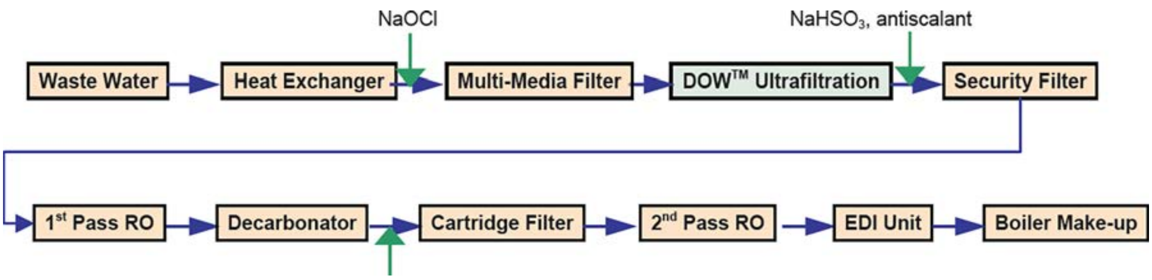


Figure 5.2. MF schemes. Source: Demoware (2016) (http://cordis.europa.eu). © European Union 2016.

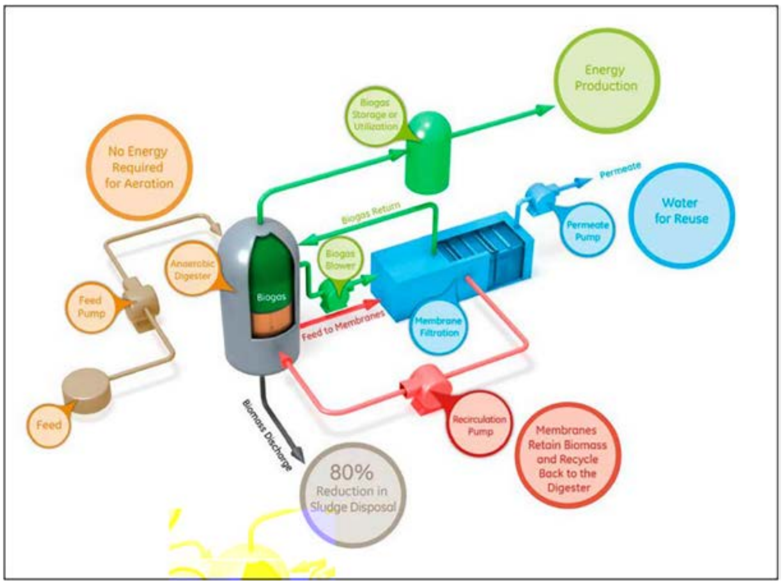


Figure 5.3. AnMBR reactor. Source: Demoware (2016) (http://cordis.europa.eu). © European Union 2016.

suspended biomass and inert solids, the AnMBR can achieve complete separation of the solid retention from the hydraulic retention, independently of the characteristics of the wastewater, biological process conditions and sludge properties. The membrane filtration can be integrated with anaerobic bioreactors in three different forms: (1) internal submerged membrane filtration, (2) external submerged membrane filtration and (3) external cross-flow membrane filtration.

5.4.3 Forward osmosis membrane bioreactor

A membrane bioreactor is a biological treatment process that integrates membrane systems to separate the treated effluent from the biomass in the reactor. Although usually based on MF or UF, novel MBR systems that utilise submerged forward osmosis membranes (FO-MBRs) are becoming a new alternative. FO for water application capitalises on the natural phenomenon of osmosis by exploiting an osmotic pressure gradient generated by a concentrated solution, known as a "draw" solution, to allow water to diffuse through a semipermeable membrane from saline feed water with a lower concentration (Figure 5.4). Consequently, it produces a less concentrated draw solution, which may be further treated to extract freshwater. FO is comparable with RO; in both processes water moves through a semipermeable membrane while the membrane retains salts. However, the concentration differences between the feed and the draw solutions across the membrane, in contrast to the high pressure applied in the RO process, naturally creates the driving force in the FO process. Thus, FO requires less energy.

5.4.4 Modular wastewater treatment plant

A packaged or modular WWTP is a sewage treatment module or series of linked modules that is generally factory-built, and subsequently transported to a site for connection and installation; it is normally designed to treat wastewater to secondary-stage quality using a biological process. In terms of the size of the plants that are available as packaged plants, they typically range from 4 PE to a larger than 9,000 PE, although the size can vary according to geographic conditions, customer requirements and the nature of the effluent required to be treated. This type of technology is included here because in certain situations it may be appropriate to consider water reuse from smaller-scale secondary-stage treatment, perhaps as part of an overall treatment train. As such, it is considered appropriate to compare the characteristics of this type of unit / process relative to the other, more advanced treatment processes described in this section.

The types of process that are most often used in packaged plants include moving bed biological reactors (an expensive option), AS, rotating biological contractors, the SAT treatment process, sequencing batch reactors and MBRs, which are becoming increasingly popular. A typical set-up for a modular WWTP is shown in Figure 5.5.

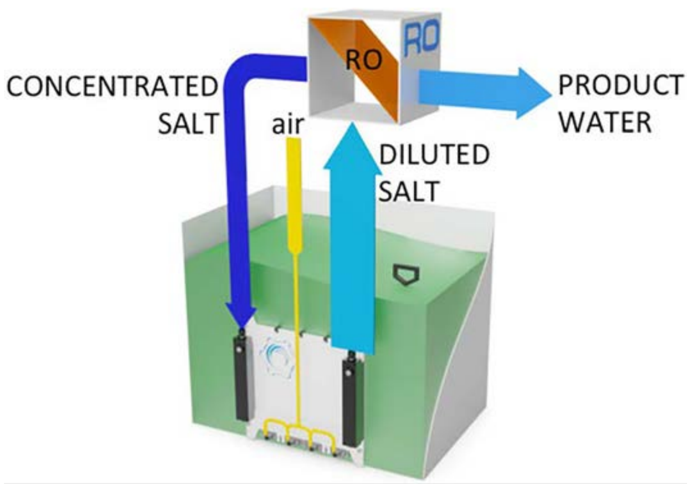


Figure 5.4. FO scheme. Source: Demoware (2016) (http://cordis.europa.eu). © European Union 2016.

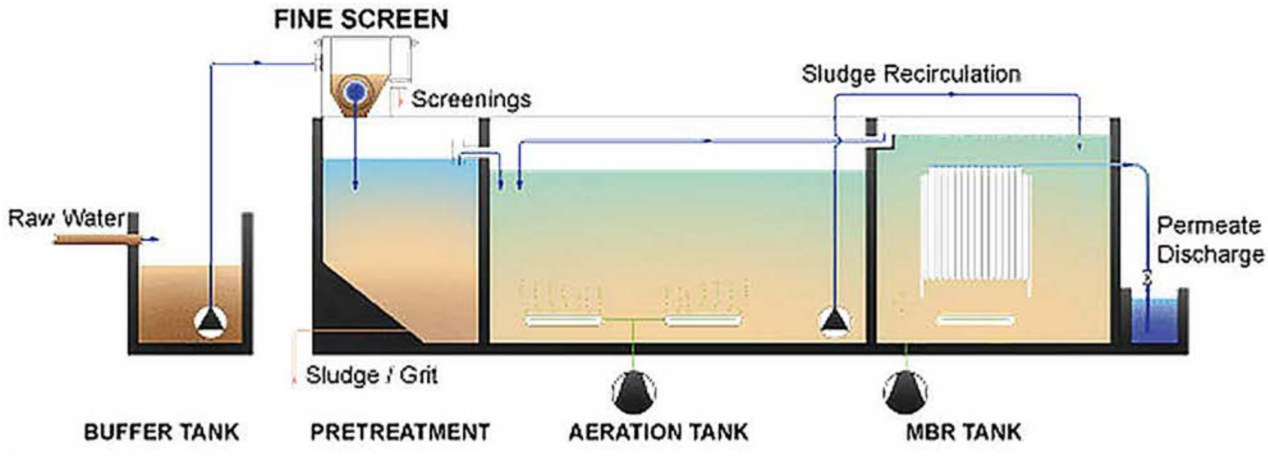


Figure 5.5. Modular WWT schemes. Source: Demoware (2016) (http://cordis.europa.eu). © European Union 2016.

5.4.5 Soil aquifer treatment for recharge

Managed aquifer recharge (MAR) refers to different recharge techniques that release the reclaimed water from above the ground, percolating through unsaturated soil or from below the ground, by injection or recharge wells. SAT is one of many MAR methods and is receiving growing attention on account of advantages such as inherent natural treatment, inbuilt storage capacity to buffer seasonal variations of supply and demand and the ability to mix it with natural water bodies, which promotes the acceptance of further uses, particularly indirect potable uses. A typical set-up for a SAT system is shown in Figure 5.6. SAT is an artificial groundwater aquifer recharge option. Water is introduced into the groundwater through soil percolation under controlled conditions. SAT is used either to artificially increase the groundwater in order to withdraw freshwater again at a later stage or as a barrier to prevent saltwater or contaminants from entering the aquifer. During percolation, natural soil filtration occurs and the water enters the aquifer where mixing, and possibly some other physical and chemical reactions, may occur. This method can be used with treated wastewater or relatively lightly polluted water (e.g. pretreated grey water or storm water), which is typically entered through a recharge basin or an injection well. Effluent is intermittently infiltrated through infiltration ponds to facilitate nutrient and pathogen removal in passage through the unsaturated zone for recovery by wells after residence in the unconfined aquifer. Depending on the wastewater quality, land availability and intended water supply usage, SAT can be complemented by various pretreatment technologies, such as horizontal, vertical and free-surface constructed wetlands, WSPs and upflow anaerobic sludge blanket (UASB) reactors and advanced treatments such as AS, membrane filtration or AOP.

5.4.6 Advanced oxidation process

Advanced oxidation process refers to a set of chemical treatment procedures designed to remove organic (and sometimes inorganic) materials in water and wastewater by oxidation through reactions with hydroxyl radicals (OH·). The AOP is of great importance, as, unlike conventional oxidation, it can completely destroy trace constituents of concern for public health and the environment, such as endocrine disruptors. The process is therefore particularly suitable for water pretreatment in MAR techniques such as SAT. Many systems come under the broad definition of AOP. Most of these use a combination of strong oxidants (e.g. O_3 and H_2O_2), catalysts (e.g. transition metal ions or photo catalyst) and irradiation (e.g. UV, ultrasound or electron beam). Reactors used for water treatment by chemical oxidation include batch Fenton reactors, ozone transfer reactors and reactors using hydrogen peroxide. AOPs may be used in WWT for organic content reduction (reduction in chemical oxygen demand or COD), specific pollutant removal, sludge treatment, increasing the bioavailability of recalcitrant organics, and colour and odour reduction. Figure 5.7 depicts an AOP process.

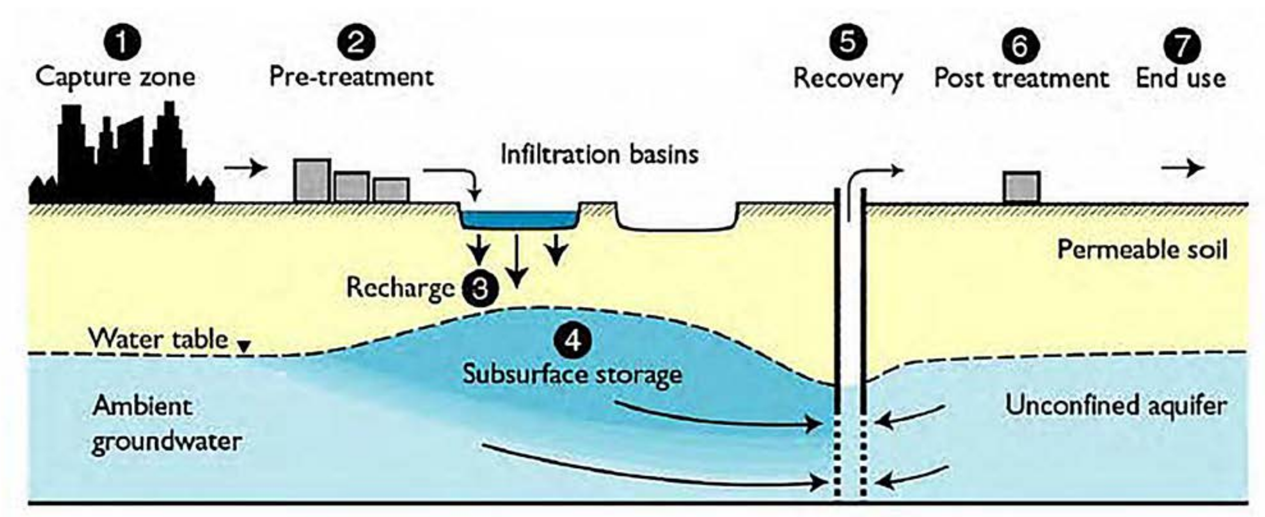


Figure 5.6. SAT for recharge. Source: Demoware (2016) (http://cordis.europa.eu). © European Union 2016.

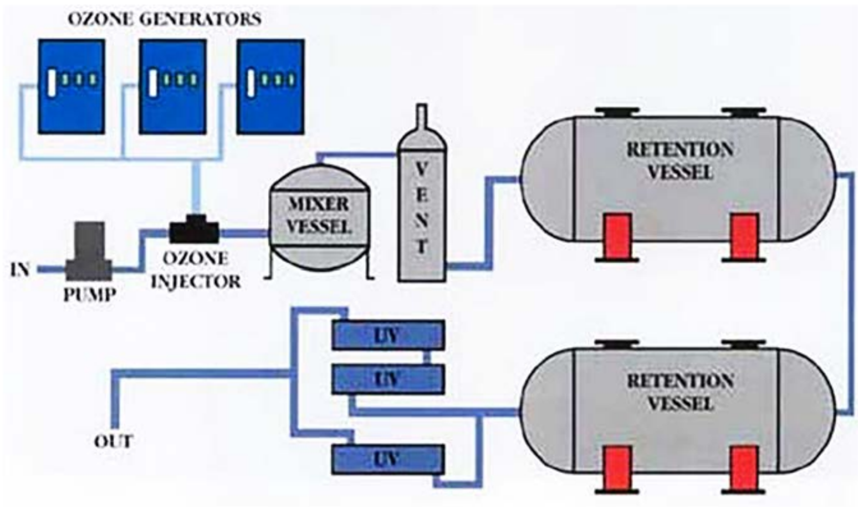


Figure 5.7. AOP. Source: Demoware (2016) (http://cordis.europa.eu). © European Union 2016.

5.4.7 Ultraviolet light disinfection

Davis (2010) gives a very thorough technical description of disinfection technologies used and classifies them into (1) chlorination/dechlorination, (2) ozone disinfection and (3) UV lamp filtration. For water reuse applications UV is a popular and reliable technology to remove contaminants from already treated wastewater. In small plants, the UV system is enclosed. In medium-to-large plants, UV systems are placed in an open channel. Typically, two parallel channels are provided. A water level controller is placed at the effluent end to keep the lamps submerged. In the majority of UV disinfection applications, low-pressure mercury lamps are used. Medium-pressure, high-intensity lamps have found application in larger plants where the flow rate exceeds 20,000 m^3/day. The advantage of the medium-pressure, high-intensity lamp is that the UV output can be modulated over a range of 60–100% of full power. In addition, fewer lamps are required. Quartz sleeves are used to isolate the lamps from direct water contact and to control the wall temperature. Mechanical wiping or a periodic acid dip of the sleeve is essential to avoid the formation of an opaque film. The dose to achieve regulatory standards is typically in the range of 50–140 mJ/cm^2. Using higher doses to overcome elevated suspended particulate matter concentrations has proven ineffective. Filtration prior to disinfection and conservative estimates of dose are recommended.

Factors that affect the number, type and rating of lamps include (1) the hydraulic loading rate, (2) the ageing and fouling characteristics of the lamps,

(3) the wastewater quality and (4) the discharge standards. For existing facilities, pilot testing is highly recommended.

5.4.8 Activated carbon

Because industrial wastewater operators face regulations and many contaminants in their work, making treatment and compliance challenging, AC has been an effective treatment option for years and can be used to remove contaminants from wastewater streams. AC is commonly used to adsorb natural organic compounds, taste and odour compounds, and synthetic organic chemicals in drinking water treatment. Adsorption is both the physical and the chemical process of accumulating a substance at the interface between liquid and solid phases. AC is an effective adsorbent because it is a highly porous material and has a large surface area to which contaminants may adsorb. The two main types of AC used in water treatment applications are GAC and PAC. The primary characteristic that differentiates GAC from PAC is its particle size. GAC has a larger particle size than PAC, with an associated greater surface area. GAC is used as a filter medium, either as a layer in a rapid sand filter or in a separate filter known as a contactor. GAC can remove trihalomethane precursors as well as taste and odour compounds. On its own or paired with an UV disinfection system, GAC can facilitate the removal of DBPs, EDCs, PPCPs, taste- and odour-causing compounds, and organic materials from decaying plants and other naturally occurring matter that serve as the precursors for DBPs. PAC is a form of AC with a very small particle size. Treatment involves adding PAC to water, allowing the PAC to interact with contaminants in the water and then removing the PAC by sedimentation or filtration. The removal of contaminants to low treatment objectives requires a high dosage of PAC, which makes it less economical than GAC from a carbon-use perspective. PAC and GAC remove organic chemicals and reduce toxicity in some wastewaters to allow for safe discharge into surface water and are widely accepted technologies for treating and removing organics, free chlorine, colour and many other impurities. For some industrial wastewaters, secondary treatment following AC may be required.

