A Review of Current Knowledge

Water Reuse

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This review is one of a series of Reviews of Current Knowledge (ROCKs) produced by FWR. They focus on topics related to water supply, wastewater disposal and water environments, which may be the subject of debate and inquiry. The objective of each review is to produce concise, independent scientific and technical information on the subject to facilitate a wider understanding of the issues involved and to promote informed opinion about them.

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Review of Current Knowledge

Water Reuse

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Review of Current Knowledge

CONTENTS

TABLES

FIGURES

1 Introduction

The amount of water that is available for water companies to abstract from the environment to put into supply is declining as changing weather patterns disturb traditional water resource systems and environmental regulations reduce unsustainable water abstractions. Increasing demand requires water utilities to explore alternative ways of managing demand and generating water supply. Reusing water is one of a suite of alternatives that are being considered and developed in the UK.
Over the next decade it is likely that water companies in the UK will put more emphasis on investing in reuse schemes and that will involve engaging with customers. It is important then to understand:

- the differences between different types of reuse scheme and how they work;
- the facts regarding safety and human health;
- the relationship between providing reliable water supplies, achieving environmental outcomes, and the economic implications.

This Review of Current Knowledge (ROCK) is aimed at non-technical readers interested in understanding this alternative water supply option. It sets out the facts (and perceptions) and aims to clarify some of the most common questions that people have about 'water reuse'.

This ROCK explains the differences between the very small scale and very large scale schemes, the differences between reuse to create non-potable and drinking water, the types of technology used, actual and perceptions of risk, how reuse schemes are regulated and risks managed and finally, an explanation of the energy and other resource requirements of reuse and the implications of these on cost.
This ROCK is intended to provide a factually correct and unbiased overview. It is not intended to either support or contend the reuse agenda.

1.1 What is 'Water Reuse'?

Water is constantly on the move, changing state and moving through the water cycle and around the planet. At some point in the past the water coming out of a tap may have been part of a glacier, or even part of previous organic material. In that sense water reuse is nothing new.

Similarly, our traditional water services infrastructure (abstractions, supply treatment, distribution, use, drainage, sewerage, wastewater treatment and subsequent disposal back into the natural water cycle) inherently includes an element of water reuse. The water that is discharged from inland wastewater

treatment works mixes with rainfall that runs off land and into the river, and from groundwater. Diluted treated effluent is inevitably part of the water that is abstracted further downstream, including for public water supply. This pattern continues until the water reaches a coastal wastewater treatment works. At that point the water is traditionally discharged into the sea, or into an estuary or other type of coastal water.

Many industries already reuse water in their processes. It makes good business sense to use incoming clean water for processes that need very clean water, and then to cascade the water through subsequent processes that need lower and lower quality water. This is straightforward and reduces the volumes of water to be managed on site. Water can be an expensive overhead so reuse in this way could save business a lot of money. Some businesses have decided that it makes financial and sustainability sense to treat used water and reuse it as make-up water, so that as well as cascading water through the processes, they are able to move towards a more circular (rather than linear) reuse pattern.

Individuals are also capable of reusing water, in the most basic of ways such as taking water that has been used to clean inside the home and reusing it to clean the exterior. Small scale domestic systems are also available which add some level of treatment, for example to clean kitchen sink 'greywater' to a quality which is sufficient for toilet flushing. This type of activity is typically called, 'domestic greywater recycling' although it is sometimes referred to as reuse.

This ROCK does not include material on domestic greywater recycling. For more information on domestic recycling readers are encouraged to refer to the Foundation for Water Research Guide: (FR/G0006) '*Urban Rainwater Harvesting and Water Reuse'* (Foundation for Water Research, 2015). That guide does not cover in any detail water reuse for agricultural and industrial purposes nor large municipal scale indirect potable water reuse schemes.

Key Definitions

The terminology describing 'water reuse' is wide and varied, and often interpreted in different ways. This can lead to confusion and misunderstanding. Terminology varies because the concept of reusing water has evolved differently in different places. Definitions used in this ROCK (and in the related Urban Rainwater Harvesting and Water Reuse Guide) are listed in Table 1.1

Table 1.1 Reuse Terminology & Definitions

Term	Definition
Blackwater	Foul waste (i.e. from toilets, urinals, or bidets)
Greywater recycling	Reuse of water originally supplied as wholesome (tap) water that has already been used for bathing, washing, or laundry. This does not include foul waste (see Blackwater). There is some dispute as to whether water containing residual food waste should be classified as Greywater or Blackwater.
Domestic sewage	Wastewater draining from household properties.
Industrial trade effluent	Trade effluent is any liquid waste (not surface water or domestic sewage) that is discharged from premises being used for a business, trade or industrial process. Trade effluent can come from both large and small premises, including businesses such as car washes and launderettes. It can be effluent from the industrial process that is discharged into a public sewer, washed down a sink or toilet, or put into a private sewer that connects to the public sewer. Trade effluent may contain: fats, oils and greases; chemicals; detergents; heavy metals; solids; and food wastes (NetRegs, online).
Municipal	Municipal is an international term that refers to resources or infrastructure serving the general public. It is less commonly used in the UK than in other countries where water services are not privatised.
Non-potable water	International terminology referring to water that is not suitable for human consumption. Note: the term 'non-potable' has no meaning in UK law.
Potable water	International terminology referring to water that is suitable for human consumption. Note: the term 'potable' has no meaning in UK law. 'Drinking water' is the official term stipulated by the Drinking Water Inspectorate in the UK.
Public water supply (PWS)	Water supplied by a company or organisation licensed for that purpose and regulated by the Drinking Water Inspectorate in accordance the Drinking Water Quality regulations (Section 5).
Reclaimed water **Reclaimed effluent**	Water (other than mains or privately supplied drinking water) that has been collected or otherwise deliberately retrieved from fluvial or coastal waters, or from industrial uses, to be reused. It can also refer to water that is 'reclaimed' from urban surface areas i.e. by drainage systems or localised water harvesting. This ROCK distinguishes between reclaimed water and water that is subsequently treated (see Treated effluent).
Stormwater (Surface water runoff)	Rainwater that collects and runs off land, e.g. water that runs down the street and into drains. In this context it is sometimes referred to as surface water (runoff). This is not to be confused with the term surface water that differentiates surface from groundwater.
Treated effluent	Water that has been treated for discharge or reuse. This can include primary, secondary, or tertiary effluent (Section 3.5).
Unplanned reuse (*de facto*)	Situation whereby abstractions for public water supply contain a proportion of treated effluent from an upstream wastewater treatment works.

Term	Definition
Wastewater	Water that has been used, either in domestic, commercial, or industrial properties. Commonly used in an international context to mean sewage. This is separate to, but can be mixed, with stormwater in wastewater drainage and sewer systems.
Wastewater treatment works (WwTW)	Treatment works which treat wastewater and/or industrial wastewater for discharge back into the environment. Also called sewage treatment works (STW) and sometimes water recycling centres (WRC).
Water reuse	The use of reclaimed water for a direct beneficial purpose.
Water treatment works (WTW)	Treatment works which treat raw water for input into the drinking water supply network.

1.2 What Drives Water Reuse

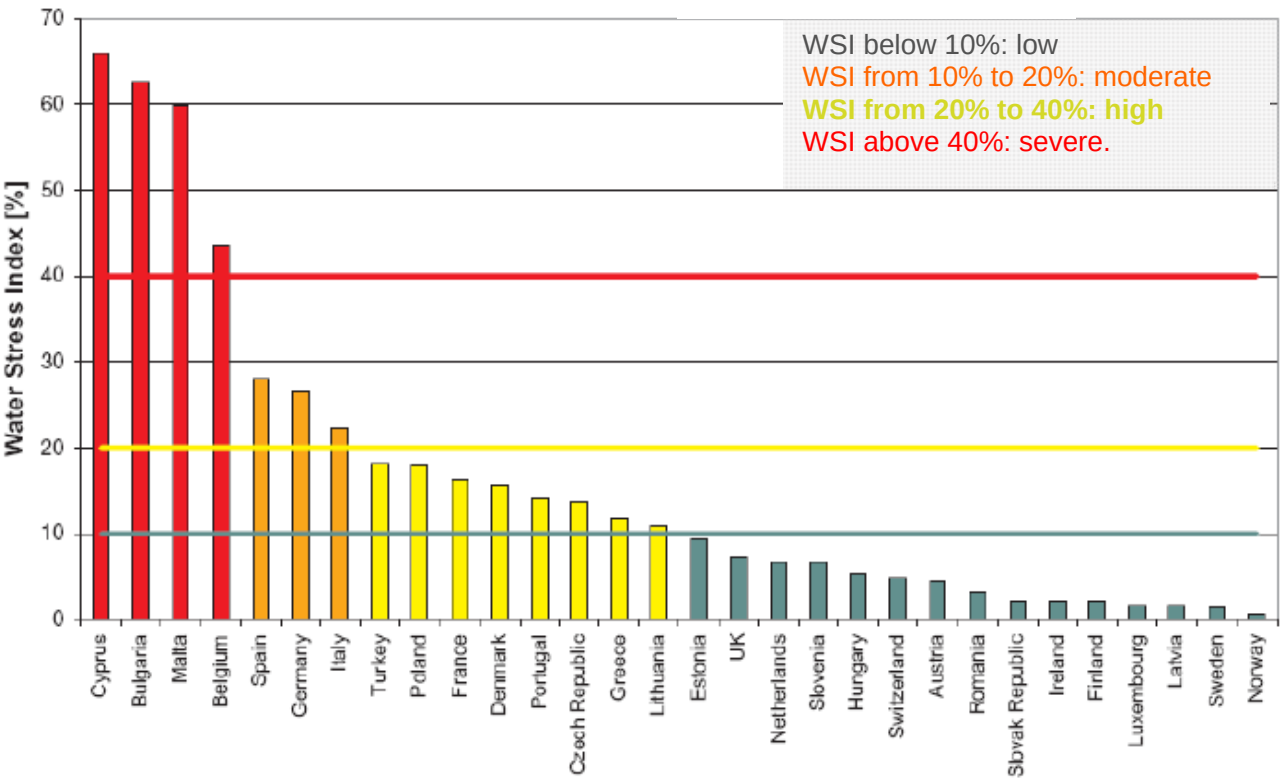
The most obvious factor driving water utilities and industries to reuse water is a shortage of freshwater. The limitations of traditional water resource systems largely went unnoticed until populations began to increase and then 20th century solutions (e.g. major reservoirs) masked looming water problems. Access to a range of other resources (such as oil, fertile agricultural land, historical trade-routes etc.) led to many arid and semi-arid locations attracting large populations of people despite chronic shortages of water.

Environmental water stress

A lack of freshwater can be driven by, or lead to poor water quality, as well as quantitative shortages and can be a symptom of 'water stress'. The European Environment Agency defines water stress as "*when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. Water stress causes deterioration of fresh water resources in terms of quantity (aquifer over-exploitation, dry rivers etc.) and quality (eutrophication, organic matter pollution, saline intrusion etc.)* (European Environment Agency, 2007). The level of Water Stress is measured by comparing the amount of water that is abstracted compared to the total volume of annual runoff. A WSI above 20% implies that water resources are under stress, a score of more than 40% indicates severe stress and unsustainable use (European Environment Agency, 2016). Figure 1.1 shows that countries across Europe are severely water stressed.

Figure 1.1 Water Stress Index.

(Source: TYPSA, 2013)



Country level assessments hide localised water stress in certain countries, for example parts of south and east England experience acute and serious water stress (Defra, 2013). The level of stress is often underestimated by those outside the water industry due to perceptions of high annual rainfall. The truth is that annual rainfall in London is on average 557 millimetres per year (Met Office, online), this is drier than parts of Texas and there is a much higher concentration of people in and around London than across the US state. Due to the relatively low rainfall and the very large population there is less water available per Londoner than for people in Dallas, Rome, or Istanbul (Ryan, 2016).

Environmental regulations aimed at improving the quality of the aquatic habitat and ecosystem services (Water Framework Directive) are driving investigations by regulators and utilities into the impact of abstraction on the environment. Abstractions found to be causing unacceptable environmental conditions (low flows) are being restricted via modified abstraction licences. This is generally accepted as the right way forward but is driving interest in alternative solutions such as reuse.

Whilst water stress levels are likely to continue increasing, the demand for and supply of drinking water generates a reliable output, wastewater. Traditionally

seen by municipal utilities and industrial uses as an expensive problem, wastewater is increasingly being viewed as a valuable resource.

Access to a reliable supply

Farmers need reliable sources of water to irrigate crops during the growing season (either to produce edible crops, non-food related crops such as cotton or biofuel, or animal fodder). Irrigating increases the yield and quality of crops when compared to rain-fed cropping (FAO, 2012) and so water shortages, risking diminished harvests trigger urgent searches for alternative supplies of water.

Similarly, industry needs access to stable and reliable resources to continue operating, being productive and to attract investment. Reuse is being seen as a way of reducing vulnerability to 'unpredictable external forces' (i.e. climate change) and increasing numbers of high water-intense businesses have begun to invest in reuse systems.

Reducing costs associated with discharge permitting

Treating wastewater is an expensive process for water utilities and industry, even to non-potable standards to meet environmental objectives. In the UK businesses that discharge significant volumes into the sewer system are required to get a trade effluent consent (or agreement with the sewerage provider) before they can discharge liquid trade effluent to the sewer (NetRegs, online). These consents may include requirements to pre-treat the effluent before discharge. Alternatively, other businesses have discharge permits (regulated by the same Environmental Permitting Regulations as the municipal wastewater treatment works) that allow them to discharge directly to a local controlled waterbody. Businesses that are required to treat their used water before discharging to the sewer or local waterbody are increasingly recognising that they may as well reuse the 'clean' water that they have produced.

Embedded carbon being discharged to the sea

Most of the UK's large wastewater treatment works are located in coastal areas and treated wastewater is discharged into the sea. Bathing water quality standards require that coastal discharges meet high water quality standards and thus high levels of treatment. Water utilities are recognising waste in discharging water with a very high financial and carbon footprint to the sea. In the USA where water reuse is becoming more mainstream a Californian Senate Bill (SB 163) intended to ban the discharge of treated effluent to the sea on the basis that it is a waste of water "*to discharge treated wastewater from an ocean or bay outfall, or for a water supplier or water replenishment district to not take treated wastewater made*

available for certain purposes" (California Legislative Information, 2015). This bill has been challenged on the basis that it could inadvertently damage efforts to reclaim and reuse water. However, it provides a clear example of Government policy driving water reuse systems.

Industrial Zero Liquid Discharge (ZLD) targets

Zero Liquid Discharge is a process that benefits industrial and municipal organisations because it can save money (money not being spent on discharging or procuring new water). Whether it benefits the environment is debatable and site specific. In the UK all discharges into controlled waters have to comply with water quality levels and withholding water from the environment can potentially impact on volumetric requirements. ZLD systems use the most advanced wastewater treatment technologies (Section 3.5) to purify and recycle virtually all of the wastewater produced. A ZLD facility is an industrial site that does not discharge any water. ZLD plants produce solid waste. Target ZLD is normally achieved by:

- Efficient water reclamation processes;
- Evaporating off parts of the wastewater that are not reusable;
- Using crystallizers and condensate recovery to capture the remaining water.