5.5 Technical, Economic and Environmental Assessment

The eight water reuse technologies selected and described in section 5.4 are assessed in terms of technical and economic feasibility and in terms of the potential environmental impacts. For each of the subsections in section 5.5, the following key components were analysed thoroughly:

1. Technical analysis:
   - (a) Treatment capacity (m^3/day). This indicates the maximum daily flow that can be treated in 24 hours. The result will also depend on the treatment plant size and capacity, but this gives an indication of the potential of the technology relative to other technologies.
   - (b) Pollutant removal efficiency. This includes the rate efficiency at which certain mineral and organic/biological compounds are being removed.
   - (c) Technological maturity. This indicates the technology readiness level (TRL) and whether the technology can be used widely at industrial, urban or agricultural levels, or whether it remains at the pilot phase, implying that further development and pilot testing are needed before it is ready to be introduced to the market.
   - (d) Advantages and limitations. Here, the specific technological advantages and limitations characterising the water reuse technology are presented.
2. Economic analysis:
   - (a) CAPEX analysis. This looks at the initial capital investment and CAPEX required.
   - (b) Operational expenditure (OPEX) analysis. This determines the OPEX required, which is generally linked to energy consumption, maintenance and replacement needs.
3. Environmental analysis. This examines the environmental impact of the reviewed technologies, taking account of removal of CECs, as well as energy consumption in relation to CO_2 emissions.

5.5.1 Technical analysis

Treatment capacity

When selecting a treatment train, the wastewater flow and characteristics, such as organic load, suspended solids and other factors affecting the applicability of a certain technology, should be taken into account, as should the general plant layout. An important consideration is the wastewater flow; typical WWTP flows can have large variations over 24-hour time periods and are dependent on several factors, such as the type of application (industrial, urban, agriculture), type of wastewater collection system (separate or combined), weather conditions (summer, winter) and climate. As a general rule, a uniform flow rate through such systems results in better performance.

In general, the type of technologies being considered here are modular in nature and are technically scalable; different flow capacities can be accommodated by selecting appropriate type and numbers of units for the treatment train in question. However, wastewater flow is only one of the technical parameters for choosing a treatment technology for water reuse purposes, and others, such as organic load and suspended solids, must also be assessed. In selecting the type of technology to be deployed, therefore, considerations of purification performance, and total lifetime cost, are more critical than absolute flow rate per se.

Pollutant removal efficiency

In terms of technological qualitative analysis, the following investigation has been performed to compare technologies according to the main wastewater quality parameters that the technology can remove at the end of each treatment train. Generally, water quality parameters can be classified as chemical or biological and are described in Table 5.1. The last two lines in Table 5.1 take into account water micropollutants such as pharmaceutical by-products and heavy metals.

After assessing the various technologies, we focused on a thorough analysis of their pollutant removal efficiencies. Use of the term “removals” is defined as a reduction of the target chemical observed after treatment compared with before treatment. The removal percentage can be found using equation 5.1.

$$\text{Removal (\%)} = 100 \times (\text{influent concentration} - \text{effluent concentration})/\text{influent concentration}) \tag{5.1}$$

Expected efficiencies are >90–95% for COD and BOD removal, >80–85% for TSS and >90% for coliforms and nematodes. However, the technologies vary in their effectiveness at removing other micropollutants that can accumulate in water and soil over time. These hard-to-remove micropollutants can be split into three categories: (1) pharmaceuticals and their metabolites, (2) DBPs and (3) heavy metals. Table 5.2 summarises the efficiency of removal of micropollutants for the selected technologies; and Table 5.3 summarises removal efficiencies for bacteria, viruses and protozoa.

Technological maturity

Technology readiness levels are indicators of the maturity level of particular technologies. There are nine TRLs, with TRL 1 being the lowest and TRL 9 the highest. The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technology. Horizon 2020 (2014) defines TRLs as:

- TRL 1 – basic principles observed;
- TRL 2 – technology concept formulated;
- TRL 3 – experimental proof of concept;
- TRL 4 – technology validated in laboratory;
- TRL 5 – technology validated in relevant environment;
- TRL 6 – technology demonstrated in relevant environment;
- TRL 7 – system prototype demonstration in operational environment;
- TRL 8 – system complete and qualified;
- TRL 9 – actual system proven in operational environment.

Analysis of the selected technologies and their level of maturity is depicted in Figure 5.8. UV, SAT, modular WWT and MBR technologies are classified as TRL 9. These technologies have been successfully employed in industry and municipal applications, on small and large scales, for more than 20 years. However, other technologies are not as advanced. Although the concept of the AnMBR was developed in the 1980s, large-scale applications of anaerobic membrane technology have been limited as a result of membrane fouling in the anaerobic environment, energy consumption of the membrane processes and the technological limitations of large-scale WWT

Table 5.1. Biochemical parameters used to characterise water quality

Biochemical parameter	Description
BOD	Biological oxygen demand is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at a certain temperature over a specific time period. Measured in milligrams per litre (mg/l)
COD	Chemical oxygen demand is commonly used to indirectly measure the amount of organic compounds in water
Coliforms	Coliform bacteria are a commonly used bacterial indicator of sanitary quality in water. Measured in colony-forming units per 100 ml (cfu/100 ml)
E. coli	The presence of *E. coli* provides a warning of failure in WWT, a break in the integrity of the distribution system or possible contamination with pathogens. When levels are high there may be an elevated risk of waterborne gastroenteritis. This is important with regard to water reuse, especially for high-grade applications. Measured in coliform count per 100 ml
Suspended solids	Suspended solids refer to solid particles generally > 2 µm that remain in suspension in water as a colloid or as a result of the motion of the water. Measured in milligrams per litre (mg/l)
N_{total}	Total nitrogen is the sum of nitrate (NO_3), nitrite (NO_2), organic nitrogen and ammonia (all expressed as nitrogen). N_{total} is measured to determine the total amount of nitrogen-based nutrients in water; a high concentration of N_{total} can be a cause of eutrophication. Measured in milligrams of nitrogen per litre (mg/l)
P_{total}	Phosphorus in natural waters is divided into three component parts: (1) soluble reactive phosphorus (SRP), (2) soluble unreactive or soluble organic phosphorus (SUP) and (3) particulate phosphorus (PP) (Rigler, 1973). The sum of SRP and SUP is called soluble phosphorus (SP) and the sum of all phosphorus components is termed total phosphorus. P_{total} is measured to determine the total amount of phosphorous-based nutrients in water; a high concentration of P_{total} can be a cause of eutrophication. Measured in milligrams of phosphorous per litre (mg/l)
Fats and oils	Fats and oils consist of a group of related constituents that are of special concern in WWT as a result of their unique physical properties and highly concentrated energy content. They are hydrophobic and thus have low solubility in wastewater, resulting in relatively low biodegradability by microorganisms. Measured in milligrams per litre (mg/l)
Nematodes	Nematode removal can play an important role in evaluating the degree of efficiency of WWT systems. Nematode eggs are a direct threat to human health and are an indication of organic enrichment in wastewater. Measured as egg count per litre
Turbidity	Measuring turbidity gives a quick and momentary indication of a problem with the integrity of the water treatment technologies, as there are direct correlations between turbidity and pathogenic organisms, including viruses. Measured as nephelometric turbidity units (NTUs)
Pharmaceutical by-products	Key pharmaceuticals for monitoring in wastewater identified in the PILLS Project (Nafo *et al.*, 2012) include atenolol, carbamazepine, diclofenac, naproxen, lidocaine, ifosfamide, cyclophosphamide, ciprofloxacin, erythromycin, clarithromycin, sulfamethoxazole (and its metabolite N-acetyl sulfamethoxazole), iopromide, opamidol, diatrizoate and bezafibrate
Treatment by-products	Treatment by-products are relevant if disinfection, with chemicals or UV, is included in the treatment train. They generally occur in low concentrations; however, there are emerging concerns regarding DBPs. DBPs include trihalomethanes (THMs), haloacetic acids (HAAs), bromate and chlorite (measured in µg/l). "Emerging" DBPs include halonitromethanes, haloacetonitriles, haloamides, halofuranones iodoacetic acid, iodo-THMs (iodotrihalomethanes) and nitrosamines (measured in µg/l)
Metals	Common metals include arsenic, lead, mercury and cadmium (measured in µg/l)
	Less common metals include chromium, copper, nickel and zinc (measured in µg/l)

Source: adapted from Demoware (2016).

membrane filtration. Large-scale membrane filtration systems have improved significantly in recent years. These advancements, combined with the potential of energy recovery from the AnMBR and the capacity to handle wastes with very high concentrations of COD, have contributed to the emergence of AnMBR as a potential technology for high-rate anaerobic treatment. The maturity of the technology is still at the prototype demonstration phase (TRL 7) and it is thought that it will be another 10 years before large-scale centralised AnMBR is operational. As of 2015, 100% of its use is industrial. FO-MBR has primarily been of research and academic interest and is not considered a mature technology, as it has been validated only at the laboratory scale (TRL 4). AOPs have been applied in a pilot phase to treat wastewater from groundwater remediation pump-and-treat systems, manufacturing facilities, domestic WWTPs and others. However, AOP has not been widely applied in WWT so far, as the chemical processes behind advanced oxidation

Table 5.2. Removal rates (%) for typical pharmaceutical by-products, by individual process type

Process Type	BAP (%)	Antibiotics (%)[a]	Pharmaceuticals				Hormones		NDMA
			DZP (%)	CBZ (%)	DCF (%)	PCT (%)	Steroid (%)[b]	Anabolic (%)[c]	
MF	nd	<20	<20	<20	<20	nd	>90	nd	>90
UF	nd	>90	>90	>90	>90	nd	>90	nd	>90
NF	>80	50–80	50–80	50–80	50–80	50–80	50–80	50–80	nd
RO	>80	>95	>95	>95	>95	>95	>95	>95	25–50
SAT	nd	50–90	10–50	nd	50–90	nd	>90	nd	nd
AOP	nd	50–80	50–80	>80	>80	>80	>80	>80	>90
UV	nd	20–80	<20	20–50	>80	>80	>80	20–50	>90
AC	80–95	80–95	80–95	80–95	80–95	80–95	80–95	80–95	80–95

Note: modular WWT not included as this technology is a secondary-stage treatment; it would be followed by one of the advanced processes in a treatment train.

[a]Antibiotics: erythromycin, sulfamethoxaole, triclosan and trimethoprim.

[b]Steroid hormones: ethynylestradiol, oestrone, oestradiol and oestriol.

[c]Anabolic hormones: progesterone and testosterone.

BAP, benz(a)pyrene; CBZ, carbamazepine; DCF, diclofenac; DZP, diazepam; nd, no data available; NDMA, *N*-Nitrosodimethylamine; PCT, paracetamol.

Sources: Ternes and Joss (2006); Gerrity and Snyder (2011); Nafo *et al.* (2012).

Table 5.3. Validated log reduction values (LRVs) based on challenge testing and operational monitoring sensitivity for indicative treatment processes

Treatment process	Log reduction value[a]			Basis for validation
	Bacteria	Viruses	Protozoa[b]	
MF/UF	4	1.5	2	Daily direct integrity testing supported by online turbidity. Higher LRVs for UF
RO	1.5–4	1.5–4	1.5–4	Dependent on nature of control. Lower for online monitoring of conductivity or total organic carbon; higher for offline monitoring of sulphate or online/offline monitoring of fluorescent dyes
MBR	4	1.5	2	5th percentiles of published LRVs using probability density functions correlated with operational characteristics
Modular WWT	1	0.5	0.5	Pathogen removals from well-operated and well-designed plants. LRVs can be increased using system-specific testing
SAT	System specific			LRVs dependent on nature of soil and retention time in the aquifer
UV/AOP	6	6	6	Major contribution by UV. Oxidant dose also provides inactivation
UV	6	6	6	Transmitted UV dose of 186 mJ/cm^2 can provide a 4-log inactivation of viruses. At an extrapolated dose of 235 mJ/cm^2, 6-log inactivation can be achieved. Lower doses required for protozoa and bacteria
Ozone-AC	4	4	0	Achieving an ozonation Ct value of ≥ 1 mg/min/L at ≥ 10°C. Higher Ct values could increase LRVs
Conventional water treatment	6	6	3–4	For comparison, values for conventional water treatment: treatment train of coagulation, flocculation, filtration, chlorination

[a]The WHO recommends that, generally, LRV based on challenge testing and sensitivities of operational monitoring should be used in designing potable reuse schemes, particularly where operational monitoring is relied on for demonstrating ongoing performance of treatment processes.

[b]Protozoa LRVs based on *Cryptosporidium*.

Source: adapted from WHO (2017b).

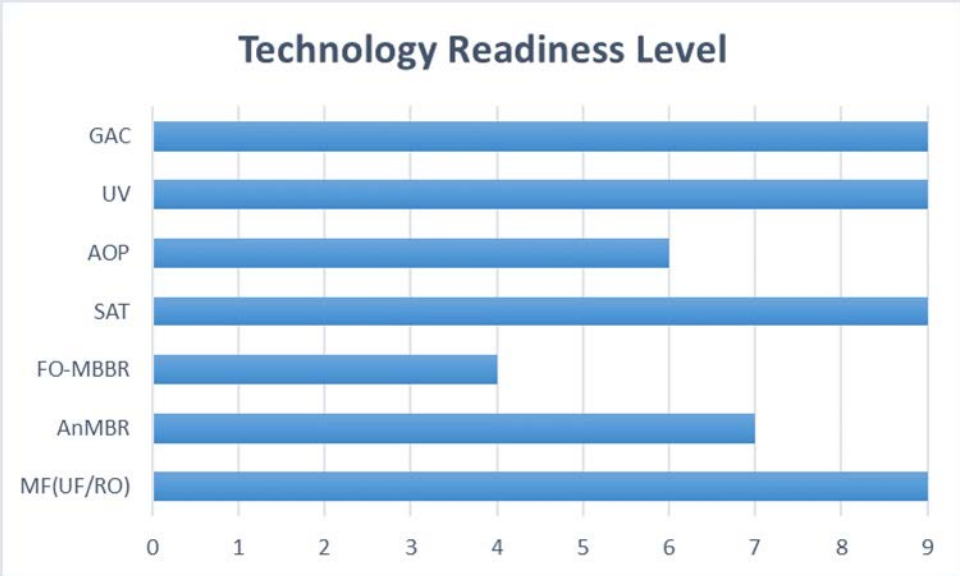


Figure 5.8. Level of maturity and water reuse technologies. Note: modular WWT is not listed as this technology group includes well-established secondary-stage process types; it would be followed by one of the advanced processes in a treatment train.

require deeper research. For drinking water, advanced oxidation has already matured to TRL 9, which should speed up the process of development for WWT. AOP is characterised as level TRL 5–6 for water reuse.

Advantages and disadvantages

Following a review from a technical perspective, Table 5.4 presents the advantages and limitations for each of the selected technologies.

5.5.2 Economic assessment

Technically, wastewater can be treated to any intended quality level. However, the price of the treatment influences the desired water quality and a compromise must then be reached between the quality and the cost at which such water quality could be achieved (Salgot, 2008). Wastewater reuse can help to maximise the use of limited water resources and contribute to economic development through reduction of budgets allocated for energy, chemical procurement and reduction of highly treated water usage for non-potable purposes (Janosova *et al.*, 2006). As water reuse is not free, it is necessary to identify the cost bearer during the planning phase and the potential treatment level that could be achieved for the planned budget (Salgot, 2008). Some of the technologies reviewed in the literature review carried out prior to the technical assessment in this chapter also included nutrient recovery technologies and water reuse as a by-product. A relevant example of this is struvite crystal recovery, which is an innovative technology currently used in the USA and South Africa for nitrogen and phosphorus recovery from wastewater.

The following sections analyse the CAPEX and OPEX for water reuse technologies. Information is lacking for the CAPEX and OPEX for individual treatment technologies, as this depends on each specific application. An overview of the CAPEX and OPEX is provided for water reuse treatment trains currently in operation, analysed through the EU FP7 Demoware project. Although these examples do not exactly align with the selected technologies for this assessment, they provide an indication of the CAPEX and OPEX for various water reuse treatment trains.