Why not desalinate?

A common and understandable response to the topic of water scarcity is, "why not desalinate seawater?" Desalination has become a major component of water supply networks in arid zones, notably the Middle East. However, it is not necessarily the most appropriate option. Not all places experiencing or at risk of water scarcity have access to seawater, and for those that do, the extremely high energy demand of the process, and the subsequent ultra-saline waste-streams are at odds with financial and sustainability considerations.

1.3 Different Types of Reuse

Water can be reused in many different ways, for different purposes. The most common applications include agricultural irrigation, non-potable industrial use, urban landscape irrigation, and drinking water. Even within these main categories there are many variations. It is important to be aware of the different scenarios as these have different implications in terms of risks to human health (Section 3), and regulation (Section 5).

Agricultural irrigation

There are two main sources of water that can be reused:

i) Reclaimed water from industrial sites;

ii) Municipal treated effluent. This can be reclaimed indirectly, by abstracting from a river that contains effluent from a wastewater treatment works, or directly via a piped non-potable supply from a local wastewater treatment works. In developed countries the wastewater that is reused is always treated. However, in less developed countries that have less well developed wastewater treatment infrastructure reclaimed irrigation water is often of a much lower quality.

Section 3.3 explores the health risks of irrigating different types of crops with different quality reuse water. It sets out the different mitigation measures that are taken depending on the quality of the water to be reused.

Industrial use

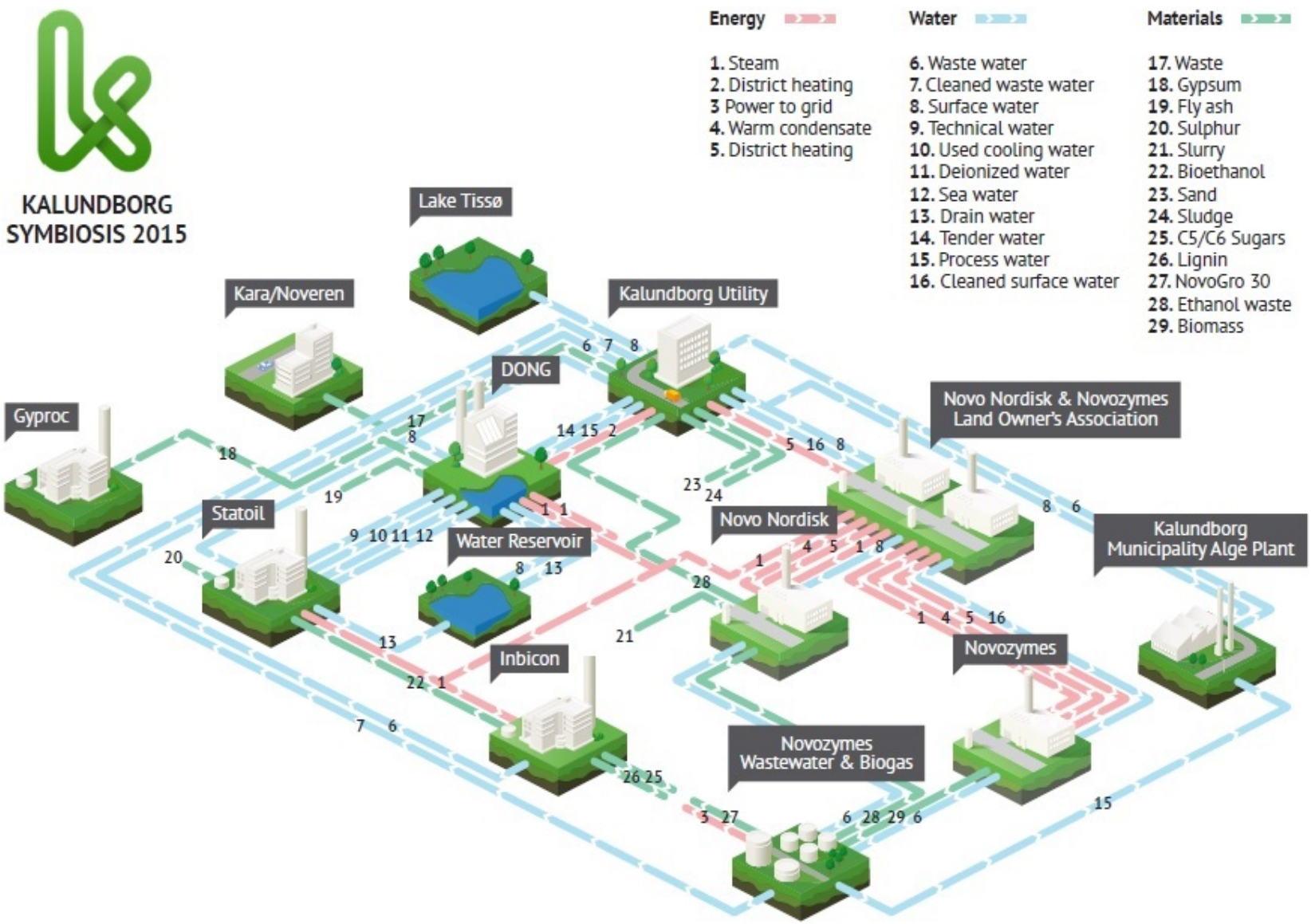
There are many different types of industrial activity but when discussing water reuse they are generally discussed in terms of whether foodstuffs will be exposed to the water. Industrial systems can access water for reuse in three main ways:

a) Cascade (and therefore reuse) water through increasingly low grade requirements but then dispose of the water (trade effluent into a sewer or with a discharge permit to discharge back into the environment) at the end of the final stage;

b) Reclaim industrial water, treat it to an appropriate standard, and then recirculate through the industrial process. This is often called Water Symbiosis. In most cases this is managed within the confines of an individual building but it is possible for multiple businesses to work together to share Water Symbiosis. The Kalundborg System in Denmark is a pioneering example of what is possible (Figure 1.2);

c) Reclaim municipal treated effluent from large scale wastewater treatment works and diverting this to industrial sites to replace either mains supply or a private water abstraction.

Figure 1.2: Schematic Diagram of the Kalundborg Water Symbiosis Reuse System
Source: Symbiosis Center Denmark



Urban irrigation

In arid and semi-arid places urban landscaped areas (gardens and parks etc.) are often irrigated, streets are cleaned, and dust kept under control with treated effluent (non-potable standard as the irrigation water is not intended to come into contact with food). Signs are positioned to inform people that the water is non-potable and should not be digested. Other forms of urban irrigation such as in allotments do bring water into contact with food and so could potentially be more vulnerable to risks associated with reusing treated effluent (Section 3.3).

Domestic non-potable use

The problem of 'wasting' high quality fresh water for non-potable purposes such as toilet flushing is well recognised and documented (Waterwise, online). In addition to measures aimed at reducing the volume used (demand management), replacing the freshwater with a non-potable source is one option to reduce the pressure on the environment. There are several different types of non-potable source that are available to individual properties including in-situ domestic rainwater harvesting or greywater recycling (Foundation for Water Research, 2015), or distributing a treated effluent from a centralized treatment works via a secondary supply network (also known as dual-reticulation systems).

Drinking water (potable supplies)

Treating wastewater for reuse as drinking water already takes place around the world and in the UK (Section 2). As water scarcity issues increase, the option is being seriously considered by more water utilities. There are several different ways of doing this:

i) **Indirect Potable Reuse (IPR) via surface water flows**: Indirect systems re-introduce treated effluent into environmental water body, typically a river (referred to as a buffer) before it is re-abstracted. Conventional wastewater treatment works produce effluent at qualities that meet environmental water quality standards. In the UK this is regulated via the Environmental Permitting Regulations, the components of which are driven by the Water Framework Directive. In most cases the treated effluent is discharged downstream of the wastewater treatment works, but treated effluent is sometimes piped back upstream or into another catchment to support river flows. Decisions on where to re-introduce treated effluent are usually made

by the water utilities based on the local hydrological regime and flow requirements.

ii) **Indirect Potable Reuse (IPR) via surface water:** This approach takes treated effluent from a wastewater treatment works and then either discharges into a river for subsequent re-abstraction, or stores it, typically in a raw water reservoir (as opposed to a service reservoir which stores drinking water). The water may be subsequently re-abstracted directly from the reservoir, or from river water that has been released from the reservoir (and mixed with rainfall runoff). It is then subjected to additional drinking water treatment before being put into supply.

iii) **Indirect Potable Reuse (IPR) via groundwater:** In this case treated effluent is stored underground. This process is sometimes called 'Aquifer Storage and Recovery – ASR, or Artificial Groundwater Recharge). In the UK there are strict groundwater regulations which stipulate what can and cannot be introduced into groundwater. Quality levels notwithstanding, water can be introduced into aquifers and stored for later reuse either through infiltration (which adds another level of treatment), or direct injection. The water is later re-abstracted either directly from the groundwater (e.g. via a borehole) or from the surface if the groundwater supports springs. In this way there will always be an element of mixing with 'fresh' environmental water.

In coastal areas fresh groundwater can be at risk of saline intrusion, where seawater encroaches into the underground aquifer. This happens when freshwater is abstracted from the aquifer and the change in pressure draws in seawater. Treated effluent is increasingly being introduced into at risk groundwaters to provide a freshwater 'lens' to help prevent saline water intruding into the aquifer.

iv) **Direct Potable Reuse (DPR):** This is the most contentious type of drinking water reuse scenario, as there is no environmental buffer or external dilution. It is sometimes referred to as 'Pipe to Pipe'. In this type of system wastewater is treated to higher levels than at conventional treatment works (Section 3.5 for descriptions of type of treatment) and then put directly back into supply. Systems that discharge treated wastewater directly into 'uncontrolled water bodies' (e.g. non-state controlled rivers or groundwater) are also classified as direct systems.

v) **Unplanned IPR *'de facto' reuse:*** This is the default situation for many existing public water and industrial supply abstraction that are downstream of treated effluent discharges.

Environmental enhancement (e.g. maintaining river flows and maintaining wetlands)

Wetlands provide important habitat for flora and fauna, in particular for many wading, migratory, and breeding birds. However, water abstractions from across a catchment (watershed) can affect flows and levels in wetlands. Instead of reducing those abstractions and finding alternative sources of water for supply, it can be more effective to support the wetland itself using appropriately treated effluent.

1.4 Overview of the challenge: barriers and obstacles

Despite these drivers there are many barriers to water reuse systems:

- **Human health** risks (and perceived risks): Actual or perceived risks to human health can be a major barrier to acceptance and to reuse systems being implemented. The potential hazards of using 'reuse' water for agricultural irrigation are a particular concern and this is explored in more detail in Section 3.
- **Industrial performance**: Many industrial processes require water that meets specific water quality requirements. Whilst this is not necessarily a health risk, the risk of industrial process problems or reduced product quality is a concern for industry considering replacing a freshwater source with a 'reuse' source.
- **Economics**: Whilst reuse provides a reliable supply of water transitioning from one supply system to another raises cost concerns. Capital and operating costs associated with new treatment systems and potential new distribution networks are a major investment concern. Similarly, industrial and agricultural water users need to understand how a reuse supply would compare economically to continued access to water from a traditional supply. The factors that drive costs in traditional and reuse systems are explored further in Section 4.
- **Regulation**: It is important that water service infrastructure is regulated to ensure human health is not compromised, to protect the environment, and (particularly for privatised water industries such as the UK) to ensure that investment is appropriate and water supply remains affordable for

customers. The issues and the current regulatory situation relevant to the UK is examined in Section 5.

These are all valid barriers that need to be understood, worked through and resolved in order for appropriate water reuse systems to be implemented. There are thousands of small-scale non-potable reuse systems supporting agriculture and industry, and also many high-profile large-scale potable systems successfully providing drinking water to people in major cities around the world. There are also many examples of proposed reuse systems that have failed to be implemented or have been delayed, either because the technical elements have not been resolved, or more typically because the risks and measures to safeguard against risk have been poorly communicated. Section 2 sets out how water reuse systems have emerged around the world including in the UK.

2. Extent of Water Reuse

2.1 Water Reuse Systems around the World

Reusing water has long been a solution to the scarcity and poor water quality problems that plague arid and semi-arid regions. Reusing water has enabled communities and cities to grow and prosper beyond what could otherwise have been achieved. There are thousands of water reuse systems operating around the world; many are small-scale non-potable use systems but an increasing number provide or supplement drinking water supplies. Large populations in Australia, the USA, Singapore, China, and Japan (among others) are already being supplied with water from large-scale reuse systems. In fact, water reuse (beyond simple reuse in agriculture) is already taking place in over 30 countries as more and more places find themselves water stressed. However, at a global level only 0.18% of water demand is met by reusing treated wastewater (United Nations, 2015).

The agricultural sector has a long history of reclaiming 'pre-used' water to irrigate crops. The level and type of treatment, and application methods varies around the world. As treatment levels have improved in developed countries the quality of water used to irrigate crops has increased. Domestic wastewater that is treated to non-potable levels contains nutrients that are valuable to farmers, reducing the volume of additional fertiliser required. This benefit is a supplementary driver across the agricultural sector. In some developing countries farmers are still limited to accessing water of poorer quality. The implications in terms of risk and mitigation of different farming techniques and water sources are discussed in Section 3**.**

USA: the USA has a history of reusing water for potable supply going back to the 1960s. Arid conditions in California and Texas drove the authorities to implement a groundwater recharge project in Los Angeles and the El Paso Water Utilities has been delivering reclaimed water to the community since 1963 (EPWU online). Since then water reuse systems have been successfully implemented in other States including major projects supplying Miami and Orlando in Florida, Arizona, and Virginia. One of the biggest water reuse systems, and in many ways a flagship project, is the Orange County Groundwater Replenishment Scheme which supplies over 320 million litres of reclaimed water to 600,000 citizens of Orange County, California every day.

The United States is one of the leading nations driving research to enable more water utility authorities to include water reuse as a viable option to diversify and secure water supplies. It has established a trade association 'WateReuse' (www.watereuse.org) that focuses on advancing laws, policy, and funding to increase water reuse. Other countries continue to join the USA based association

as ‘international divisions’ to share knowledge and support for reuse around the world, including Australia.

Japan & China: Not known for having an arid climate, Japan has embraced water reuse since the late 1970s. The country has faced severe water shortages driven by rapid economic growth and urbanisation concentrating its population in urban areas. Even in 2001 the immense stress that urbanised demand was exerting on traditional water supply systems was documented (Ogoshi, 2001). The focus in Japan has been to use reclaimed water to provide supply for non-potable demands such as toilet flushing, irrigation, and industrial demand. This means that used water only needs to be treated to meet lower quality standards, but in turn that creates a dual-supply system that requires additional supply infrastructure. China is also experiencing significant growth in water reclamation and reuse for many of the same reasons: intense population growth and concentration in urban areas, and an economy largely based on water intensive industry.