Capital expenditure analysis

A key factor for deciding which technology train to use is the initial investment and CAPEX that it requires. Important variations can be observed at this level regarding the level of technology it implies, the infrastructures needed and so on. A segmentation has been applied between the technologies that need "high" (≥€100 million), "medium" (€10 million–99 million) and "low" (≤€9 million) investments. Table 5.5

Table 5.4. Advantages and disadvantages of water reuse technologies

Technology	Advantages	Disadvantages
1. MF (UF + RO)	• MF/UF filtration allows for the chemical cleaning requirements and power consumption for RO membranes to be reduced significantly and increases the permeate production per unit membrane area	• Fouling and energy cost of RO
2. AnMBR	• Nearly absolute biomass retention • Low nutritional requirements • Allows for operation at high sludge retention time; low-energy requirements • Ability to produce net energy (biogas) • Produces mineralised nutrients (NH_3, PO_4) for agricultural use	• Cake formation: membrane fouling more severe than under aerobic conditions • WWT in lower temperate climates (< 20°C) is still a challenge
3. FO-MBR	• Much higher rejection than MF/UF + RO scheme at a lower hydraulic pressure • Lower fouling propensity than pressure-driven systems, meaning less frequent backwashing	• Low water flux resulting in large FO membrane areas/cost • Accumulation of salts into the bioreactor resulting in salt leakage • High-energy demand linked to the need for re-concentration
4. Modular WWT	• Portable and easy to install • Suitable for previously untreated wastewater • Designed for use in projects with time, space and budget constraints • Can be placed strategically to generate reclaimed water at the point of reuse • Can be installed incrementally to meet growing demand • Well-established technology	• Sludge disposal can be a challenge in some cases • Resulting treated water only suitable for limited reuse purposes.
5. SAT	• SAT is a natural pre-treatment system that allows the securing and enhancing of water supplies while mitigating floods and flood damage • It is a low-cost and fitting option for wastewater reclamation • SAT can contribute to improving the aquifer water while preserving water levels in wetlands, mitigating contaminant intrusion and freshening saline aquifers or preventing aquifer salinisation, creating a buffer against salt water intrusion • Enhances environmental flows in water supply catchments and augments water supplies and improves coastal water quality by reducing urban discharges	• Introducing pollutants into groundwater aquifers may have long-term negative impacts and SAT could change the soil and groundwater hydrological properties • Surface SAT requires a big area for the infiltration basin, which adds to the cost of the project and may increase the risk of flooding in areas where groundwater levels are already high
6. AOP	• The strength of advanced oxidation lies in the hydroxyl radical (HO·), one of the most active oxidants, which can break down most organic components into CO_2, water and mineral acids • No secondary waste stream is generated, so there are no costs related to stream management • AOP can be operated with equipment of small dimensions • AOP has the capacity to remove micropollutants favouring the biodegradability of effluents in the SAT treatment and avoiding aquifer clogging	• May generate by-products of concern, such as brominated by-products, various oxygenated by-products, and carboxylic acids and halogenated acetic acid. The performance of the process is affected by high concentrations of bicarbonate (HCO_3) and carbonate (CO) ions, which react with HO· • Some metal ions [such as Fe(II) and Mn(II)] or suspended material can also interfere with AOP • AOP also implies relatively high treatment costs and special safety requirements because of the use of very reactive chemicals and high-energy sources (UV lamps, electron beams and radioactive sources)

Table 5.4. Continued

Technology	Advantages	Disadvantages
7. UV disinfection	• Improves the performance of the WWTP and has a high pollutant removal rate • Offers a broad range of installations for small capacities of < 100 m³/day up to 120,000 m³/day • It is flexible and can be adapted to any of the treatment schemes selected for the process	• Costs of energy consumption and maintenance (regular changing of quartz lamp) can be high depending on the type of installation and capacity
8. GAC and PAC	• GAC can remove DBPs, EDCs, PPCPs, taste and odour • GAC is easily incorporated into existing facility infrastructure and requires a small footprint • GAC can be recycled • PAC has a low initial cost but GAC is a more economical choice in larger systems	• AC will not affect total dissolved solids • PAC cannot be recycled • PAC has a high operating cost if used continuously • PAC produces large quantities of sludge • GAC has a high initial cost

Table 5.5. CAPEX for selected technology treatment trains

Technology treatment trains	Low (≤€5/m³/day)	Medium (€6–99/m³/day)	High (≥€100/m³/day)
Sand filtration–UV–hypochlorite (4500 m³/day)	✔		
Conventional secondary treatment with no tertiary treatment (55,000 m³/day)	✔		
Sand filtration and RO (150 m³/day)			✔
UF–UV (360 m³/day)		✔	
SAT (350,000 m³/day)	✔		
UF–RO (17,000 m³/day)	✔		
UV–hypochlorite (500 m³/day)		✔	
MBR–GAC–hypochlorite (574 m³/day)		✔	
MBR–UV–hypochlorite (15,000 m³/day)	✔		

Sources: Nafo *et al.* (2012); Demoware (2016).

provides the CAPEX for the selected technologies using the criteria defined (Demoware, 2016).

Operational expenditures analysis

The OPEX may vary dramatically between different technologies. Although some technologies might be relatively inexpensive in terms of investment, they may have high operational costs. Major operational costs in the water reuse sector are linked to energy consumption, maintenance (use of chemicals for cleaning the processes) and replacement needs (directly linked to the lifespan of the technology). Operational costs have been classified for the purpose of the study as "high" (≥€2.1/m³ of water treated), "medium" (€0.6–2/m³ of water treated) and "low" (≤€0.5/m³ of water treated). Table 5.6 provides examples of reuse technologies and their OPEX values, referenced from the EU FP7 Project Demoware and PILLS Project. Table 5.6 takes into account different treatment trains for water reuse processes with a range of flows from 360 m³/day to 55,000 m³/day.

Energy consumption of treatment technologies is a major operational cost; the more complex the treatment trains, the higher the energy demand. The energy consumption cost of the selected technologies is presented in Table 5.7. For a complete analysis, a review of American Membrane Technology Association papers (AMTA, undated) and relevant European literature (Kemira, 2003; Krzeminski *et al*., 2012; Marcano, 2012; Sharma *et al*., 2012; Abel, 2014)

Table 5.6. OPEX for selected technology treatment trains

Technology treatment trains	Low (≤€0.5/m^3)	Medium (€0.6–2/m^3)	High (≥€2.1/m^3)
Sand filtration–UV–hypochlorite (4,500 m^3/day) (agricultural)	✔		
Conventional filtration with no tertiary treatment (55,000 m^3/day) (agricultural)		✔	
Sand filtration and RO (150 m^3/day) (industrial)			✔
UF–UV (360 m^3/day) (agricultural)			✔
SAT (350,000 m^3/day) (agricultural)	✔		
UF–RO (17,000 m^3/day) (agricultural)	✔		
UV–hypochlorite (500 m^3/day) (urban)		✔	
MBR–GAC–hypochlorite (574 m^3/day) (urban)			✔
MBR–UV–hypochlorite (15,000 m^3/day) (urban)	✔		

Sources: Demoware (2016); Nafo *et al*. (2012).

Table 5.7. Energy consumption of WWT technologies

Technology	Energy consumption (€/m^3)	Comments
MBR: UF/NF/RO/AnMBR/ modular WWT	0.5–1.0	Aeration determines c. 50% of energy consumption. Newer systems can be <€0.5/m^3
SAT	0.1–0.12	The cost of SAT is lower than that of conventional above-ground-treatment systems. Its operation is simple and no chemical or expensive treatment units and equipment are required. However, CAPEX costs can be high as a result of land prices and availability
AOP	0.2–1.19	Dependent on the AOP type, prices could reach €1/m^3. Reagents necessary for reaction generally make up 80% of AOP energy costs
UV disinfection	<0.5	Energy-efficient installation with small footprint. CAPEX price could be high but is dependent on type of application

Sources: adapted from Aharoni *et al*. (2011), Sharma *et al*. (2012), US EPA (2012) and WHO (2017b).

was carried out. Fifty per cent or more of energy requirements usually come from the aeration required to maintain activated suspended growth and fixed growth.

5.4.3 Environmental impact

The environmental impact of water reuse technologies is an important aspect to consider and is one that may be overlooked in favour of the technical and economic assessment. However, if water reuse is to become a viable water management solution, it must take account of the potential environmental impacts of the treatment trains. These environmental impacts can be considered as the risk of contaminants to the environment from treated wastewater and the energy consumption of WWT for reuse and, in turn, the CO_2 emissions.

Although the water treatment technology market that facilitates reuse is considered advanced and is continuing to mature, there is a question around the feasibility of these technologies in terms of removal of contaminants and increased cost of treatment. Irrigation with reused water, even if treated correctly, might add certain contaminants, such as chlorides, to the groundwater and salts to agricultural land. This risk has an accumulative nature, as the contaminants appear in the water supply systems; they flow to the treatment plants and back to the aquifer. The risks in this respect have a long-term influence and are difficult to evaluate. High salinity in agricultural terrains can cause soil structure deteriorations, decrease of soil permeability and reduction of crop yields as a result of toxic effects. Furthermore, local flora and fauna can be affected by the soil and water in the surrounding environment. If crops are affected, there is also a risk associated with human health and food consumption (Shakir *et al.*, 2017). Other threats to groundwater and surface water include contamination with pharmaceutically active compounds and endocrine-disrupting chemicals, nutrients, pathogens and heavy metals. The risks to the environment must be taken into account when assessing water reuse technologies for each specific use.

Section 2.5, on barriers to expanding water reuse, discusses the risks to the environment and possibly human health from CECs such as PPCPs, EDCs, FRs and DBPs. Table 5.2 summarises the efficiency of removal of pharmaceutical pollutants for the eight technologies. The US EPA (2010) provides a useful review of the performance of full-scale treatment systems that incorporate one of six commonly used treatment technologies for the removal of 16 selected CECs.[4] The six treatment technologies discussed are AS, GAC adsorption, chlorine disinfection, UV disinfection, ozone disinfection and RO. The treatment technologies relevant to water reuse are summarised in Table 5.8 in relation to their removal efficiency of CECs, which could have negative environmental impacts.

5.6 Water Reuse Technologies in Industry in Ireland

Section 5.4 provides an assessment of current water reuse technologies as well as technologies still under development. Although water reuse from municipal WWTPs does not occur in Ireland, Irish industries are leading the way with water reuse projects. Treatment technologies currently employed in water reuse projects in Ireland were investigated by means of an industry survey, discussed in section 3.4, of the chemical sector and food- and drink-, and wood-processing sites treating large quantities of wastewater. Of the 57 responses, 16 sites carried out internal recycling of wastewater and the technologies used included RO ($n=7$), AS ($n=5$), filtration ($n=5$), sedimentation ($n=4$), MBR ($n=3$), disinfection ($n=3$),

Table 5.8. CEC removal of treatment technologies for water reuse

Technology	Contaminant removal
MF/UF + RO	On account of the high level of treatment through RO, MF or UF with RO treatment schemes offer the best option for removal of CECs. The average removal efficiencies for treated effluent range from 81% for sulfamethoxazole to 100% for iopromide, triclosan and naproxen (EPA, 2010) Although RO systems are very effective, the generation of a concentrate stream is a major drawback as the presence of CECs in the concentrate could also be a significant underlying health consideration for final disposal of concentrate to the environment, be it to the ocean or inland disposal. RO combined with an MF/UF system provides an opportunity to capture higher concentrations of CECs from a stream that has not undergone aerobic biological treatment (Juby *et al.*, 2017)
Modular WWT	Modular WWT systems can be built according to the wastewater that they have to treat and for the specific application. Thus, a suitable treatment train to remove CECs can be employed
AOP	With the addition of AOP, ozonation effectively breaks down a wide range of CECs. However, there are some resistant CECs and there can also be the issue of NDMA and bromate by-products. The effectiveness of ozone oxidation can be enhanced by the addition of either hydrogen peroxide or UV light. The average removal efficiencies for treated effluent range from 38% for iopromide to 100% for diclofenac (EPA, 2010)
UV disinfection	UV disinfection is used to inactivate pathogens in wastewater and it can also transform CECs. The effectiveness of UV oxidation depends on the energy and wavelength of the light, the clarity of the water and the target CECs. The effectiveness of UV oxidation can be enhanced by the addition of hydrogen peroxide to increase concentration of hydroxyl radicals. The average removal efficiencies for municipal wastewater range from 33% for sulfamethoxazole to 97% for caffeine and naproxen (EPA, 2010)
GAC	Granular activated carbon adsorption is a polishing treatment step, most commonly used to remove low concentrations of organic pollutants. Pollutants removed from water and wastewater will be adsorbed to the solid wastes generated by this process. AC filtration can lead to elimination rates of >95% for all compounds with a fresh GAC filter (Nafo *et al.*, 2012)
Chlorine disinfection	Chlorine is sometimes used to disinfect wastewater, particularly prior to reuse. Chlorine can transform organic chemicals via oxidation and chlorination; however, the reaction of chlorine with organic material can generate chloroform and other potentially harmful DBPs. The average removal efficiencies for municipal wastewater range from 4.5% for the flame retardant tri(chloroethyl) phosphate to 98% for caffeine (EPA, 2010)

4 Of the 16 CECs, two are naturally occurring oestrogens (oestradiol and oestrone). The other 14 CECs include 10 PPCPs, one pesticide, one surfactant (nonylphenol, NP), one flame retardant [tri(chloroethyl) phosphate] and one plasticiser (bisphenol A).

UF ($n=2$), coagulation ($n=2$), flotation ($n=2$) and no treatment ($n=6$). The technologies adopted by each site were specific to the water reuse application and level of treated water required. Applications that require high-quality water, such as process input, employed a higher treatment level and technologies (RO, UF) than those that required a lower grade water, such as yard or truck washing, and less sophisticated treatment technology (secondary treatment or no treatment). The responses show that there are opportunities for the adoption of secondary treatment and less expensive advanced treatment in industrial water reuse depending on the application, as well as more expensive advanced treatments.

5.7 Treatment Technology Application Areas

In the adoption of water reuse in Ireland, whether in industry or municipal WWTP, an understanding of the most suitable technologies and treatment trains for the intended application is necessary. This implies the need of understanding the advantages and disadvantages for each application, whether it be agricultural, industrial, urban or environmental. The technology assessment analysed the technical and economic feasibility and the environmental impact of key water reuse technologies. It provides the reader with a broad understanding of the advantages and limitations of each technology and their characteristics, which can be utilised in assessing their adoption for water reuse projects in Ireland. Each technology must be assessed in relation to its potential application. Table 5.9 displays the final reuse application by type of technology.

5.8 Technology Conclusions and Recommendations

To summarise the results of the technology assessment in this chapter, a table has been created providing a qualitative overview of the treatment technologies assessed for water reuse. Table 5.10 allows for comparison of technologies regarding technical and economic feasibility and environmental impact. Any selection of a technology must take into account the relevant criteria, the application area and specific requirements. The technologies with the highest removal efficiency include MF/UF + RO, FO-MBR and GAC. However, RO and FO systems can have a high CAPEX and OPEX. GAC has lower costs and also has low energy consumption, making it the recommended technology. If removal efficiency is not a key requirement, other technologies that are more cost-effective may be more suitable, such as SAT or UV. Most of the technologies assessed have a high TRL, with the exception of AnMBR, AOP and FO-MBR.

Recommendations on water reuse technologies for municipal WWTPs:

1. Application: the potential applications for water reuse from municipal WWTPs include agriculture irrigation and urban applications (street cleaning, private garden watering, car washing, toilet flushing, etc.). For agricultural irrigation, MF/UF + RO, modular WWT and SAT treatments are applicable, whereas for urban applications MF/UF + RO, FO-MBR, modular WWT, SAT, AOP for SAT and GAC are all suitable (see Table 5.9).

Table 5.9. Final reuse application by type of technology

Technology	Agriculture irrigation	Urban application	Industrial
MF/UF + RO	✔	✔	✔
AnMBR			✔
FO-MBR		✔	✔
Modular WWT	✔	✔	✔
SAT	✔	✔	✔
AOP		✔	✔
UV	✔	✔	✔
GAC		✔	✔

Source: Demoware (2016).

Table 5.10. Technology assessment summary

Water reuse technology	Technical analysis			Cost assessment		Environmental analysis	
	Capacity range	Removal efficiency	TRL	CAPEX	OPEX	Energy consumption	CEC removal
MF/UF + RO	Medium–high	High	High	High	High	Medium–high	High
AnMBR	Low	Medium	Medium	Low	Medium	Medium	Low–high
FO-MBR	Low	High	Medium	High	High	Medium–high	High
Modular WWT	Low	Low–high	High	Low–high	Low–high	Medium–high	Low–high
SAT	High	Medium–high	High	Low	Low	Low	nd
AOP-SAT	High	High	Low	nd	nd	Medium	Medium
UV disinfection	Medium–high	Middle	High	Low–medium	Low–medium	Low	Medium
GAC	nd	High	High	Medium	Medium–high	Low	High

AOP-SAT, advanced oxidation process for soil-aquifer treatment; nd, no data.

2. Capacity: technological schemes should be chosen with hydraulic capacities starting from 100 m^3/day and reaching 200,000 m^3/day dependent on the agglomeration (from 1000 PE up to 1,000,000 PE). Currently, Ireland has 157 large WWTPs and section 3.3 identifies eight of these, treating a PE of over 100,000, which may offer potential sources for treated wastewater to be recovered in future water reuse programmes.
3. Water biochemical characteristics: technologies and treatment trains should be chosen while taking in account domestic water loading and discharge limits [carbon : nitrogen : phosphorous ratios, low toxicity, pH values, final discharged total organic carbon (TOC) values, final suspended solid concentrations and biological characterisation].
4. Technological readiness: for the identified technologies suitable for municipal WWTP, MF/UF + RO, modular WWT, SAT and GAC are all successfully employed. AOP and FO-MBR are at TRL 6 and 4, respectively, and so are not ready to be employed at present. However, as water reuse in Ireland, if adopted, is on a long-term timescale, these technologies may be further developed.

Recommendations on water reuse technologies for industry:

1. Application: for internal water recycling in industry the following technologies are all suitable: MF/UF + RO, AnMBR, FO-MBR, modular WWT, SAT, AOP for SAT and GAC (Table 5.9).
2. Capacity: technological schemes would usually comprise small to medium applications of 100–1000 m^3/day; however, there is the potential for even larger water reuse capacities in Irish industry. The industry survey found that Irish industries have wastewater capacities ranging from 50 m^3/day to 1400 m^3/day for the chemical sector and ranging from 16 m^3/day to 12,000 m^3/day for the food and drink sector (see Table 3.1).
3. Water biochemical characteristics: technological schemes applicable in industry sectors should be chosen taking in account wastewater loading and discharge limits. Industry sites must also take account of specific contaminants relevant to their industry. Treated industrial wastewater could still contain levels of toxicity, biological contaminates such as *E.coli*, oestrogen disruptors and other types of compounds, such as β-phenols, phthalates and metals (zinc, lead, chromium), even after advanced treatment process.
4. Technological readiness: for the identified technologies suitable for industry, UV, SAT, modular WWT, MBR and GAC technologies are all successfully employed. Other technologies are not as advanced: AnMBR, AOP and FO-MBR are at TRL 7, 6 and 4, respectively, and so are not ready to be employed at present.

6 Conclusions and Recommendations

This project addresses water reuse in the context of the circular economy in Ireland. The scope of the report covers planned water reuse for potable and non-potable purposes, whether direct or indirect, and does not examine unplanned water reuse. The reuse of rainwater and grey water, or domestic reuse, is not included in the scope of this report. This project does not address the cost–benefit of water reuse compared with other measures for improving water supply security. It was helpful to subdivide water reuse into two main sectors: (1) industrial reuse and (2) municipal reuse. Industrial reuse refers to recovery of wastewater from industrial processes and reusing it for a beneficial purpose within the confines of the site where it was generated. Municipal reuse refers to recovery of wastewater at a municipal WWTP and reusing it in the broader economy, i.e. outside the confines of the treatment plant site. This study has:

- reviewed the policy background for water reuse;
- assessed the international practices in water reuse, including how public engagement is carried out when projects are being planned;
- examined the level of water reuse in Ireland in industry and municipal sectors;
- conducted significant stakeholder engagement, including the first national public survey on attitudes to water reuse in Ireland; and
- assessed a range of technologies that are used for water recovery and their suitability.

In particular, the stakeholder engagement with industry, relevant organisations and the public survey yielded new insights into the present attitudes towards water reuse in Ireland, which can serve as a reference point for future work in this area.

6.1 Conclusions

- There is increasing interest internationally in water reuse, as an integral part of the circular economy, for water-stressed regions to address the effects of climate change and water scarcity. In the global context, water scarcity and cost are the two main drivers of water reuse practices.
- Scarcity is not as significant an issue for Ireland as a whole as it is for other countries, despite some areas having shortages at times, and cost is not a driving factor for the domestic sector on account of the absence of water charges. Cost may become a future driver for increased water reuse in industry in Ireland with the harmonisation of non-domestic water tariffs and possible water abstraction charges. Sustainability is another driver for industry and agriculture in Ireland.
- The key barriers to water reuse include the risk to human health and the environment, public perception, regulatory challenges and market failures relating to the cost of reused water. Although the European policy context aims to encourage the practice, there is no formal public policy or legislation for water reuse in Ireland relating to municipal sources. There are no quality standards in the legislation in Ireland for water that has been recovered and is intended for reuse, either as a whole or for specific purposes. Emerging persistent and exotic compounds, including pharmaceutical residues, antibiotic-resistant bacteria, DBPs and pesticides, pose a challenge for conventional WWT technologies. More research is required on the transmission of these contaminants after WWT, if recovered water is to be reused, especially for purposes involving direct human contact.
- There are no municipal water reuse projects or measures in Ireland at the time of writing.
- The primary applications for treated wastewater from municipal WWTPs would be urban, industrial and agriculture uses. In Ireland, the opportunities for reuse of treated wastewater for irrigation are very limited as neither food nor non-food crops generally require additional irrigation, on account of the adequate average rainfall across the country. There is also very little irrigation of public parks and green areas carried out; therefore, at present there is no meaningful demand for water reuse for this type of application. Any urban or industrial applications would need to be assessed regarding the water scarcity in the specific region in question and the risks arising from the intended use.

- Certain industries – chiefly those with higher levels of water usage, such as the food and drink sector and pharmaceutical companies – are pursuing water conservation and reuse programmes for their own reasons of cost and corporate social responsibility, but there is little publicly available data on the extent and nature of such measures.
- There is a high level of openness to the idea of water reuse among people in Ireland, and a recognition of its potential benefits, for most purposes. The major exception is reuse of water for drinking, about which strong negative opinions were expressed, and perhaps agricultural irrigation for food production, on which opinions were mixed. There is a strong view among Irish people in favour of upgrading the existing water supply network to address potential shortages of water, rather than investing in water reuse projects. In terms of water conservation, there was strong feedback that the immediate priority should be the ongoing national leakage reduction programme. Internationally, it has been shown that meaningful public engagement is critical to ensuring any water reuse measures are accepted and successful. This is echoed by comments received from the public survey.
- The key drivers for water reuse in industry in Ireland are companies' organisational goals around sustainability or environmental protection, wastewater effluent limits for sites and technological advancements. The important challenges for industry are the risk of product becoming contaminated by reused water, the need to meet regulatory or required water quality standards and the high CAPEX cost of investment.
- The prevailing attitude among key stakeholders towards broader water reuse from municipal WWTPs in the economy could be stated as: "Perhaps a good idea for some purposes, but probably not for now".
- The technology assessment shows that higher grade water reuses require higher levels of treatment prior to reuse, with associated higher energy (and cost) inputs. Individual treatment processes have been successfully combined into treatment trains in other jurisdictions to generate reusable water of suitable quality for its intended purpose. Appropriate technologies and treatment trains must be assessed in relation to the intended application of the recovered water.

6.2 Recommendations

- Although Ireland is a country renowned for frequent rainfall and flooding, the actual security of supply of water services is delicate in certain areas. There are increasing pressures on freshwater supplies and demand for water. These drivers are compounded for commercial users, who may face increasing costs and other constraints, such as ELVs and sustainability goals. Water reuse is already a viable option for heavy water-using industries in Ireland and may provide a solution for the municipal sector in an integrated water resource management strategy for Ireland.
- In the short term, it appears that water reuse applications for Ireland should focus on internal recycling in industry (e.g. cooling water, process water, washing) and agricultural uses (e.g. milk production), where water reuse is already occurring. The "low-hanging fruit" for water reuse projects is in the non-domestic sector, where water-dependent and environmentally conscious firms and organisations, such as those in the pharmaceutical, food and drink, and wood industries, have the strongest drivers for adoption. However, it must also be considered that reusing water in industrial sites may increase the concentration of effluents discharged to the receiving environment, which may impact on sites' discharge licences. Additionally, there are opportunities for water reuse in large public entities such as hospitals and the HSE, or one-off specific applications such as in airports or power stations. Although agricultural irrigation does not occur in Ireland, opportunities do exist in milk production. The harmonisation of non-domestic water tariffs and registration for water abstractions could potentially increase water costs for industry and provide a significant driver for water reuse.
- Data on industrial water reuse should be collected in a more structured and detailed manner than at present, by modifying the nature of the reporting to the EPA on this topic in the AERs from industries.
- As no water reuse occurs from municipal WWTPs at present in Ireland, the following steps are recommended for future assessments:
    a. An analysis to identify water-stressed regions in Ireland is required, which is currently being carried out by Irish Water.

b. Potential large-scale users of reused water in the region and the quality of water required need to be identified.
c. A suitable WWTP is required that could be upgraded to treat the wastewater to a higher standard.
d. The delivery of the wastewater to the end customer should be considered.
e. Risk and mitigation assessment should be undertaken, from both an environmental and a human perspective, relative to the specific purposes for which recovered water would be employed.

- The drought conditions experienced across the country in summer 2018 have highlighted the need to conserve water and to explore alternative sources of water for non-potable urban and industrial purposes. It is recommended that a water reuse feasibility study for a municipal WWTP should be run to investigate (1) the benefits of reusing treated wastewater for specific purposes, (2) potential applications for water reuse, (3) the cost of treatment and conveyance to the end user and (4) the potential associated risks.
- The stakeholder engagement results suggested that any future municipal water reuse measures should target "lower grade" purposes to attract the best possible public support.
- If municipal water reuse measures are contemplated in future, public engagement should begin at the pre-design stage and involve two-way, and ongoing, interaction with strategic decisions from the outset. A meaningful public engagement process will need to be designed that avoids any suggestion of a minimalist approach or a one-way information-giving exercise.
- There are numerous treatment technologies applied globally for water reuse. A selection of current and developing technologies was reviewed for technical and economic feasibility and environmental impact. Among other technologies, MF or UF with RO, modular WWT, SAT, AOP for SAT, and GAC are recommended for municipal WWTPs, and UV, SAT, modular WWT, MBR and GAC technologies are recommended for industry.
- Water quality standards should be adopted for water that has been recovered from waste streams for reuse; the standards should address different purposes of reuse rather than adopt a single standard for all recovered water. There are a number of examples internationally where such standards have been established, including by the WHO and US EPA, as well as by individual countries within the EU (e.g. Spain) and further afield. There are draft EU regulations to lay down minimum requirements for water quality and monitoring for water reuse, which will provide important guidance for water reuse adoption in Ireland.

Water reuse is occurring in industry in Ireland and further opportunities exist to develop this on a site-by-site basis for all sizes of enterprises. Water reuse is an interdisciplinary and cross-sectorial matter that needs to be considered using an integrated approach. Water reuse practices must be adapted to each local situation in order to be safe, beneficial and sustainable, both financially and environmentally. Public acceptance of the need for such measures and maintaining confidence in their ongoing operation and quality control would require meaningful engagement and effective communication by the scheme promoters.

References

Abel, C.D.T., 2014. Assessment and applicability of primary effluent reuse in developing countries. PhD Thesis. Institute for Water Education, Delft, the Netherlands.

Aharoni, A., Cikurel, H., Jekel, M. and Ernst, M., 2011. Improved SAT processes for all-purpose water production from secondary effluents. Poster presentation, Switch Project Final Conference, The Future of Urban Water: Solutions for Livable and Resilient Cities, UNESCO, Paris, France, January, pp. 24–26.

Alcalde Sans, L. and Gawlic, B., 2014. *Water Reuse in Europe: Relevant Guidelines, Needs for and Barriers to Innovation.* Available online: http://publications.jrc.ec.europa.eu/repository/handle/JRC92582 (accessed 10 March 2018).

AMTA (American Membrane Technology Association), undated. *Membrane Technology Fact Sheets*. Available online: https://www.amtaorg.com/publications-communications/ (accessed 30 April 2019).

Angelakis, A.N. and Bountaux, L., 2001. Wastewater reclamation and reuse in Eureau countries. *Water Policy* 3: 47–59.

Angelakis, A.N. and Durham, B., 2008. Water recycling and reuse in EUREAU countries: trends and challenges. *Desalinisation* 218: 3–12

Angelakis, A.N. and Gikas, P., 2014. Water reuse: overview of current practices and trends in the world with emphasis on EU states. *Water Utility Journal* 8: 67–78.

AQUAREC, 2006. *Integrated Concepts for Reuse of Upgraded Wastewater*. Available online: http://www.susana.org/en/resources/library/details/550 (accessed 30 April 2019).

Asano, T., 2001. Water from (waste) water – the dependable water resource. Paper presented at the 11th Stockholm Water Symposium, Stockholm, Sweden, 12–18 August.

Asano T., Burton, H., Leverenz, H., Tsuchihashi, R. and Tchobanogglous, G., 2007. *Water Reuse: Issues, Technologies and Applications*. McGraw-Hill Professional, New York, NY.

Becerra-Castro C., Lopes, A.R., Vaz-Moreira, I., Silva, E.F., Manaia, C.M. and Nunes, O.C., 2015. Wastewater reuse in irrigation: a microbiological perspective on implications in soil fertility and human and environmental health. *Environment International* 75: 117–135.

BIO, 2015. *Optimising Water Reuse in the EU*. Publications Office of the European Union, Luxembourg. Available online: http://ec.europa.eu/environment/water/blueprint/pdf/BIO_Water%20Reuse%20Public%20Consultation%20Report_Final.pdf (accessed 30 April 2019).

Bird, A.R., 2015. Evaluation of the feasibility of struvite precipitation from domestic wastewater as an alternative phosphorus fertilizer resource. MSc Thesis. University of San Francisco, San Francisco, CA.

Bixio, D., Weemaes, M., Thoeye, C., Ravazzini, A., Miska, V., De koning, J. and Melin, T., 2006. *Water Reuse System Management Manual.* Available online: http://www.lu.lv/materiali/biblioteka/es/pilnieteksti/vide/Water%20Reuse%20System%20Management%20Manual.%20AQUAREC.pdf (accessed 30 April 2019).

Bord Bia, 2017. *Sustainable Horticulture Assurance Scheme: Producer Standard for Growing, Packing & Produce Handling*. Available online: https://hort.bordbia.ie (accessed 30 April 2019).

Brinkmann, T., Santonja, G.G., Yükseler, H., Roudier, S. and Delgado Sancho, L., 2016. Best Available Techniques (BAT) *Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector*. EUR 28112 EN. Available online: http://eippcb.jrc.ec.europa.eu/reference/BREF/CWW_Bref_2016_published.pdf (accessed 30 April 2019).

Brouwer, S., Maas, T., Smith, H. and Frijns, J., 2015. *Trust in Water Reuse: Review Report on International Experiences in Public Involvement and Stakeholder Collaboration.* Available online: http://demoware.eu/en/results/deliverables/deliverable-d5-2-trust-in-reuse.pdf (accessed 30 April 2019).

CIWEM (Chartered Institution of Water and Environmental Management), 2016. *Water Reuse for People and the Environment.* Policy Position Statement. CIWEM, London.

Clean Technology Centre, 2017. *Water Efficiency: A Best Practice Guide for Irish Healthcare Facilities*. Green Healthcare Programme. Available online: https://www.greenhealthcare.ie/wp-content/uploads/2017/10/Healthcare-Water-Efficiency-Guide.pdf (accessed 30 April 2019).

Clere, J., 2016. True cost of water: monetization of water risks, shared value creation, and local acceptability of extractive projects. *Journal of Field Actions* 14. Available online: https://journals.openedition.org/factsreports/4069 (accessed 30 April 2019).

Crook, J. and Jacques, R., 2005. Monterey County water recycling projects: a case study. In *Water Conservation, Reuse, and Recycling: Proceedings of an Iranian–American Workshop.* National Academic Press, Washington, DC. Available online: https://www.nap.edu/read/11241/chapter/1 (accessed 30 April 2019).

Crook, J., Mosher, J.J. and Casteline, J.M., 2005. *Status and Role of Water Reuse: An International View*. Available online: http://www.waterrf.org/resources/Lists/SpecialReports/Attachments/23/WaterReuse.pdf (accessed 25 May 2017).

CSO (Central Statistics Office), 2015. Local authority non-domestic tariff structures. Available online: https://www.cso.ie/en/media/csoie/newsevents/documents/irishwater/7publicsectornondomesticwatercharges.pdf (accessed 30 April 2019).

DAFM (Department of Agriculture, Food and the Marine), 2015. Food Wise 2025. Available online: www.agriculture.gov.ie (accessed 30 April 2019).

Dairywater, 2016. DairyWater project. Available online: http://dairywater.ie/wp-content/uploads/2014/04/DairyWater-Newsletter-Issue-3.pdf (accessed 30 April 2019).

Davis, M., 2010. *Water and Wastewater Engineering: Design Principles and Practice*. McGraw Hill Publishing, New York, NY.

Deloitte, 2016. *Options for a Strategic Approach to Pharmaceuticals in the Environment*. Available online: https://ec.europa.eu/info/sites/info/files/study_report_public_consultation_pharmaceuticals_environment.pdf (accessed 30 April 2019).

Demoware, 2016. *D4.1 – Market Analysis of Key Water Reuse Technologies*. Available online: http://demoware.eu/en/results/deliverables/deliverable-d4-1-market-analysis-of-key-water-reuse-technologies.pdf (accessed 30 April 2019).

Department of Health, 2017. *Ireland's National Action Plan on Antimicrobial Resistance 2017–2020*. iNAP Available online: https://health.gov.ie/wp-content/uploads/2017/10/iNAP_web-1.pdf (accessed 30 April 2019).

DHPLG (Department of Housing, Planning and Local Government), 2018. *River Basin Management Plan for Ireland 2018–2021*. Available online: https://www.housing.gov.ie/sites/default/files/publications/files/rbmp_full_reportweb.pdf (accessed 30 April 2019).

Dolnicar, S. and Hurlimann, A., 2011. Water alternatives – who and what influences public acceptance? *Journal Public Affairs* 11: 49–59.

Duong, K. and Saphores, J.-D.M., 2015. Obstacles to wastewater reuse: an overview. *WIREs Water* 2:199–214.

EC (European Commission), 2010. Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emission (integrated pollution prevention and control). OJ L 334, 17.12.2010, p. 17–119. Available online: http://ec.europa.eu/environment/industry/stationary/ied/legislation.htm (accessed 30 April 2019).

EC (European Commission), 2012a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "A blueprint to safeguard Europe's water resources". COM(2012) 673 final, 14.11.2012, Brussels. Available online: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0673&from=en (accessed 30 April 2019).

EC (European Commission), 2012b. Guidance document on the implementation of certain provisions of Regulation (EC) No 852/2004 on the Hygiene of Foodstuffs. Publications Office of the European Union, Brussels.

EC (European Commission), 2015. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Closing the loop – an EU action plan for the Circular Economy". COM(2015) 614 final, 2.12.2015, Brussels. Available online: https://www.eea.europa.eu/policy-documents/com-2015-0614-final (accessed 30 April 2019).

EC (European Commission), 2016a. *Common Implementation Strategy for the Water Framework Directive and the Floods Directive*. Available online: http://ec.europa.eu/environment/water/pdf/Guidelines_on_water_reuse.pdf (accessed 30 April 2019).

EC (European Commission), 2016b. *EU-level Instruments on Water Reuse*. Publications Office of the European Union, Luxembourg. Available online: http://ec.europa.eu/environment/water/blueprint/pdf/EU_level_instruments_on_water-2nd-IA_support-study_AMEC.pdf (accessed 30 April 2019).