Australia: Australia suffered during the Millennium drought – cities such as Melbourne were at severe risk of running out of water as traditional water resource systems were not able to cope with the prolonged conditions. Huge reservoirs simply did not refill as normal during the winters, as the rain didn’t come. At that time water recycling projects increased in number but most of these focused on applying recycled treated effluent to land (e.g. to irrigate agriculture or to support amenity use) but these projects did little to increase supply of drinking water or to reduce the consumption of water (Australian Academy of Technological Sciences and Engineering, 2004). By 2004 there were over five hundred wastewater treatment works across Australia recycling at least part of their treated effluent (between 150 and 200 billion litres of effluent were being recycled each year).

Since then Australia has moved towards more strategic large-scale systems to secure water supplies. Australia gets most of its water from groundwater and so water recycling projects are focusing on taking treated wastewater, applying extra treatment to bring it to drinking water quality, and then using this to replenish groundwater for future abstraction. In Western Australia a major groundwater replenishment scheme (treating used water to drinking water standards and then using this to replenish groundwater) is being built near Perth following a successful three year trial (Water Corporation, online). It will deliver 28 billion litres of recycled water each year, enough to supply 100,000 homes. The first stage to deliver 14 billion litres is on track for 2017.

Singapore: Unlike other countries Singapore made the decision to focus on water reuse to provide potable water for drinking supplies. The small island is exceptionally vulnerable to water shortages due to low rainfall levels and no significant natural river basins. Traditionally Singapore has imported water from

Malaysia and so reducing this dependency has been a major priority. The country invested in developing membrane technology and in 2000 became able to purify wastewater on a large scale and relatively cheaply (i.e. compared to desalinating, the long-term costs of continuing to import, and other alternative supply augmentation systems).

Between 2007 and 2014 the Singaporean Government invested $3.5 billion (£2.7 billion) to build water-related infrastructure including five plants that recycle wastewater for use in homes and industries. This very successful project has been nicknamed 'NEWater' and produces water that is safe to drink and safe to use in the semiconductor micro-chip factories that underpin Singapore's economy. In 2015, 30% of Singapore's water needs were met by 'NEWater'.

2.2 Reuse in Europe

Closer to home water reuse has long been employed in the Mediterranean region to support agriculture, but now there are already two water reuse systems supplying drinking water in Europe, major plans by water companies to include water reuse as an option to augment drinking water supplies, and appetite in the European Commission to create policy to accelerate the uptake of reuse (for non-potable purposes) across EU Member States.

Belgium: There is currently only one full-time potable water reuse system in Europe. Northern Belgium is one of the most water stressed areas in Europe due its lack of internal water resources (most of its surface waters drain into neighbouring countries). In the 1960s hydrogeologists identified that its limited groundwater resources were at risk of saline intrusion due to the high abstraction levels and so a 'replenishment' system was put in place. Treatment levels and regulatory consents were upgraded and the Torreele/St.André reclaimed wastewater groundwater recharge project in Flanders, Northern Belgium has supplied drinking water to around 60,000 people every day since 2003 (Ryan, 2016).

Figure 2.1 Torreele Advanced Water Treatment Plant and Groundwater Infiltration Zone

Photos: Sandra Ryan

UK: 2003 brought Europe's second major potable water system when Essex and Suffolk Water launched the Langford Water Recycling system (also known as the Chelmer Augmentation scheme). Unlike Torreele/St.André, Langford is only intended to augment drinking water supplies during drought. Langford is an Indirect Potable Reuse system which takes treated effluent from neighbouring Anglian Water and instead of discharging it into the sea, diverts the effluent for additional treatment and storage in Hanningfield Reservoir. It has a maximum capacity of 40Ml/d but when operated typically generates 25 Ml/d (contributing about 10% of drinking water supplied from the Hannington Reservoir) (UKWIR, 2014).

The unplanned IPR type system described in Section 1 is very common in the UK. Analysis undertaken by UK Water Industry Research (UKWIR) has confirmed that at very low flow levels (Q95, i.e. flow rate that is exceeded 95% of the time), such as during prolonged dry periods or drought in the south and east of England treated effluent can make up 10% to 20% of the water that is abstracted for public water supply. At higher flows and in other parts of the country that proportion declines significantly but there are no water companies in England and Wales (Scotland was not part of the analysis) where the potential to re-abstract treated effluent is zero (UKWIR, 2015). How to differentiate between a water reuse system, and de facto reuse is a technical issue that water scientists, engineers, and regulators are currently exploring.

Non potable reuse in Southern Europe: in Southern European countries agriculture accounts for 73% of water consumption and Greece and Cyprus, Spain, Italy, and Portugal are amongst those that consume the most amount of water for

irrigation (TYPSA, 2013). These southern European countries have been reusing water for decades, largely driven by dominant agricultural sectors operating in arid conditions, and reuse has been limited to activities which do not require drinking water quality. In Cyprus 90% of wastewater is reused primarily by agriculture. 59Mm^3/year (59 billion litres) is reclaimed and used for agriculture across a substantial number of schemes supplying the entire country.

In Spain just under 80% of treated effluent is used to irrigate agriculture and this is a volume of around 323 billion litres/year (Iglesias, R., 2008). Several Spanish regions also reuse treated wastewater to irrigate golf courses, agriculture, to augment river flows, and to recharge groundwater (in particular to stop saltwater intrusion in coastal aquifers). After decades of unofficial and unregulated reuse in 2007 the 1620/2007 Royal Decree was passed creating legislation to manage the reuse of municipal effluent (i.e. former drinking water). The law prohibits using treated effluent for human consumption, including its use in the food industry and hospitals.

3. Health Risks, Industrial Performance, & Treatment

The main concern that people have regarding reusing (treated) wastewater is the risk to human health. There are other concerns relating to the potential impact on the local water cycle (hydrological impacts of not discharging treated effluent back into water courses, and associated water quality impacts), and different parties abstracting and discharging water in the same river catchments (watersheds).

3.1 Human Health Hazards Associated with Reusing Wastewater

It is important to note that with regard to all major water reuse systems referred to in this ROCK the 'source water' is treated effluent, that is water which has been treated at conventional wastewater (sewage) treatment works to quality standards that comply with environmental regulations. This ROCK does not examine the full range of health risks associated with exposure to untreated raw sewage.

There are many different sources of wastewater all of which provide opportunities for reuse. Small municipal treatment works in rural areas usually receive wastewater from households and surface water runoff. This water contains hazardous bacteriological matter, and may contain contaminants such as hydrocarbons from roads and other hard standing, but typically does not include industrial trade effluent. It is the larger wastewater treatment works that serve more urbanised and industrialised areas that receive incoming sewage containing a wider range of potentially more toxic materials and higher concentrations of contaminant. However, those larger volumes also increase their viability as potential sources of reclaimed water.

Health risks are a product of the relationship between the source of water to be reused, the water quality requirements of the purpose of use, and the treatment that is applied. This is called the Source-Pathway-Receptor principle. The pathway needs to be complete in order for health risks to be realised. It is important to understand that potential contaminants within treated wastewater can vary considerably in terms of how likely they are to occur, survive, and persist, as well as how detectable they are. Even for contaminants that are known to persist knowledge on the consequences to human health and the environment remains an area of research.

The ability to mitigate or completely neutralise these risks through advanced treatment and application of other 'risk-based' health protection measures is discussed in Section 3.5. Information on existing guidelines and regulations is provided in Section 5.

Domestic wastewater, i.e. that from people's homes, is dominated by microbial contaminants (pathogens, bacteria, viruses, parasites etc.) but can also contain

potentially toxic elements (such as copper, lead, cadmium and other metals) and organic contaminants (e.g. hydrocarbons) from chemicals. If the wastewater contains industrial trade-effluent then the range and concentration of chemicals will be higher.