EC (European Commission), 2016c. Commission implementing Decision (EU) 2016/902 of 30 May 2016 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for common waste water and waste gas treatment/management systems in the chemical sector. OJ L 152, 9.6.2016. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.152.01.0023.01.ENG (accessed 30 April 2019).

EC (European Commission), 2017. *Scientific Advice on Proposed EU Minimum Quality Requirements for Water Reuse in Agricultural Irrigation and Aquifer Recharge*. Publications Office of the European Union, Luxembourg. Available online: https://ec.europa.eu/health/sites/health/files/scientific_committees/scheer/docs/scheer_o_010.pdf (accessed 30 April 2019).

EC (European Commission), 2018. Proposal for a Regulation of the European Parliament and of the Council on Minimum Requirements for Water Reuse. 2018/0169 (COD). Publications Office of the European Union, Luxembourg. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018PC0337 (accessed 30 April 2019).

Engineers Ireland, 2017. Process water recovery in the food & beverage and pharma & bio-pharma industries; opportunities, challenges & latest technologies. Paper presented at the Seminar at Ballsbridge, Dublin, Ireland, 25 May.

EPA (Environmental Protection Agency), 2010. *Drinking Water Guidance on Disinfection By-Products. Advice Note No. 4. Version 2.* EPA, Johnstown Castle, Ireland. Available online: http://www.epa.ie/pubs/advice/drinkingwater/DrinkingWaterGuide4_v8.pdf (accessed 24 July 2019).

EPA (Environmental Protection Agency), 2011. *The EPA & Climate Change. Responsibilities, Challenges and Opportunities 2011 Update*. EPA, Johnstown Castle, Ireland. Available online: http://www.epa.ie/pubs/reports/climatechange/The%20EPA%20and%20Climate%20Change%20-%202011%20Update.pdf (accessed 31 August 2017).

EPA (Environmental Protection Agency), 2016a. *Urban Waste Water Treatment in 2015*. EPA, Johnstown Castle, Ireland. Available online: https://www.epa.ie/pubs/reports/water/wastewater/2015%20urban%20waste%20water%20report_Web%20Version.pdf (accessed 30 April 2019).

EPA (Environmental Protection Agency), 2016b. *Ireland's Environment: An Assessment*. EPA, Johnstown Castle, Ireland. Available online: http://www.epa.ie/pubs/reports/indicators/SoE_Report_2016.pdf (accessed 30 April 2019).

EPA (Environmental Protection Agency), 2016c. *Drinking Water Report for Public Water Supplies 2016*. Johnstown Castle, Ireland. Available online: http://www.epa.ie/pubs/reports/water/drinking/EPA_DW_Report%202016.pdf (accessed 25 July 2019).

EPA (Environmental Protection Agency), 2017. *Urban Waste Water Treatment in 2016*. EPA, Johnstown Castle, Ireland. Available online: http://www.epa.ie/pubs/reports/water/wastewater/uwwreport2016.html (accessed 30 April 2019).

EU (European Union), 1991. Council Directive 91/271/EEC concerning urban waste-water treatment. OJ L 135, 30.5.1991, p. 40–52. Available online: http://ec.europa.eu/environment/water/water-urbanwaste/index_en.html (accessed 30 April 2019).

EU (European Union), 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. OJ L 327, 22.12.2000, p. 1–73. Available online: http://ec.europa.eu/environment/water/water-framework/index_en.html (accessed 1 April 2019).

EU (European Union), 2004. Regulation (EC) No 852/2004 of the European Parliament and the Council of 29 April 2004 on the hygiene of foodstuffs. OJ L 139, 30.4.2004, p. 1.

Fiorentino, A., Ferro, G., Castro, A.M., Polo-López, M.I., Fernández-Ibañez, P. and Rizzo, L., 2015. Inactivation and regrowth of multidrug resistant bacteria in urban wastewater after disinfection by solar-driven and chlorination processes. *Journal of Photochemistry and Photobiology B: Biology* 148: 43–50.

Frijns, J., Smith, H., Brouwer, S., Garnett, K., Elelman, R. and Jeffrey, P., 2016. How governance regimes shape the implementation of water reuse schemes. *Water* 8: 605.

FSAI (Food Safety Authority of Ireland), 2016. *Guidance Note 31 – Fresh Produce Safety in Primary Produce Production*. FSAI, Dublin.

Gaines, M., 2014. Dairy Crest invests in wastewater treatment and water reuse plant. *Water & Wastewater Treatment*, 25 September. Available online: http://wwtonline.co.uk/news/dairy-crest-invests-in-wastewater-treatment-and-water-reuse-plant#.WWXIPojyvIU (accessed 10 April 2017).

GEA Process Engineering, 2018. Membrane filtration: reverse osmosis, nanofiltration, ultrafiltration and microfiltration. Available online: https://www.gea.com/en/binaries/membrane-filtration-ultrafiltration-nanofiltration-microfiltration-reverse-osmosis-gea_tcm11-34841.pdf (accessed 30 April 2019).

Gerrity, D. and Snyder, S., 2011. Review of ozone for water reuse applications: toxicity, regulations, and trace organic contaminant oxidation. *Ozone: Science & Engineering* 33: 253-266.

Giakoumis, T. and Voulvoulis, N. The transition of EU water policy towards the Water Framework Directive's integrated river basin management paradigm. *Environmental Management* 62: 819–831.

Giannakis, S., Voumard, M., Grandjean, D., Magnet, A., De Alencastro, L.F. and Pulgarin, C., 2016. Micropollutant degradation, bacterial inactivation and regrowth risk in wastewater effluents: influence of the secondary (pre)treatment on the efficiency of advanced oxidation processes. *Water Research* 102: 505–515.

Gleeson, E., McGrath, R. and Treanor, M., 2013. *Ireland's Climate: The Road Ahead*. Met Éireann, Dublin.

Guo, C., Krasner, S., Fitzsimmins, S., Woodside, G. and Yamachika, N., 2010. *Source, Fate, and Transport of Endocrine Disruptors, Pharmaceuticals, and Personal Care Products in Drinking Water Sources in California*. National Water Research Institute, Fountain Valley, CA.

Hamilton, A., Versace, V., Stagnitti, F., Peijun, L., Wei, Y., Maher, P., Hermon, K., Premier, R. and Ierodiaconou, D., 2007. *Balancing Environmental Impacts and Benefits of Wastewater Reuse*. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.453.8633&rep=rep1&type=pdf (accessed 30 April 2019).

Hartley, T.W., 2006. Public perception and participation in water reuse. *Desalination* 187: 115–126.

Horizon 2020, 2014. Technology readiness levels classification 2014–2015. Available online: https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf (accessed 30 April 2019).

Hurlimann, A. and Dolnicar, S., 2010. When public opposition defeats alternative water projects: the case of Toowoomba Australia. *Water Research* 44: 287–297.

Irish Water, 2015a. *Water Services Strategic Plan – A Plan for the Future of Water Services*. Available online: http://www.water.ie/docs/WSSP_Final.pdf (accessed 30 April 2019).

Irish Water, 2015b. Irish Water publishes the "Need Report" for the Eastern and Midlands Region Water Supply Project. Available online: http://www.watersupplyproject.ie/2015/03/11/irish-water-publishes-the-need-report-for-the-proposed-eastern-and-midlands-region-water-supply-project-wsp/ (accessed 30 April 2019).

Irish Water, 2018. *National Water Resources Plan: Strategic Environmental Assessment Scoping Report*. Dublin. Available online: https://www.water.ie/projects-plans/our-plans/nwrp/SEA-Scoping-Report-FINAL.PDF (accessed 30 April 2019).

Janosova, B., Miklankova, J., Hlavinek, P. and Wintegns, T., 2006. Drivers for wastewater reuse: regional analysis in the Czech Republic. *Desalination* 187: 103–114.

Jiménez, B. and Asano, T., 2008. *Water Reuse: An International Survey of Current Practices, Issues and Needs*. IWA Publishing, London.

Juby, G.J.G. and Zacheis, G.A., 2017. Brine treatment scaling control system and method. US Patent 9,561,471. Available online: https://patents.justia.com/inventor/graham-john-gibson-juby (accessed 24 July 2019).

Lacey, C., 2008. Assessment of pharmaceutical residue levels in three Irish sewage treatment plants. PhD Thesis, Dublin City University, Dublin. Available online: http://www.epa.ie/researchandeducation/research/epafunding/postgraduateprogrammes/doctoral/abstract-clairlacey/ (accessed 30 April 2019).

Lautze, J., Stander, E., Drechsel, P., da Silva, A.K. and Keraita, B., 2014. *Global Experiences in Water Reuse.* Available online: www.iwmi.cgiar.org/Publications/wle/rrr/resource_recovery_and_reuse-series_4.pdf (accessed 30 April 2019).

Li, D., Zeng, S., Gu, A.Z., He, M. and Shi, H., 2013. Inactivation, reactivation and regrowth of indigenous bacteria in reclaimed water after chlorine disinfection of a municipal wastewater treatment plant. *Journal of Environmental Sciences* 25: 1319–1325.

McEneff, G., Barron, L., Kelleher, B., Paull, B. and Quinn, B. 2014. A year-long study of the spatial occurrence and relative distribution of pharmaceutical residues in sewage effluent, receiving marine waters and marine bivalves. *Science of the Total Environment* 476–477: 317–326.

Marcano, L., 2012. Energy optimization of membrane bioreactors. MSc Thesis. Lund University, Lund, Sweden.

Marks, J.S., Martin, B. and Zadoroznyj, M., 2006. Acceptance of water recycling in Australian national baseline data. *Water* 33: 151–157.

Mitch, W.A., Sharp, J.O., Trussell, R.R., L. Valentine, R.L., Alvarez-Cohen, L. and Sedlak, D.L., 2003. *N*-Nitrosodimethylamine (NDMA) as a drinking water contaminant: a review. *Environmental Engineering Science* 20(5).

Molinos-Senante, M., Hernández-Sancho, F. and Sala-Garrido, R., 2011. Cost–benefit analysis of water-reuse projects for environmental purposes: a case study for Spanish wastewater treatment plants. *Journal of Environmental Management* 92: 3091–3097.

Murphy, E., 2018. Written answers – water services infrastructure [15624/18]. 17 April 2018. Dáil Éireann Debate, vol. 967, no. 4. Available online: http://oireachtasdebates.oireachtas.ie/ (accessed 30 April 2019).

Murray, F., Hamill, A. and Clancy, M., 2010. *Recovery & Reuse of Water and Carbon Dioxide from Industrial Waste Streams*. Environmental Protection Agency, Johnstown Castle, Ireland.

Nafo, I., Evenblij, H., Cornelissen, A., McArdell, C., Pahl, O. and Dagot, C., 2012. *Pharmaceutical Input and Elimination from Local Sources*. Final report of the European cooperation project PILLS. Emscher Genossenschaft (DE) on behalf of the PILLS partnership. Available online: https://www.researchgate.net/profile/Karin_Helwig/publication/290451422_Pharmaceutical_input_and_elimination_from_local_sources/links/573b1f7e08ae9f741b2d773f/Pharmaceutical-input-and-elimination-from-local-sources.pdf (accessed 30 April 2019).

NFGWS (National Federation of Group Water Schemes), 2017. *Annual Report: National Federation of Group Water Schemes*. Available online: https://nfgws.ie/wp-content/uploads/2018/10/Annual-Report-2017-final.pdf (accessed 24 July 2019).

NRC (National Research Council), 2012. *Understanding Water Reuse: Potential for Expanding the Nation's Water Supply through Reuse of Municipal Wastewater*. National Academies Press, Washington, DC. Available online: https://www.nap.edu/read/13303/chapter/6 (accessed 30 April 2019).

Ormerod, K.J. and Scott, C.A., 2013. Drinking wastewater: public trust in potable reuse. *Science Technology and Human Values* 38: 351–373.

Po, M., Kaercher, J.D. and Nancarrow, B.E., 2004. *Literature Review of Factors Influencing Public Perceptions of Water Reuse*. Technical Report 54/03. CSIRO, Perth, Australia.

PUB (Singapore's National Water Agency), 2017a. *Annual Report and Financial Report FY2015*. Available online: https://www.pub.gov.sg/annualreports/annualreport2016.pdf (accessed 30 April 2019).

PUB (Singapore's National Water Agency), 2017b. NEWater technology. Available online: https://www.pub.gov.sg/Documents/NEWater%20Technology.pdf (accessed 30 April 2019).

Quinn, B., McEneff, G. and Schmidt, W., 2015. *Pharmaceuticals in the Irish Aquatic Environment: The Assessment and Potential Human Impact of Exposure to Pharmaceuticals on Marine and Freshwater Bivalves*. Environmental Protection Agency, Johnstown Castle, Ireland. Available online: https://www.epa.ie/pubs/reports/research/health/Research%20Report%20143%20web.pdf (accessed 30 April 2019).

Raab, J. and Susskind, L., 2009. New approaches to consensus building and speeding up large-scale energy infrastructure projects. The Expansion of the German Transmission Grid Conference, Göttingen University, Göttingen, Germany, 23 June 2009.

Raghav, M., Eden, S., Mitchell, S. and Witte, B., 2013. Contaminants of Emerging Concern in Water. *Arroyo*, pp. 1–12. Available online: https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/Arroyo2013LR_0.pdf (accessed 30 April 2019).

Rigler, F.H., 1973. A dynamic view of the phosphorus cycle in lakes. In Griffith, E.J., Beeton, A., Spencer, J.M. and Mitchell, D.T. (eds), *Environmental Phosphorus Handbook*. J. Wiley & Sons, New York, NY, pp. 539–568.

Ross, V.L., Fielding, K.S. and Louis, W.R., 2014. Social trust, risk perceptions and public acceptance of recycled water: testing a social-psychological model. *Journal of Environmental Management* 137: 61–68

Salgot, M., 2008. Water reclamation, recycling and reuse. *Desalination* 218: 190–197.

Salimi, M., Esrafili, A., Gholami, M., Jafari, A.J., Kalantary, R.R., Farzadkia, M., Kermani, M. and Sobhi, H.R., 2017. Contaminants of emerging concern: a review of new approach in AOP technologies. *Environmental Monitoring and Assessment* 189: 414.

Shakir, E., Zahraw, Z. and Al-Obaidy, A.H.M.J., 2017. Environmental and health risks associated with reuse of wastewater for irrigation. *Egyptian Journal of Petroleum* 26: 95–102.

Sharma, S.K. and Sanghi, R. (eds), 2012. *Advances in Water Treatment and Pollution Prevention*. Springer, Dordrecht, the Netherlands.

Sharma, S.K. and Kennedy, M.D., 2017. Soil aquifer treatment for wastewater treatment and reuse. *International Biodeterioration & Biodegradation* 119: 671–677.

Spanish Association for the Sustainable Use of Water, 2011. Spanish Regulations for Water Reuse Royal Decree 1620/2007 of 7 December. Available online: https://www.boe.es/eli/es/rd/2007/12/07/1620/con (accessed 24 July 2019).

STOWA (Stichting Toegepast Onderzoek Waterbeheer), 2018. *Pacas – Poederkooldosering in Actiefslib voor Verwijdering van Microverontreinigingen*. Available online: https://www.stowa.nl/sites/default/files/assets/PUBLICATIES/Publicaties%202018/STOWA%202018-02%20Pacas.pdf (accessed 30 April 2019).

Suldovsky, B., 2017. The information deficit model and climate change communication. *Oxford Research Encyclopaedia of Climate Science*. Available online: http://oxfordre.com/climatescience/view/10.1093/acrefore/9780190228620.001.0001/acrefore-9780190228620-e-301 (accessed 30 April 2019).

Ternes, T.A. and Joss, A., 2006. *Human Pharmaceuticals, Hormones and Fragrances: The Challenge of Micropollutants in Urban Water Management*. IWA Publishing, London, p. 443.

Ternes, T., Joss, A. and Oehlmann, J., 2015. Occurrence, fate, removal and assessment of emerging contaminants in water in the water cycle (from wastewater to drinking water). *Water Research* 72: 1–2.

Thames Water, 2013. *Technology Choice for Planned Indirect Potable Reuse for London*. Final Report of the Independent Expert Review Panel. Available online: https://corporate.thameswater.co.uk/About-us/Our-strategies-and-plans/Water-resources (accessed 19 July 2017).

Thomas, J.-S. and Durham, B., 2003. Integrated Water Resource Management: looking at the whole picture. *Desalination* 156: 21–28.

TYPSA, 2013. *Updated Report on Wastewater Reuse in the European Union*. Available online: http://ec.europa.eu/environment/water/blueprint/pdf/Final%20Report_Water%20Reuse_April%202013.pdf (accessed June 2019).

UN (United Nations), 2015. *Transforming our World – The 2030 Agenda for Sustainable Development*. A/RES/70/1. Available online: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (accessed 1 April 2019).

US EPA (United States Environmental Protection Agency), 2012. *Guidelines for Water Reuse.* US EPA, Washington, DC. Available online: https://www3.epa.gov/region1/npdes/merrimackstation/pdfs/ar/AR-1530.pdf (accessed 30 April 2019).

Veolia Water Technologies, 2013. *Reclamation Relieves Water Stress in Tarragona*. Available online: http://www.veoliawatertech.com/vwst-southeastasia/ressources/documents/1/44500-Reclamation-in-Tarragona-WRD-WEFP.pdf (accessed 24 July 2019).

Walesh, S., 1999. DAD is out, Pop is in. *Journal of the American Water Resources Association* 35: 535–544.

WEDECO, (undated). UV technical specifications. Available online: http://www.xylemwatersolutions.com/scs/russia/en-us/products/disinfection/Documents/K_series_english.pdf (accessed 30 April 2019).