Microbes in wastewater

Untreated sewage is hazardous due to its microbial content. Sewage contains *Escherichia coli* (O157:H7*)* a pathogen, the gastrointestinal pathogen *Campylobacter*, various strains of Salmonella (including *Salmonella enteritidis*), listeria, and legionella bacteria; viruses such as rotavirus and adenovirus; *Cryptosporidium parvum* and *Giardia* protozoa (enteric[1] pathogens); and parasites such as nematodes. These are well known to cause major health problems (infections and diseases) if ingested.

Hormones in wastewater

As well as hazardous microbes, domestic wastewater contains hormones that pass through and out of the body. These include naturally occurring oestrogen steroid hormones (such as oestrone (E1) and oestradial (E2)), synthetic oestrogen, and 17 α-ethynylestradiol (EE2 the contraceptive pill hormone) (UKWIR, 2014). The outcome is that untreated and even treated wastewater may contain endocrine disrupting compounds (EDCs) which can disrupt hormone systems in animals (including humans). Monitoring programmes have also found alkylphenols (non-steroid chemicals that exhibit estrogenic activity[2]) present in environmental water. Several types of alkylphenol are liable to bio-accumulate in organisms living in the water immediately downstream of treated effluent discharges.

The feminisation of aquatic animals (fish and macroinvertebrates) downstream of wastewater treatment works is an issue that has attracted media attention in the UK since the 1990s (Independent, 1994) and is often a concern raised in relation to the reuse of treated wastewater. The effects of EDCs on wildlife has been confirmed by laboratory and field investigations internationally (WHO, 2012) and extensively in the UK (Rodgers-Gray *et al.*, 2000).

Significant research has been undertaken investigating both the presence of EDCs in UK freshwaters and their consequence on human health. The conclusions are that nearly all of these substances are unstable and breakdown naturally and quite rapidly in river water. In its advice leaflet, *Endocrine disrupters and drinking water*, the Drinking Water Inspectorate goes on to state that EDCs "*tend to occur*

[1] intestinal
[2] Similar to female sex hormones

only in immediate proximity to industrial and wastewater discharges. Endocrine Disrupting Compounds are not widespread in rivers and the risk of them being present at abstraction points for drinking water treatment is minimal" (DWI, 2010a). In a policy statement Water UK[3] states that, "*research carried out for the European Commission has shown that treatment and other barriers are effective in preventing such substances reaching drinking water*" (Water UK, 2011). The issue of proximity could have implications on certain configurations of Indirect Potable Reuse system depending how far downstream the treated effluent is reclaimed, or in Direct Potable Reuse systems where treated effluent is not discharged into an environmental buffer.

Other known contaminants

Wastewater from urban areas and industrial trade effluent contains large numbers of other organic and inorganic pollutants, many of which are persistent (i.e. do not break down easily). Runoff from agricultural land washes pesticides and herbicides into water courses degrading the natural environment and entering drainage systems and wastewater treatment works. Potential toxins such as hydrocarbons (e.g. butane and propane from petroleum substances) drain from roads into the sewerage network.

Other hydrocarbons, along with chlorinated solvents, and heavy metals (such as lead, mercury, arsenic, copper, cadmium, and chromium) are found in industrial wastewater. Many industrial sites have their own on-site treatment works, the effluent from which they either discharge back into the environment (regulated via a discharge permit), into a sewer (via a trade effluent consent), or which they reclaim.

Contaminants of emerging concern (CECs)

Pharmaceuticals (such as ibuprofen, paracetamol, and prescription drugs such as diclofenac) and personal care products (PPCPs) are among a range of contaminants increasingly being detected at low levels in surface water (rivers) the implication being that these are not being fully treated and removed by conventional wastewater treatment processes (Section 3.5). In general, CECs are chemicals that could potentially pose risks to human health or to the environment but which are not yet subjected to regulatory criteria. This gap is due to the lack of scientific data (environmental persistence and ecotoxicological or toxicological data) that inhibits robust evaluation of associated risks.

[3] a membership organisation which represents all major statutory water and wastewater service providers in England, Scotland, Wales and Northern Ireland

These chemicals remain categorised as 'emerging' until the level of scientific knowledge and information on their presence and the potential problems they can cause increases. As scientific monitoring and analysis continues to develop already regulated and "known contaminants" could be re-classified as "emerging" status as new scientific information becomes available. This would require regulatory agencies to re-evaluate their norms and guidelines.

3.2 Perception and the Yuck Factor

It is unsurprising that reusing wastewater is a contentious issue. The instinctive disgust associated with the idea of recycling sewage and the fear that exposure to reclaimed water is unsafe is known as the "Yuck Factor" (Garcia-Cuerva, *et al.*, 2016) and can have a major influence on whether water reuse projects are able to progress. However, it is important to recognise the difference between perceived and actual hazards, especially when actively engaging in consultation.

Emotional attitudes towards reusing treated wastewater are influenced by the language used in non-technical media: "Toilet to Tap", "Recycled Sewage" and phrases such as "drinking your toilet water" focus on the direct link between the source water and the destination but do not reflect the level of treatment that is applied.

Figure 3.1 Example of "Yuck Factor" response to water reuse as a supply option

Source: Watereuse.org, 2015

Treated effluent that is used to create drinking water is subject to much more advanced levels of treatment than the conventional treatment used to clean water for disposal back into the environment (Section 3.5). A lack of information on the major differences in the level of treatment that is applied for potable and non-potable reuse purposes and on the controls applied to those different types of water can contribute to the persistence of the "Yuck Factor". Conversely, complex and inconsistent terminology alienates people from what should be inclusive discussions on how best to manage water resources and supplies.

Misunderstandings also occur when referring to water recycling, which is used to refer to both small-scale recycling of water in the home (e.g. greywater recycling where water from showers and bathroom taps is used to flush toilets) and the strategic-scale treatment and reuse of water from main wastewater treatment works. A glossary is provided in Section 1 to define the terminology used in this ROCK and how it relates to terminology sometimes used by others. Terminology differs because of how reusing water has evolved differently in different places and the wider range of terminology used to describe water infrastructure assets and activities.

Other factors that affect how people respond to potential water reuse systems include:

- how early on in the process they are engaged and invited to contribute their views and opinions;
- the opinions of mobilized and influential people;
- how individual communities will be served by treated wastewater compared to neighbouring communities, i.e. if there is a sense of 'social injustice', one area being served with another area's treated wastewater;
- how the production of treated effluent for reuse is presented, i.e. processes and systems that are celebrated as examples of pioneering science and technology and offering environmental and urban resilience are typically perceived as more favourable than reuse which is not presented particularly well and thus maintains an air of being secondary in quality and less desirable than water that has not been used before.

None of these factors relate directly to the actual hazards and levels of risk that are associated with reusing treated wastewater but nevertheless create genuine challenges for water utilities and communities seeking to integrate reuse to augment their water supply situation.

3.3 Actual Hazards Associated with Different Types of Reuse

There is significant research being undertaken around the world on the nature and extent of the actual risks associated with reusing municipal treated wastewater. This typically focuses on the risks associated with using it for non-potable purposes (e.g. agricultural irrigation, urban irrigation, and toilet flushing etc.). This is because water treated for drinking water purposes (from whatever source) is required to meet very strict (and well defined) drinking water quality standards (Section 5). For non-potable uses the water quality requirements are much less well defined (and vary in different countries).

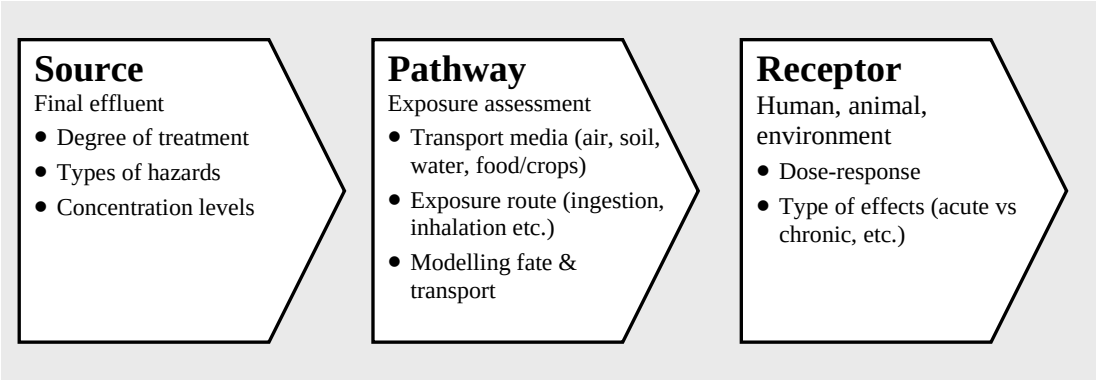
The Centre of Expertise for Waters (CREW) at the James Hutton Institute in the UK has recently completed an in-depth research project examining the actual risks associated with various non-potable reuse scenarios (Troldborg *et al*., 2016, herein referred to as the CREW Report).

A Framework to Define Actual Risks

The CREW Report has defined a framework that explains how risks can and should be assessed (Figure 3.2). For a real risk to be present there needs to be:

- a hazard within the treated effluent (i.e. after treatment);
- a receptor (i.e. a person); and
- a pathway for the receptor to be exposed to that hazard.

Figure 3.2 Source-Pathway-Receptor Concept for Reuse Risk Assessment



Source: the CREW Report 2016

At each stage there are factors and mitigations that either reduce or remove the hazard, or which prevent people from being exposed to the hazard. The Effluent > Pathway > Receptor relationship varies considerably depending on the type of water reuse scenario, and it is this relationship that is recommended and is used to assess the

primary level of risk relating to non-potable supply and demand. Section 1 lists five different types of non-potable reuse system. Table 3.1 summarises the effluent hazards, pathways, and exposure risks of those different types.

Table 3.1 Source > Pathway > Receptor Relationships of Water Reuse Scenarios

Reuse scenario		Source of water to be reused / hazard	Pathway / exposure route	Receptor / Risk
1.	**Agricultural irrigation**	On-site reclaimed water. Unlikely to contain microbial pollutants such as pathogens, or toxins such as heavy metals. Treatment processes may be limited. Volumes to supply limited to volumes used. Effluent from municipal wastewater treatment works treated to non-potable standard. Concerns that water may contain residual substances capable of causing harm if ingested directly or within food that has been irrigated.	Water applied to pasture, water applied to soils and incorporated within fodder crops, water incorporated in food root crops, water incorporated in leaf crops.	People consuming irrigated food, livestock consuming irrigated fodder, on-site workers.
2.	**Industrial use**	On-site used water (untreated) i.e. cascading through the industrial process (symbiosis). On-site treated wastewater. Treated effluent from municipal wastewater treatment works.	Water put into direct contact with industrial processes, water leaks/pooling, steam, spray (aerosol).	Technical process, on-site workers direct contact with or inhaling effluent.
3.	**Urban irrigation**	Municipal treated effluent.	Water applied to landscaping, public green spaces, sports turf (e.g. golf courses). Exposure from skin contact with water or irrigated material (soil, grass, other vegetation).	Gardeners, grounds people etc. exposed to liquid, public exposed to spray (if spray irrigating). People using these spaces coming into contact with vegetation exposed to irrigated water.
4.	**Domestic non-potable**	Municipal treated effluent (domestic greywater recycling is not considered within the scope of this ROCK).[4]	Water supplied for use in non-potable purposes, e.g. toilet flushing. Potential risk of cross-contamination with drinking water supplies.	Exposure to airborne flush droplets, residual contaminants on surfaces. Consumption of cross-contaminated supply.
5.	**Drinking water**	Municipal treated effluent (advanced treatment). Hazards removed from source water.	Mains water supply.	n/a
6.	**Environmental enhancement**	Municipal treated effluent.	Non-potable water discharged into surface and groundwater water bodies.	Recreational water users (e.g. kayakers).

[4] More information is available in Foundation for Water Research 2015 (ROCK: Urban Rainwater Harvesting and Water Reuse)

Factors that affect the Source > Pathway > Receptor relationship

Understanding the factors that affect the pathway/exposure of receptors to the hazards provides opportunities to mitigate the residual risks of reusing treated effluent (Section 3.5). The CREW Report has examined the different scenarios in significant detail including analysis on the level of concentration of contaminants that can be considered safe depending on the exposure conditions. This section outlines the main risk pathways, the factors that influence the level of risk associated with reusing treated effluent, and the conclusions that have been made on overall level of risk.

Agricultural reuse

Treated effluent is a valuable resource for agriculture as it is not vulnerable to climatic conditions and non-potable effluent can contain high levels of nutrients. Nutrients are a problem when discharging wastewater into watercourses as they feed biological activity and can lead to algal blooms and other poor water quality conditions. When applied to agricultural land though nutrients are a valuable resource. It is the potential to transfer pathogens or toxins into the food chain (and agricultural workers) that is the main risk of reusing treated effluent in agriculture.

Factors which affect the pathway / exposure of agricultural receptors to the hazards:

The method of irrigation:

- Spray irrigation exposes edible parts of crops (e.g. leaves) to the non-potable water. Farm workers are exposed to atmospheric atomised water (fine spray), and any ponding which occurs. A Food Standards Association study in 2004 confirmed that the potential risk of contamination is "*supported by studies that have demonstrated the ability of pathogens such as E. coli O157 to persist on lettuce, watermelon, and cantaloupe after harvesting*" (FSA, 2004). However, in the UK even secondary treatment which is applied at all major treatment works remove these hazards from treated effluent. Moreover, spray irrigation is generally applied to high volume cereal and root crops which are low risk crops (UKWIR, 2014).
- Drip irrigation applies water directly to the soil and avoids direct contact with the crop. This technique is most commonly applied to horticultural high value crops. There remain concerns about the likelihood and consequence of treated effluent being incorporated into the crop as it grows.

Type of crop:

- Crops which are grown on the surface are more exposed to any contaminants that are present in treated effluent in spray irrigation;
- Grazing livestock ingest soil and high proportions of vegetation relative to their body mass, and so are at greater risk of ingesting any retained contaminants in irrigated vegetation;
- If any pathogens are present, the type of crops most at risk of transferring the pathogens to humans are those that are grown ready-to-eat (consumed raw). Risks are lower for crops that are cooked before being eaten (e.g. the risks are lower for potatoes than for carrots which could be eaten raw);

Time between irrigation and harvest**:**

- Pathogens have a short lifespan when subject to sunlight (ultraviolet radiation and desiccation) and so the time interval between irrigating with treated effluent and harvesting the crop can significantly impact any residual risk of using effluent that may contain trace amounts of microbial contaminant.

In an agricultural context the greatest risk to human health is the potential to ingest pathogens or dioxins from eating vegetables and fruit grown on soil treated with effluent. The risk from coming into contact with the soil itself (skin contact or ingesting) is much less, and the risks to livestock farming may be more significant for farmers than consumers as livestock directly ingest soil and plant matter.