Wester, J., Timpano, K.R., Çek, D., Lieberman, D., Fieldstone, S.C. and Broad, K., 2015. Psychological and social factors associated with wastewater reuse emotional discomfort. *Journal Environmental Psychology* 42: 16–23.

WHO (World Health Organization), 2006. *Guidelines for the Safe Use of Wastewater, Excreta and Greywater – Volume 4: Excreta and Greywater Use in Agriculture*. WHO, Geneva.

WHO (World Health Organization), 2017a. *Guidelines for Drinking-water Quality*, *4th Edition, Incorporating the First Addendum*. WHO, Geneva. Available online: http://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en (accessed 30 April 2019).

WHO (World Health Organization), 2017b. *Potable Reuse: Guidance for Producing Safe Drinking-Water.* Available online: https://apps.who.int/iris/bitstream/handle/10665/258715/9789241512770-eng.pdf?sequence=1&isAllowed=y (accessed 30 April 2019).

Wintgens, T. and Hochstrat, R., 2006. *Report on Integrated Water Reuse Concepts – Integrated Concepts for Reuse of Upgraded Wastewater*. Aquarec. EVK1-CT-2002-00130, D19. Available online: https://www.susana.org/_resources/documents/default/2-551-wintgens-hochstrat-2006-d19-integrated-reuse-aquarec-en.pdf (accessed 30 April 2019).

WWAP (United Nations World Water Assessment Programme), 2017. *The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource*. United Nations Educational, Scientific and Cultural Organization, Paris.

Xie, 2006. *Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement*. Available online: http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf (accessed 24 July 2017).

Abbreviations

AC	Activated carbon
AER	Annual Environmental Report
AnMBR	Anaerobic membrane bioreactor
AOP	Advanced oxidation process
AS	Activated sludge
BAT	Best available technique
BOD	Biological oxygen demand
CAPEX	Capital expenditure
CEC	Contaminant of emerging concern
CIT	Cork Institute of Technology
CIWEM	Chartered Institute of Water and Environmental Management
COD	Chemical oxygen demand
CRU	Commission for Regulation of Utilities
CSO	Central Statistics Office
DBP	Disinfection by-product
EC	European Commission
EDC	Endocrine disruptors compound
ELV	Emission limit values
EPA	Environmental Protection Agency
EU	European Union
EU FP7	Seventh Framework Programme
FO	Forward osmosis
FO-MBR	Forward osmosis membrane bioreactor
FR	Flame retardant
GAC	Granular activated carbon
HSE	Health Service Executive
IED	Industrial Emissions Directive
MAR	Managed aquifer recharge
MBBR	Moving bed biofilm reactor
MBR	Membrane bioreactor
MF	Microfiltration
NDMA	*N*-Nitrosodimethylamine
NF	Nanofiltration
N_{total}	Total nitrogen
NTU	Nephelometric turbidity unit
NWRP	National Water Resources Plan
OPEX	Operational expenditure
PAC	Powdered activated carbon
PE	Population equivalent
PFAS	Polyfluoroalkyl substance(s)
PPCPs	Pharmaceuticals and personal care products
P_{total}	Total phosphorus
PUB	Public Utilities Board
RO	Reverse osmosis
SAT	Soil aquifer treatment

SDG	Sustainable Development Goal
TRL	Technology readiness level
TSS	Total suspended solids
UF	Ultrafiltration
US EPA	US Environmental Protection Agency
UV	Ultraviolet
UWWTD	Urban Wastewater Treatment Directive
WFD	Water Framework Directive
WHO	World Health Organization
WSP	Waste stabilisation pond
WWT	Wastewater treatment
WWTP	Wastewater treatment plant

Appendix 1 Quality Criteria for Water Reuse

Table A1.1. Proposed EU requirements for quality of reclaimed water for agricultural irrigation

Reclaimed water quality class	Indicative technology target	Quality requirements				Other
		E. coli (cfu/100 ml)	BOD (mg/l)	TSS (mg/l)	Turbidity (NTU)	
A	Secondary treatment, filtration and disinfection	≤10 or below detection limit	≤10	≤10	≤5	*Legionella* spp.: <1000 cfu/l where there is risk of aerosolisation in greenhouses. Intestinal nematodes (helminth eggs): ≤1 egg/l for irrigation of pastures or forage
B	Secondary treatment and disinfection	≤100	According to Council Directive 91/271/EEC (EU, 1991; Annex I, Table 1)	According to Council Directive 91/271/EEC (EU, 1991; Annex I, Table 1)	–	
C	Secondary treatment and disinfection	≤1000			–	
D	Secondary treatment and disinfection	≤10,000			–	

A, all food crops, including root crops consumed raw and food crops where the edible part is in direct contact with reclaimed water (all irrigation methods); B and C, food crops consumed raw, where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops, including crops to feed milk- or meat-producing animals (B, all irrigation methods; C, drip irrigation only); D, industrial, energy and seeded crops (all irrigation methods).

Table A1.2. Spanish quality criteria for water reuse (sample)

Intended use of water	Maximum acceptable value				
	Intestinal nematodes (eggs/10 l)	*E. coli* (cfu/100 ml)	Suspended solids (mg/ml)	Turbidity (NTU)	Other criteria
Urban uses					
Quality 1.1 – Residential					
Irrigation of private gardens	1	0	10	2	Other contaminants are included in the treated effluent disposal permit; discharge of these contaminants to the environment must be limited. In the case of hazardous substances, use of reclaimed water must comply with environmental quality standards. *Legionella* spp.: 100 cfu/l (if there is a risk of aerosolisation)
Supply to sanitary appliances	1	0	10	2	
Quality 1.2 – Services					
Landscape irrigation of urban areas	1	200	20	10	Other contaminants are included in the treated effluent disposal permit; discharge of these contaminants to the environment must be limited. In the case of hazardous substances, use of reclaimed water must comply with environmental quality standards. *Legionella* spp.: 100 cfu/l (if there is a risk of aerosolisation)
Street cleaning	1	200	20	10	
Fire hydrants	1	200	20	10	
Industrial washing of vehicles	1	200	20	10	

Table A1.2. Continued

Intended use of water	Maximum acceptable value				
	Intestinal nematodes (eggs/10 l)	*E. coli* (cfu/100 ml)	Suspended solids (mg/ml)	Turbidity (NTU)	Other criteria
Agricultural uses					
Quality 2.1					
Crop irrigation using a system whereby reclaimed water comes into direct contact with edible parts of crops to be eaten raw	1	100	20	10	*Legionella* spp.: 100 cfu/l (if there is a risk of aerosolisation)

Appendix 2 Plant and Agglomeration Data (2015)

Table A2.1. Municipal wastewater treatment plant data for Ireland

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Dublin City Council	Ringsend	D0034-01	2,316,000	1,640,000	Estuarine	Yes	2	Yes	Large	Large
Cork City Council	Cork City	D0033-01	300,013	413,200	Estuarine	Yes	2	No	Large	Large
Waterford City and County Council	Waterford City	D0022-01	86,671	190,600	Estuarine	No	2	No	Large	Large
Dún Laoghaire–Rathdown County Council	Shanganagh	D0038-01	122,182	186,000	Coastal water	No	2	No	Large	Large
Louth County Council	Dundalk	D0053-01	54,604	179,107	Estuarine	Yes	2	No	Large	Large
Kildare County Council	Leixlip	D0004-02	117,398	150,000	Freshwater (river)	Yes	3NP	No	Large	Large
Limerick City and County Council	Limerick City	D0013-01	263,814	130,000	Estuarine	No	2	No	Large	Large
Louth County Council	Drogheda	D0041-01	65,186	101,600	Estuarine	Yes	2	No	Large	Large
Galway City Council	Galway	D0050-01	145,000	91,600	Coastal water	No	2	No	Large	Large
Kildare County Council	Osberstown	D0002-01	101,620	80,000	Freshwater (river)	Yes	3P	No	Large	Large
Tipperary County Council	Clonmel	D0035-01	32,144	80,000	Freshwater (river)	Yes	3NP	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Kilkenny County Council	Kilkenny City	D0018-01	41,605	77,000	Freshwater (river)	Yes	3P	No	Large	Large
Fingal County Council	Balbriggan – Skerries	D0023-01	37,423	70,000	Coastal water	No	2	Yes	Large	Large
Fingal County Council	Portrane Donabate	D0114-01	22,222	65,000	Coastal water	No	2	Yes	Large	Large
Cork County Council	Ringaskiddy-Crosshaven-Carrigaline	D0057-01	116,982	65,000	Coastal water	No	2	No	Large	Large
Fingal County Council	Swords	D0024-01	82,342	60,000	Estuarine	Yes	3NP	No	Large	Large
Westmeath County Council	Mullingar	D0008-01	16,762	55,000	Freshwater (river)	Yes	3NP	No	Large	Large
Kerry County Council	Killarney	D0037-01	41,836	54,000	Freshwater (river)	No	3NP	No	Large	Large
Kerry County Council	Tralee	D0040-01	17,070	50,333	Estuarine	Yes	2	Yes	Large	Large
Meath County Council	Navan	D0059-01	45,881	50,000	Freshwater (river)	Yes	3NP	No	Large	Large
Sligo County Council	Sligo	D0014-01	27,408	50,000	Estuarine	No	3P	Yes	Large	Large
Offaly County Council	Tullamore	D0039-01	20,080	45,000	Freshwater (river)	Yes	3P	No	Large	Large
Wexford County Council	Wexford Town	D0030-01	38,696	45,000	Estuarine	Yes	3NP	Yes	Large	Large
Donegal County Council	Letterkenny	D0009-01	29,542	40,000	Estuarine	No	3P	No	Large	Large
Wicklow County Council	Greystones	D0010-01	41,284	40,000	Coastal water	No	2	No	Large	Large
Laois County Council	Portlaoise	D0001-01	42,832	39,000	Freshwater (river)	Yes	3NP	No	Large	Large
Monaghan County Council	Monaghan	D0061-01	13,877	37,400	Freshwater (river)	No	3P	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Carlow County Council	Carlow	D0028-01	39,296	36,000	Freshwater (river)	Yes	3NP	No	Large	Large
Wicklow County Council	Wicklow	D0012-01	17,770	34,000	Coastal Water	No	2	No	Large	Large
Cork County Council	Ballincollig	D0049-01	36,493	33,000	Freshwater (river)	No	3NP	No	Large	Large
Cavan County Council	Cavan	D0020-01	36,047	30,000	Freshwater (river)	Yes	3P	No	Large	Large
Westmeath County Council	Athlone	D0007-01	32,435	30,000	Freshwater (river)	Yes	3NP	No	Large	Large
Limerick City and County Council	Castletroy	D0019-01	24,151	29,477	Freshwater (river)	No	3P	No	Large	Large
Kildare County Council	Kildare Town	D0178-01	8215	28,000	Freshwater (river)	No	3P	No	Large	Large
Mayo County Council	Castlebar	D0047-01	18,500	28,000	Freshwater (river)	Yes	3NP	No	Large	Large
Tipperary County Council	Roscrea	D0025-01	14,658	26,000	Freshwater (river)	Yes	3P	No	Large	Large
Mayo County Council	Ballina	D0016-01	20,094	25,000	Estuarine	No	3P	No	Large	Large
Waterford City and County Council	Dungarvan	D0017-01	24,552	25,000	Coastal Water	No	2	No	Large	Large
Galway County Council	Tuam	D0031-01	16,368	24,834	Freshwater (river)	No	3P	No	Large	Large
Fingal County Council	Malahide	D0021-01	19,613	21,000	Estuarine	No	2	Yes	Large	Large
Cork County Council	Clonakilty	D0051-01	27,352	20,500	Estuarine	Yes	2	No	Large	Large
Cork County Council	Bandon	D0136-01	10,396	20,000	Freshwater (river)	No	2	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Waterford City and County Council	Tramore	D0015-01	16,000	20,000	Coastal Water	No	2	No	Large	Large
Tipperary County Council	Nenagh	D0027-01	17,986	18,000	Freshwater (river)	Yes	3P	No	Large	Large
Clare County Council	Ennis North	D0048-01	20,873	17,000	Freshwater (river)	Yes	2	No	Large	Large
Longford County Council	Longford	D0060-01	18,398	17,000	Freshwater (river)	Yes	3NP	No	Large	Large
Wexford County Council	Enniscorthy	D0029-01	17,023	16,000	Estuarine	Yes	2	No	Large	Large
Wexford County Council	New Ross	D0036-01	12,841	16,000	Estuarine	No	2	No	Large	Large
Mayo County Council	Westport	D0055-01	18,152	15,042	Estuarine	No	3NP	No	Large	Large
Cork County Council	Midleton	D0056-01	16,879	15,000	Coastal Water	Yes	3N	Yes	Large	Large
Kildare County Council	Athy	D0003-01	13,800	15,000	Freshwater (river)	Yes	3P	No	Large	Large
Tipperary County Council	Thurles	D0026-01	11,534	15,000	Freshwater (river)	Yes	3P	No	Large	Large
Roscommon County Council	Monksland	D0042-01	8731	14,381	Freshwater (river)	No	3P	No	Large	Large
Galway County Council	Ballinasloe	D0032-01	8838	13,500	Freshwater (river)	No	3P	No	Large	Large
Cork County Council	Blarney	D0043-01	10,160	13,000	Freshwater (river)	No	3NP	No	Large	Large
Laois County Council	Portarlington	D0158-01	10,013	13,000	Freshwater (river)	Yes	2	No	Large	Large
Monaghan County Council	Castleblayney	D0205-01	11,560	12,960	Freshwater (lake)	Yes	3P	No	Large	Large
Clare County Council	Shannon	D0045-01	17,552	12,500	Estuarine	No	2	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Kerry County Council	Listowel	D0179-01	8003	12,500	Freshwater (river)	No	2	No	Large	Large
Monaghan County Council	Carrickmacross	D0062-01	12,041	12,150	Freshwater (river)	Yes	3NP	No	Large	Large
Cork County Council	Carrigtwohill	D0044-01	16,200	12,000	Estuarine	Yes	2	No	Large	Large
Donegal County Council	Donegal Town	D0135-01	5489	12,000	Estuarine	No	2	No	Large	Large
Meath County Council	Dunshaughlin	D0138-01	9611	12,000	Freshwater (river)	No	3P	No	Large	Large
Meath County Council	Trim	D0137-01	7224	12,000	Freshwater (river)	No	3P	No	Large	Large
Offaly County Council	Birr	D0109-01	10,363	12,000	Freshwater (river)	No	3P	No	Large	Large
Leitrim County Council	Carrick on Shannon	D0154-01	5676	11,500	Freshwater (river)	No	3P	No	Large	Large
Cork County Council	Fermoy	D0058-01	17,125	11,000	Freshwater (river)	Yes	3P	No	Large	Large
Tipperary County Council	Carrick-on-Suir	D0148-01	8924	11,000	Estuarine	Yes	3NP	No	Large	Large
Cork County Council	Mallow	D0052-01	9661	10,500	Freshwater (river)	Yes	3P	No	Large	Large
Wexford County Council	Courtown Gorey	D0046-01	9416	10,000	Coastal Water	No	2	No	Large	Large
Cork County Council	Kinsale	D0132-01	7414	9800	Estuarine	Yes	3NP	Yes	Large	Large
Tipperary County Council	Tipperary Town	D0146-01	10,103	9800	Freshwater (river)	No	3P	No	Large	Large
Roscommon County Council	Roscommon	D0116-01	6748	9550	Freshwater (river)	Yes	3P	No	Large	Large
Galway County Council	Loughrea	D0194-01	6148	9500	Freshwater (river)	No	3P	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Offaly County Council	Edenderry	D0110-01	4511	9500	Freshwater (river)	No	3P	No	Large	Large
Kildare County Council	Monasterevin	D0177-01	4896	9000	Freshwater (river)	Yes	3P	No	Large	Large
Limerick City and County Council	Newcastle West	D0108-01	14,034	9000	Freshwater (river)	No	3P	No	Large	Large
Offaly County Council	Clara	D0142-01	5167	9000	Freshwater (river)	Yes	3P	No	Large	Large
Tipperary County Council	Cashel	D0171-01	10,916	9000	Freshwater (river)	No	3P	No	Large	Large
Clare County Council	Lahinch	D0080-01	3900	8400	Freshwater (river)	No	2	No	Large	Large
Kerry County Council	Ballybunion	D0183-01	3760	8180	Estuarine	Yes	2	No	Large	Large
Mayo County Council	Ballinrobe	D0070-01	14,530	8000	Freshwater (river)	No	3P	No	Large	Large
Meath County Council	Kells	D0127-01	8192	8000	Freshwater (river)	No	2	No	Large	Large
Monaghan County Council	Ballybay	D0207-01	2316	7823	Freshwater (river)	No	2	No	Large	Large
Cork County Council	Charleville	D0204-01	11,720	7500	Freshwater (river)	No	3P	No	Large	Large
Kilkenny County Council	Thomastown	D0151-01	2966	7500	Freshwater (river)	Yes	3P	No	Large	Large
Laois County Council	Mountmellick	D0152-01	4765	7000	Freshwater (river)	No	2	No	Large	Large
Meath County Council	Duleek	D0133-01	5158	7000	Freshwater (river)	No	3P	No	Large	Large
Mayo County Council	Swinford	D0068-01	6616	6500	Freshwater (river)	No	3P	No	Large	Large
Wexford County Council	Bunclody	D0163-01	3036	6500	Freshwater (river)	No	3P	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Wexford County Council	Courtown Gorey	D0046-01	9132	6500	Freshwater (river)	No	3P	No	Large	Large
Donegal County Council	Ballyshannon	D0128-01	2104	6100	Estuarine	No	2	No	Large	Large
Clare County Council	Ennis South	D0199-01	2826	6000	Freshwater (river)	Yes	3P	No	Large	Large
Clare County Council	Sixmilebridge	D0076-01	2435	6000	Freshwater (river)	No	3P	No	Large	Large
Cork County Council	Mitchelstown	D0202-01	7272	6000	Freshwater (river)	No	3P	No	Large	Large
Galway County Council	Athenry	D0193-01	4247	6000	Freshwater (river)	No	3P	No	Large	Large
Galway County Council	Clifden	D0198-01	3737	6000	Estuarine	No	3P	Yes	Large	Large
Kerry County Council	Castleisland	D0180-01	4918	6000	Freshwater (river)	No	3P	No	Large	Large
Louth County Council	Blackrock	D0188-01	5104	6000	Estuarine	No	2	No	Large	Large
Roscommon County Council	Boyle	D0121-01	3594	6000	Freshwater (river)	No	3P	No	Large	Large
Tipperary County Council	Templemore	D0190-01	2146	6000	Freshwater (river)	No	3P	No	Large	Large
Wicklow County Council	Blessington	D0063-01	6948	6000	Freshwater (lake)	No	3P	No	Large	Large
Wicklow County Council	Enniskerry	D0088-01	4171	6000	Freshwater (river)	No	3P	No	Large	Large
Donegal County Council	Carndonagh	D0113-01	5424	5833	Freshwater (river)	No	2	Yes	Large	Large
Kerry County Council	Kenmare	D0184-01	6200	5833	Freshwater (river)	No	2	No	Large	Large
Meath County Council	Athboy	D0124-01	2885	5800	Freshwater (river)	No	3P	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Kerry County Council	Cahersiveen	D0181-01	2770	5600	Estuarine	No	2	No	Large	Large
Mayo County Council	Claremorris	D0071-01	4459	5333	Freshwater (river)	No	3P	No	Large	Large
Cork County Council	Macroom	D0126-01	4727	5055	Freshwater (river)	No	3P	No	Large	Large
Clare County Council	Newmarket on Fergus	D0079-01	6550	5000	Freshwater (lake)	No	3P	No	Large	Large
Kerry County Council	Killorglin	D0182-01	4644	5000	Estuarine	No	2	No	Large	Large
Louth County Council	Ardee	D0117-01	8639	5000	Freshwater (river)	No	2	No	Large	Large
Tipperary County Council	Cahir	D0167-01	4679	5000	Freshwater (river)	No	3P	No	Large	Large
Westmeath County Council	Moate	D0097-01	4207	5000	Freshwater (river)	No	3NP	No	Large	Large
Westmeath County Council	Kinnegad	D0104-01	4639	4800	Freshwater (river)	No	3P	No	Large	Large
Cork County Council	Skibbereen	D0166-01	4600	4700	Estuarine	No	2	No	Large	Large
Roscommon County Council	Castlerea	D0118-01	2959	4590	Freshwater (river)	No	3P	No	Large	Large
Monaghan County Council	Clones	D0206-01	2467	4500	Freshwater (river)	No	2	No	Large	Large
Tipperary County Council	Ballina/Killaloe	D0189-01	3475	4500	Freshwater (river)	No	3P	No	Large	Large
Westmeath County Council	Rochfortbridge	D0101-01	2519	4500	Freshwater (river)	No	3NP	No	Large	Large
Galway County Council	Gort	D0195-01	16,590	4310	Freshwater (river)	No	2	No	Large	Large
Carlow County Council	Muinebheag and Leighlinbridge	D0090-01	10,036	4000	Freshwater (river)	Yes	3P	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Carlow County Council	Tullow	D0091-01	6104	4000	Freshwater (river)	No	2	No	Large	Large
Donegal County Council	Ballybofey/ Stranorlar	D0120-01	6521	4000	Freshwater (river)	No	2	No	Large	Large
Kildare County Council	Rathangan	D0175-01	2808	4000	Freshwater (river)	No	3P	No	Large	Large
Kilkenny County Council	Callan	D0159-01	3504	4000	Freshwater (river)	No	2	No	Large	Large
Leitrim County Council	Drumshanbo	D0144-01	2683	4000	Freshwater (river)	No	3P	No	Large	Large
Limerick City and County Council	Rathkeale	D0112-01	2256	4000	Freshwater (river)	No	3P	No	Large	Large
Mayo County Council	Ballyhaunis	D0069-01	5864	4000	Freshwater (river)	No	3P	No	Large	Large
Cork County Council	Baltimore	D0296-01	2500	3600	Estuarine	No	2	Yes	Large	Large
Cork County Council	Kanturk	D0203-01	2291	3500	Freshwater (river)	No	3P	No	Large	Large
Kerry County Council	Milltown	D0331-01	5312	3500	Freshwater (river)	No	2	No	Large	Large
Leitrim County Council	Manorhamilton	D0150-01	5201	3500	Freshwater (river)	No	3P	No	Large	Large
Meath County Council	Enfield	D0131-01	5873	3500	Freshwater (river)	No	3P	No	Large	Large
Meath County Council	Oldcastle	D0258-01	2254	3500	Freshwater (river)	No	3P	No	Large	Large
Wicklow County Council	Rathdrum	D0086-01	2663	3500	Freshwater (river)	No	3P	No	Large	Large
Longford County Council	Granard	D0187-01	2371	3200	Freshwater (lake)	No	2	No	Large	Large
Galway County Council	Portumna	D0196-01	2870	3100	Freshwater (lake)	Yes	3P	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Cavan County Council	Ballyconnell	D0253-01	2298	3000	Freshwater (river)	No	3P	No	Large	Large
Sligo County Council	Ballymote	D0094-01	6896	3000	Freshwater (river)	No	2	No	Large	Large
Tipperary County Council	Fethard	D0164-01	4540	3000	Freshwater (river)	No	3P	No	Large	Large
Waterford City and County Council	Lismore	D0176-01	2221	3000	Freshwater (river)	No	2	No	Large	Large
Wicklow County Council	Baltinglass	D0089-01	2940	3000	Freshwater (river)	No	3P	No	Large	Large
Wicklow County Council	Kilcoole	D0087-01	2938	3000	Freshwater (river)	No	3P	No	Large	Large
Cavan County Council	Cootehill	D0082-01	4873	2756	Freshwater (river)	No	3NP	No	Large	Large
Longford County Council	Edgeworthstown	D0098-01	2839	2700	Freshwater (river)	No	3P	No	Large	Large
Cavan County Council	Baileborough	D0085-01	3245	2500	Freshwater (river)	No	3P	No	Large	Large
Offaly County Council	Banagher	D0141-01	2540	2500	Freshwater (river)	No	2	No	Large	Large
Roscommon County Council	Ballaghaderreen	D0123-01	2291	2500	Freshwater (river)	No	3P	No	Large	Large
Sligo County Council	Coolaney	D0392-01	2497	2500	Freshwater (river)	No	3P	No	Large	Large
Westmeath County Council	Killucan – Rathwire	D0100-01	3130	2500	Freshwater (river)	No	3P	No	Large	Large
Meath County Council	Stamullen	D0262-01	3395	2300	Freshwater (river)	No	3P	No	Large	Large
Longford County Council	Ballymahon	D0096-01	2654	2125	Freshwater (river)	No	3NP	No	Large	Large
Clare County Council	Ennistymon	D0081-01	2050	2100	Estuarine	No	2	No	Large	Large

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Louth County Council	Dromiskin	D0264-01	2095	2100	Freshwater (river)	No	3P	No	Large	Large
Cavan County Council	Virginia	D0255-01	2363	2000	Freshwater (lake)	No	3P	No	Large	Large
Wexford County Council	Kilmuckridge	D0161-01	3994	2000	Freshwater (river)	No	3P	No	Large	Large
Kildare County Council	Derrinturn	D0244-01	2946	1600	Freshwater (river)	No	3P	No	Large	Small
Donegal County Council	Lifford	D0352-01	2182	1550	Estuarine	No	1	No	Large	Small
Cork County Council	Newmarket	D0333-01	2539	1500	Freshwater (river)	No	2	No	Large	Small
Kilkenny County Council	Piltown	D0157-01	2870	1500	Freshwater (river)	No	2	No	Large	Small
Mayo County Council	Foxford	D0213-01	2488	1360	Freshwater (river)	No	2	No	Large	Small
Donegal County Council	Convoy	D0344-01	2887	1050	Freshwater (river)	No	1	No	Large	Small
Wexford County Council	Enniscorthy (Kilagoley)	D0029-01	980	1000	Estuarine	Yes	2	No	Small	Small
Fingal County Council	Balbriggan – Skerries (Loughshinny)	D0023-01	840	700	Coastal water	No	1	No	Small	Small
Galway County Council	Mountbellew	D0219-01	2702	700	Freshwater (river)	No	2	No	Large	Small
Fingal County Council	Swords (Toberburr)	D0024-01	450	500	Freshwater (river)	No	2	No	Small	Small
Limerick City and County Council	Hospital	D0314-01	2128	500	Freshwater (river)	No	2	No	Large	Small
Limerick City and County Council	Dromcollogher	D0316-01	2819	400	Freshwater (river)	No	2	No	Large	Small

Table A2.1. Continued

Local authority area	Agglomeration	Licence reg. no.	2015 agglomeration size (PE)	2015 treatment plant capacity (PE)	Receiving water	Is the discharge directly into a sensitive area?	Treatment type[a]	UV treatment	Urban area size	WWTP size
Galway County Council	Ballinasloe (secondary discharge)	D0032-01	70	70	Freshwater (river)	No	1	No	Small	Small
Fingal County Council	Howth – Doldrum Bay (Ringsend)	D0034-01	120	0	Coastal water	No	0	No	Small	Small
Wicklow County Council	Arklow	D0006-01	16,261	0	Estuarine	No	0	No	Large	Small
Cork County Council	Cobh	D0054-01	14,400	0	Coastal water	No	0	No	Large	Small
Cork County Council	Passage – Monkstown	D0129-01	9120	0	Estuarine	Yes	0	No	Large	Small
Cork County Council	Youghal	D0139-01	15,000	0	Estuarine	Yes	0	No	Large	Small
Donegal County Council	Bundoran	D0130-01	13,034	0	Coastal water	No	0	No	Large	Small
Donegal County Council	Killybegs	D0011-01	12,000	0	Coastal water	yes	0	No	Large	Small

All information accurate as of the date of the reference dataset.

[a]'0' means no treatment is applied prior to discharge; '1' means primary-stage treatment is the highest level applied; '2' means secondary-stage wastewater treatment is the highest level applied; 3' means tertiary stage wastewater treatment is applied; '3NP' means tertiary stage treatment with nitrate and phosphate removal is applied; '3P' means tertiary stage treatment phosphate removal is applied; '3N' means tertiary stage treatment nitrate removal is applied.

Appendix 3 Industry Water Reuse Case Studies

Carbery saves over €300,000 per annum through water reuse

3 RO Plant & Permeate Tanks

Project Background

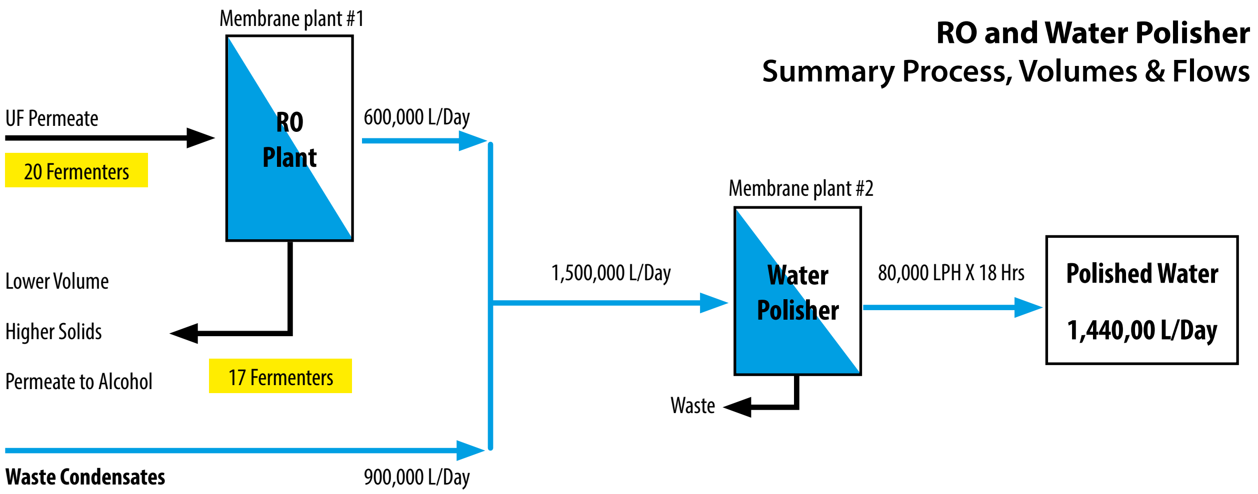
Located in Ballineen, West Cork, Carbery Group is recognised as a leading international manufacturer of speciality food ingredients, flavouring systems and as an award-winning cheese producer. Carbery Group are owned by four Irish dairy co-operatives, employ more than 500 people, and manufacture from 8 facilities worldwide, including Ireland, UK, USA, Brazil and Thailand. In 2016 the sites water usage was 1,414,718m^3, which was abstracted from the Bandon river. This is used for potable water, cooling water and steam production through demineralisation.

At the processing plant at Carbery's headquarters in Ballineen, all divisions are implementing sustainability plans, which set out initiatives and specific targets in key areas, one of which is water; both water quality and water conservation. Under Origin Green, Carbery was obligated to reduce its 2016 water consumption rates by 9% compared to 2010 levels and exceeded this target, achieving an actual water reduction level of 12.9%. Carbery carried out a water footprint of farmer suppliers, discovering that it takes 6L of water to make 1L of milk and the company is determined to reduce the overall water footprint. There are also financial savings from water conservation and management, as well as contributing to reducing the sites carbon footprint.

"UNDER ORIGIN GREEN, CARBERY WAS OBLIGATED TO REDUCE ITS 2016 WATER CONSUMPTION RATES BY 9% COMPARED TO 2010 LEVELS AND EXCEEDED THIS TARGET, ACHIEVING AN ACTUAL WATER REDUCTION LEVEL OF 12.9%"

RESULTS: MBR PERMEATE RE-USE

€3 MILLION	€365,853	1,440m^3	8.2 YEARS
INVESTMENT COST	COST SAVINGS PER ANNUM	VOLUME OF WATER SAVED	PAYBACK



Assessment:

After adopting water conservation programmes, the Ballineen site investigated the suitability of a water reuse project to achieve its sustainability goals. It was recognised that reusing treated wastewater could reduce water abstraction from the Bandon river ensuring compliance with IPPC licence, as well as assisting with compliance to the wastewater treatment plant (WWTP) discharge volumes.

Action taken:

Carbery decided to invest in Reverse Osmosis (RO) plants to concentrate permeate and to polish water from this process as well as various condensate streams on site.

Membrane Plant # 1 has the primary function of concentrating alcohol permeate solids.
Membrane Plant #2 generates polished water supply from RO Water and condensates.
Ultra Violet light sterilisation is then utilised to sterilise this water for secondary uses.

Water reuse applications include provision of reused water for demineralised water for steam manufacture and water for CIP.

The RO and ROP plants were installed in April 2016 and run for 5 months to allow membrane checking and system validation. The system was restarted in March 2017 and ran until end December 2017. This water reuse project has led to lower chlorates emanating from water supply and the insurance of greater control over emissions to water from the WWTP and water abstraction from the river complying within the IED/IPPC licensed limit.

Key learnings:

Benefits:

1. Allows Increased Production – Savings & Profitability

a) Increased Daily Cheese Production Capacity.

2. Comply with Environmental Licence and emissions reduction

a) Reduce Alcohol Steam Usage.
b) River Water Extraction Volumes reduction
c) WWTP Discharge Volumes reduction
d) Effluent Treatment Capacity increased retention time and performance

3. Other Benefits

a) Water Treatment Capacity reduction
b) Low Chlorates Water Supply
c) Export Permeate Solids if market opportunities arise
d) Future Expansion - Permeate Powder

"This project is vital for sustainability, environmental compliance, increased cheese production without increased volumetric loading, alternative use of permeate, and reduced emissions of CO_2. Barriers would be quality assurance approval for reuse options; however, continued sustainability relies on such projects being implemented to allow a zero environmental impact with increasing milk supplies and production diversification."

– PAT McCARTHY, ENVIRONMENTAL MANAGER, CARBERY GROUP

GSK saves €50K Per Annum through Water Resue

GlaxoSmithKline

Project Background

In operation since 1975, GSK's manufacturing site in Cork produces the active ingredients for GSK's medicines, including treatments for cancer, depression and Parkinson's disease.

In 2007, the overall mains water usage at the GSK Cork site was 464,202 m^3. In order to reduce costs and to meet company targets to reduce water usage (20% reduction by 2015) the potential reuse of water and improved efficiency in the use of water on site was explored:

Re-use of permeate from membrane bioreactor (MBR) plant

GSK Cork operates an MBR system as part of a plant expansion to treat sanitary waste and utility blowdown streams. Analysis of the treated water from the MBR found the water to be of satisfactory quality for use as makeup water for a cooling tower. However, the water was not being used and instead was transferred to a final holding tank and subsequently pumped to sea via an outfall line.

A second project investigating the opportunity to reduce the number of boiler blowdowns, and thus reduce water usage, was also undertaken.

"ANALYSIS OF THE TREATED WATER FROM THE MBR FOUND THE WATER TO BE OF SATISFACTORY QUALITY FOR USE AS MAKEUP WATER FOR A COOLING TOWER. HOWEVER, THE WATER WAS NOT BEING USED"

RESULTS: MBR PERMEATE RE-USE

€174,000	**€50,000**	**53,000m³**	**3.5 YEARS**
INVESTMENT COST	COST SAVINGS PER ANNUM	VOLUME OF WATER SAVED	PAYBACK


Figure: Membrane Bioreactor

Assessment:

An extensive mechanical, operational and chemical audit was completed on each of the options. This information formed the basis of a project investment proposal (PIP), which lists the benefits (financial and non-financial) and the risks associated with the proposed project. Based on this assessment the project is approved or not.

Action taken:

An audit was completed of the permeate system by a specialist contractor and concluded that two key measures were required to allow the permeate to be used in the cooling tower:

1) Online measurement of the system parameters and chemical adjustments. This would allow GSK Cork to measure and control the varied quality of permeate from the MBR.

2) An online total organic carbon (TOC) monitor to observe the permeate. Permeate above a specified TOC level (20 ppm) would be rejected and diverted to the final holding tank.

A pH regulation system was incorporated into the system to control water quality in terms of pH and to ensure system integrity on the heat exchange equipment. Control of all key parameters is maintained by automatic adjustment of the system.

A transfer line was installed between the MBR and the cooling tower, which included level control and interface with the online control system to enable diversion of rejected permeate.

Following on from the MBR Permeate Reuse project, an improved automated monitoring system for Boiler Feed Water was installed in 2012, to replace the manual process, and resulted in further water usage reductions and savings.

Key learnings:

"For GSK, the key learning was that the reduction in water can also result in a reduction in energy use, the cost reduction of which was not estimated in the return on investment (i.e. the true cost of water). Future water reuse projects should include the true cost of water when estimating saving e.g. pumping costs, water treatment, etc.

"THE PROVISION OF GRANT AID WOULD LIKELY PUSH MORE PROJECTS ACROSS THE LINE BY REDUCING THE TIME TO RECOVER THE INVESTMENT."

The principal barrier to implementation of a re-use project is the projected payback time on the investment. If a reasonable payback time could not be achieved (circa. 4 years) then the project would be unlikely to proceed. The provision of grant aid would likely push more projects across the line by reducing the time to recover the investment. The completed projects demonstrate that water reuse is a viable solution for our industry."

- JOHN LINEHAN, ENVIRONMENTAL COMPLIANCE OFFICER, GSK.

WATER SYSTEMS & SERVICES INNOVATION CENTRE: NIMBUS BUILDING, CIT, ROSSA AVE., BISHOPSTOWN, CORK T: 021-4335600

ABP Ireland Water lead the way by "doing more with less"

Food Group

Project Background

ABP Food Group, headquartered in Ardee, Co. Louth, operates across four divisions throughout Ireland, the UK and mainland Europe. ABP Proteins represents the rendering operation at two Irish sites, ABP Pet Food, t/a C&D Foods, is one of Europe's largest pet food companies and ABP Renewables, t/a Olleco, operates throughout the UK producing biodiesel from used cooking oil.

ABP Food Group is one of Europe's leading agri-business companies with an annual turnover of €2.7 billion, employing more than 10,000 people, across 46 processing sites in eight countries. Some 35,000 farmers supply ABP with over 13,000 suppliers in the Republic of Ireland.

ABP Ireland has launched a campaign called "Doing More With Less" and as a result the company has set numerous targets to reduce resource consumption by 2020 versus a baseline of 2008. One part of these targets is to reduce the Group's water consumption by 50%. This has set a challenging yet achievable target for each individual site to meet and has made ABP highly cognisant of their water usage.

Assessment:

While ABP have implemented numerous initiatives to reduce water consumption across their facilities, a key element of achieving the 50% water reduction target is to assess where water can be reused. Each site has different process and water usage needs, thus recycling water produces diverse challenges for each ABP site. The company's initial target is to re-use 5% of their water.

Action taken:

At ABP Cahir, rainwater harvesting is used together with treated wastewater for cleaning in the waste water treatment plant and chemical makeup.

ABP Waterford and ABP Clones also re-use treated wastewater in the effluent plant as well as for truck washing and cleaning in the animal handling facility. The treated wastewater is monitored and tested daily on all sites to maintain a high standard, therefore we are confident that this water stream is suitable for these applications.

"THERE ARE CHALLENGES IN REUSING WATER INSIDE OUR FACILITIES, HOWEVER ABP ARE COMMITTED TO FINDING SOLUTIONS"

There are challenges in reusing water inside our facilities, however ABP are committed to finding solutions to these challenges. In ABP Nenagh the hot water used in the tripe polishing process is re-used for the tripe wash which not only saves a large quantity of water but also thermal energy.

Another successful water re-use project at ABP Bandon re-uses hot water from the sterilisers into their tripe washing process, again saving on water and fossil fuel consumption.

In ABP Waterford, water is required to cool the refrigeration compressors. The site now re-uses water from the cooling tower into these compressors.

RESULTS: WATER REUSE

€25,000	€19,275	30,000m^3	1.3 YEARS
INVESTMENT COST	COST SAVINGS PER ANNUM	VOLUME OF WATER SAVED	PAYBACK

Results

The exact quantity of water re-use varies depending on the application at each site but the total saving across all sites was approx. 30,000m^3. The investments for these projects also varied but were all ultimately quite low. Each project had a payback period of between 1 and 2 years. We have conducted a true cost of water analysis at all sites and this allowed us to accurately calculate our payback periods.

ABP Ireland's achievements in resource reductions are independently verified by the Carbon Trust. Continued certification from the Carbon T rust in W ater, Carbon and Waste reductions over three certification c ycles demonstrate ABPs continuous improvement in resource management. These standards, matched with the supply chain standard, gives ABP an unprecedented quadruple certification and is a leader in this area.

In 2017 ABP also achieved the award for Best in Water Reduction from the Carbon Trust. To date ABP have achieved a 46% reduction in water consumption. ABP became the first company in Europe to achieve the European Water Stewardship multi-site gold standard across all Irish processing sites in early 2017 for its water stewardship initiatives. ABP are also members of the large users Community of Practice in water management and this group have allowed the company to progress ideas and develop water re-use projects.

Key learnings:

"Each project has brought ABP one step closer to our ultimate goal of 50% water reduction by 2020. Reductions derived from these water re-use projects reduces the burden on the groundwater bodies we abstract from. These reductions also mitigate against any risk to our receiving water body from our treated wastewater while also reducing fossil fuel, salt and chemical consumption.

ABP IRELAND HAVE HAD SUCCESS AND ACHIEVED MUCH OF OUR 2020 TARGETS AHEAD OF TIME

ABP Ireland have had success and achieved much of our 2020 targets ahead of time but will continue the journey in 2018 and will seek out further improvements across the Group, adapt global best practice initiatives and continue to be a sustainability leader for the sector in Ireland and in our global markets."

- JOHN DURKAN, ENVIRONMENTAL & SUSTAINABILITY MANAGER

"IN 2017 ABP ALSO ACHIEVED THE AWARD FOR BEST IN WATER REDUCTION FROM THE CARBON TRUST. TO DATE ABP HAVE ACHIEVED A 46% REDUCTION IN WATER CONSUMPTION.

Appendix 4 Water Reuse Survey

Water Reuse Public Awareness & Attitudes Survey

Introduction

The Water Systems and Services Innovation Centre (WSSIC) at Nimbus Research Centre, Cork Institute of Technology has been commissioned by the Environmental Protection Agency (EPA Research Programme 2014-2020) to investigate the potential for water reuse in the context of the circular economy in Ireland. A key aspect of the project is this survey to assess public opinion regarding the potential for reuse of treated wastewater in Ireland.

Thank you for taking part in the "Water Reuse Public Awareness & Attitudes Survey". Your participation is on a voluntary basis. All information provided by you in this questionnaire will only be used for research purposes and will remain anonymous. The survey should take less than 10 minutes of your time.

Water Reuse Public Awareness & Attitudes Survey

Section 1: Background

1. What is your age?

- ◯ 18-24
- ◯ 25-34
- ◯ 35-44
- ◯ 45-54
- ◯ 55-64
- ◯ 65+

2. What is your gender?

- ◯ Female
- ◯ Male
- ◯ Transgender
- ◯ Other

3. What is your highest education level achieved?

- Junior Certificate
- Leaving Certificate
- Higher Certificate
- Ordinary Bachelor's degree
- Honours Bachelor's degree or Higher diploma
- Master's degree
- PhD degree

* 4. Where do you live?

- Dublin city & suburbs
- Cork city & suburbs
- Galway city & suburbs
- Limerick city & suburbs
- Waterford city & suburbs
- Town, population greater than 1,500 people
- Rural area, population less than 1,500 people

* 5. What type of piped water supply does your accommodation have?

- Connection to a Public Main
- Connection to a Group Water Scheme with a Public source of supply
- Connection to a Group Water Scheme with a private source of supply (e.g. borehole, lake, etc.)
- Other private source (e.g. private well, lake, rainwater tank, etc.)
- No piped water supply
- Don't know

* 6. What type of sewerage facility does your accommodation have?

- Public sewerage scheme
- Individual septic tank
- Individual treatment system other than a septic tank
- Other sewerage facility
- No sewerage facility
- Don't know

Water Reuse Public Awareness & Attitudes Survey

Section 2: Awareness

* 7. How familiar are you with the concept of a 'circular economy'?

- Familiar
- Somewhat familiar
- Unfamiliar

A circular economy sees waste, like water, paper or glass, as a valuable resource. It is about minimising waste or ideally achieving a 'zero-waste' economy.

* 8. How familiar are you with the concept of water reuse from wastewater treatment plants?

- ◯ Familiar
- ◯ Somewhat familiar
- ◯ Unfamiliar

- ***In Ireland, most wastewater is collected by drains, treated and purified at wastewater treatment plants, and discharged into rivers or the sea. One element of the circular economy concept is the reuse of such treated wastewater.***
- ***Water reuse is the use of treated wastewater for beneficial purposes such as agricultural irrigation, industrial uses or in households.***
- ***Before reuse, wastewater from a municipal treatment plant is treated to a suitably high standard for the intended purpose.***
- ***Therefore, for lower-quality uses, reused water would not need to be treated to a drinking water standard.***
  In Ireland, there is currently no such water reuse from municipal wastewater treatment plants.

(Note: The reuse of rainwater is not included in this survey.)

Section 3: Attitudes

* 9. Do you think it is acceptable or unacceptable to use treated wastewater for the following applications?

	Acceptable	Maybe	Unacceptable
Car washing	◯	◯	◯
Agricultural irrigation for food production	◯	◯	◯
Agricultural irrigation non-food production	◯	◯	◯
Landscape irrigation (public parks, golf courses, sports fields etc.)	◯	◯	◯
Fire protection systems (in buildings)	◯	◯	◯
Street cleaning	◯	◯	◯
Toilet flushing	◯	◯	◯
Drinking	◯	◯	◯
Private garden watering	◯	◯	◯
Industrial and commercial usage	◯	◯	◯
Environmental enhancement (wetland restoration)	◯	◯	◯

* 10. There are potential benefits from the reuse of water from treatment plants. Please indicate your level of agreement with the statements below.

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know
The reuse of water will address increasing demand for water from growing urban areas and water intensive industries.	◯	◯	◯	◯	◯	◯
The reuse of water will help to address the effects of climate change on water supplies.	◯	◯	◯	◯	◯	◯
The reuse of water is good for the environment because it reduces reliance on fresh water sources.	◯	◯	◯	◯	◯	◯
The reuse of water is more environmentally sustainable than continuing to discharge treated wastewater into rivers and the sea.	◯	◯	◯	◯	◯	◯

Other benefit (please specify)

[ ]

* 11. There are potential barriers to acceptance of water reuse in Ireland. Please indicate your level of agreement with the statements below.

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know
Ireland gets a lot of rain so there is enough water available without having to reuse water.	○	○	○	○	○	○
I would have health concerns over any human contact with reused water, even if treated to a high standard.	○	○	○	○	○	○
I don’t know enough about how wastewater is treated to feel confident in the idea of water reuse.	○	○	○	○	○	○
The cost of the extra treatment and piping to distribute reused water would be too high.	○	○	○	○	○	○
I would not have confidence in the standard of treated water for any reuse.	○	○	○	○	○	○
Reuse of water for irrigation or wetlands may have negative environmental impacts.	○	○	○	○	○	○
Investment should be prioritised for repairing existing pipework.	○	○	○	○	○	○

Other barrier (please specify)

* 12. All public mains-supply water is treated to a drinking water standard and is currently used for all purposes.
Do you think it is necessary to use drinking water for the following purposes?

	Yes	Maybe	No
Agricultural irrigation for food production	◯	◯	◯
Agricultural irrigation for non-food production	◯	◯	◯
Landscape irrigation (public parks, golf courses, sports fields, etc.)	◯	◯	◯
Fire protection systems (in buildings)	◯	◯	◯
Street cleaning	◯	◯	◯
Toilet flushing	◯	◯	◯
Car washing	◯	◯	◯
Private garden watering	◯	◯	◯
Industrial and commercial usage	◯	◯	◯

* 13. Reusing water from wastewater treatment plants is a good idea.

◯ Strongly Agree
◯ Agree
◯ Neither agree nor disagree
◯ Disagree
◯ Strongly Disagree
◯ Don't know

* 14. Most people whose opinion I value would approve of reusing water from wastewater treatment plants.

◯ Strongly agree
◯ Agree
◯ Neither agree nor disagree
◯ Disagree
◯ Strongly disagree
◯ Don't know

* 15. Within my household, the choice to reuse water from wastewater treatment plants should be up to me.

◯ Strongly agree
◯ Agree
◯ Neither agree nor disagree
◯ Disagree
◯ Strongly disagree
◯ Don't know

* 16. The future adoption of water reuse in Ireland would involve many stakeholders. Please indicate the level of trust you would have in the following stakeholder groups

	Very high	High	Average	Low	Very low
Government	○	○	○	○	○
Non-profit environmental organisations	○	○	○	○	○
Academic experts (university researchers etc.)	○	○	○	○	○
Local authorities such as City and County Councils	○	○	○	○	○
Irish Water	○	○	○	○	○
News and Media	○	○	○	○	○
Social Media (Twitter, Facebook, LinkedIn)	○	○	○	○	○
Industry experts	○	○	○	○	○
Environmental Protection Agency (EPA)	○	○	○	○	○

17. Are there any other comments you would like to make?

Water Reuse Public Awareness & Attitudes Survey

Thank You

18. Thank you for participating in this survey. If you would like to be in with a chance to win a luxury break at the 5* Cliff House Hotel, please provide your email address below. All survey answers will remain anonymous and be treated in confidence by the Research Team.

epa Research Climate - Water - Sustainability
CORK INSTITUTE OF TECHNOLOGY INSTITIÚID TEICNEOLAÍOCHTA CHORCAÍ
Nimbus Embedded Systems Research
Water Systems & Services Innovation

Appendix 5 Survey Dissemination Material

A5.1 Survey Graphics Examples

A5.2 Survey Infographic

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Water Reuse in the Context of the Circular Economy

Authors: Eoin Byrne, Kevin Fitzgibbon, Anca Minescu and Julia Blanke

Identifying Pressures

Economic activity requires the input of natural resources to meet the needs of society. Most resources are finite, but are often used only once and then disposed of. Water is vital for life to flourish and for society's economic health and is scarce in some countries and regions of the world. Yet potable water is commonly used only once for societal benefit, before being returned to the environment.

The circular economy approach seeks to recover and reuse the resources used in the economy as much as possible, to reduce pressure on fresh sources, protect the environment and improve long-term sustainability. It is being pursued with greater policy focus, in Europe and elsewhere, including for water.

The main potential sources for recovery of water, based on the volumes involved, are industries using large volumes of water, for reuse on-site, and municipal wastewater treatment plants, for reuse in the broader economy. The cost of water, and pressure for reliable supplies of fresh water, have driven the adoption of water reuse by certain industry sectors. However, no water is reused from municipal wastewater sources in Ireland.

Informing Policy

There is no government policy in Ireland to pursue water reuse from municipal sources at present and no European Directive currently requires Member States to adopt such measures. However, the direction of travel is towards greater resource conservation, in line with "circular economy" thinking; water reuse is part of that overall picture.

There is a gap in standards for water reuse, both in Europe and in Ireland. At present there are no guidelines or compulsory water quality criteria for recovered wastewater that is to be reused in some beneficial way in the economy.

Clear messages have been received as part of the stakeholder engagement for this project, notably the public survey, which garnered 1102 responses. There is strong support for the principle of water reuse, although it is not an immediate investment priority. There is public opposition to any reuse for drinking purposes and strong doubts over reuse for agricultural irrigation for food production. Strong, early and meaningful public engagement will be vital for any municipal water reuse project to succeed.

Developing Solutions

A suitable set of water quality standards that addresses different types of end use for recovered water would be necessary for any future water reuse policies and programmes, and these should be developed. There are a number of examples internationally where such standards have been established, including by the World Health Organization, as well as individual countries within the European Union and further afield.

Collection, management and dissemination of data on water reuse by industry is at a basic level; consideration should be given to improving these processes.

When future water reuse programmes are contemplated, a meaningful public engagement process will need to be designed that avoids any suggestion of a minimalist approach or a one-way information-giving exercise. Factors such as emerging and exotic compounds, bioaccumulation, migration into groundwater and associated impacts will need to be considered as part of a risk assessment/environmental impact assessment process.

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