The Crew Report has significantly increased the knowledge base relating to the risks to human health from irrigating agriculture with treated effluent, but it recognises that there are important aspects that are still not fully understood: the extent that pathogens can survive in soils and remain on plants after being irrigated; how contaminants can be incorporated and retained within plants; and the relationship between dosage (the level of contaminant taken on board by the receptor) and the likely health response.

What is known is that concentrations of residual pathogen need to be very low (<1 Colony Forming Unit - CFU[5] per litre) to avoid unacceptable risk (for *S. enteritidis* the safe level is even lower especially to protect grazing sheep and cattle from infection). In the UK secondary treatment already reduces pathogen levels below these thresholds.

Concentrations of heavy metals and other Potentially Toxic Elements (PTEs) would also need to be much greater than the levels normally measured in treated

[5] CFU Colony Forming Units – microbial measurement unit

wastewater effluent in the UK and so it is unlikely that PTEs would enter the food chain if treated effluent is used to irrigate crops. The Crew Report findings are supported by earlier research from 1996 (Smith *et al*., 1996) that found heavy metal levels in soils that had been irrigated with secondary effluent over the long term were still within normal background levels. That study concluded that it may take up to 100 years for heavy metal levels in effluent-irrigated soil to reach threshold values for environmental concern.

Similarly, organic contaminants such as polycyclic aromatic hydrocarbons (PAHs) and pesticides need to be present in high concentrations before levels become unacceptably high for irrigation. Most PAH, pesticide, and dioxin substances are very lipophilic[6] which means the amount taken into plants from irrigation water will be low (Mikes *et al*., 2009; Trapp and Legind, 2011), although some uptake from soil into the peel of some root crops carrots may occur. The greatest risks are from airborne contaminants attaching to the plant but the risk of this is low.

To protect grazing livestock concentrations in effluent need to be slightly lower than for arable farming because of the volumes of soil and plant matter that grazing animals ingest. It is also worth noting that globalised food chains source products from around the world and as described in Section 2 the reuse of treated effluent in agriculture varies significantly as does the level of regulation (Section 5).

Industrial reuse

Some industrial processes require very high quality water but the majority do not. Human health risk in industries not directly involved in food or beverage related activity relate to the potential of ingesting on-site poor quality water (either internally or through the skin). Most industrial facilities should carry out appropriate health & safety risk assessments to identify the range of potential risks and necessary mitigations. Recognised techniques such as Task Risk Assessment identify risks from normal or standard procedures, whilst techniques such as HAZOP consider the risks that could arise if things go wrong. These types of Health & Safety assessments should protect staff from the risks associated with exposure to non-potable water, and ensure compliance with relevant regulatory H&S requirements.

In food production industries, water as an ingredient is either sourced from quality assured boreholes or mains supply of drinking water. Section 5 outlines the main regulations that apply to the use of water in the food industry. Treated effluent (at non-potable standard) would not be used as a replacement source. However, there are opportunities to use non-potable treated effluent for processes unrelated to food production, e.g. washing of raw products and cleaning equipment. This increases

[6] they dissolve within fats and oils, rather than water

the potential to introduce contaminants into the food chain (if present in the source water).

Factors which affect the pathway / exposure of industrial receptors to the hazards:

- Control and restriction of non-potable water to processes/equipment that do not directly come into contact with final food products;
- On-site specific operating procedures to control the movement of water of different grades, and any on-site treatment provision.

The Crew Report found that in the industrial scenario the greatest exposure risks are from ingestion or skin contact rather than inhaling effluent vapour. However, the way in which people can be at risk varies depending on the type of substance. For example, organic contaminants (especially certain types of highly toxic dioxins) are able to permeate the skin and people are much more at risk of absorbing these contaminants through skin contact than they are from inhaling or ingesting treated effluent. In general organic contaminants are found to pose a limited risk to human health. Pesticides on the other hand are highly soluble and ingesting water is much more likely to expose people to this hazard than making skin contact or inhaling water vapour.

PTEs are less likely to absorb through skin but ingesting these could be a problem if not mitigated against in high risk industry situations, for example at commercial hand wash vehicle washing centres.

Urban irrigation

The release of non-potable treated effluent into the urban environment creates a risk that those directly involved in the irrigation process, or those subsequently accessing the irrigated land (e.g. parks), will come into contact with residual contaminants. The greatest risk is inhaling or ingesting the effluent whilst the irrigation is taking place.

The actual risks associated with using non-potable treated effluent to irrigate allotments etc. are similar to those relating to agricultural reuse. The level of risk is dependent on the type and concentration of any residual contaminants in the water, how exposed people are to the water (liquid or vapour), the ability of the food crop to incorporate contaminants from irrigation water, and contaminated water residue on the plant surfaces that are to be eaten. Additional washing and cooking of foods will reduce these risks but in an uncontrolled situation these mitigations are not guaranteed. This is a major difference to the commercial agricultural use which will typically be subject to more controlled processes and monitoring.

Another key difference is the type of people that would be exposed, i.e. the urban environment has a much greater number of people accessing irrigated areas as part of their daily mobility or for recreation, including children and infants whose behaviour can increase their exposure to any substances within soil or vegetation. Similarly, in sporting environments the majority of people that are exposed to the irrigated land have no responsibility for the irrigating process and are much less likely to be aware of the impact of non-potable water.

Factors which affect the pathway/exposure of urban receptors to the hazards:

- The concentration of residual contaminants in the effluent;
- The ability of residual contaminants to permeate the skin;
- The likelihood of people ingesting the non-potable water (e.g. gardeners and grounds people, this will be reduced if irrigation is automated and occurs at times when there are few people present, e.g. at night or very early morning);
- The rate of irrigation compared to the infiltration rate of the soil (i.e. well managed irrigation should not allow irrigation water to collect on the surface which would be inefficient and also increase exposure rates to non-potable water);
- The use of mitigation measures, e.g. protective masks and clothing and clear signposting that the water being used is non-potable;
- The type of person and their activity, for example infants playing in an irrigated area are more likely than an average adult to ingest soil or plant material that has been exposed to the irrigation water.

Domestic non-potable

In a domestic situation ***mains supplied*** non-potable treated effluent would only be used for non-potable purposes, primarily toilet flushing, garden watering, and potentially clothes washing[7]. The main risk associated with introducing non-potable treated effluent for toilet flushing is the potential to inhale water droplets released during the flush process. Large droplets can contaminate the area around the toilet creating a transmission risk, but the potential for airborne transmission of infectious diseases is not widely recognised. However, the much smaller and lighter airborne droplets can remain suspended in the air for several hours increasing the potential exposure timeframe.

[7] Individual property rainwater or greywater harvesting systems for reuse are not included within the scope of this ROCK. Information is available in: FWR Guide (FR/G0006) *Urban Rainwater Harvesting and Water Reuse.*

Many pathogens and viruses are known to be able to survive on surfaces for weeks or even months (Johnson *et al*., 2013) and so the level and efficiency of cleaning practices can have a major influence on the longevity of the risk from each flush. The relationship between bacterial concentrations in bowl water and subsequent levels in the air has not been conclusively demonstrated as different studies have observed different relationships (Troldborg *et* al., 2016). In addition to the risks specific to toilet flushing there are associated risks arising from the potential to contaminate drinking water with non-potable water via accidental cross-connections.

Factors which affect the pathway/exposure of domestic receptors to the hazards:

- Toilet design (including flush volume) and flush mode (affects the release of large and small aerosol droplets);
- Flushing with the toilet lid up can increase contamination levels;
- Cleaning levels within facilities;
- Frequency and time spent in a bathroom after flushing;
- Direct access to bowl water, e.g. house pets.

Currently there remains uncertainty over how many aerosol water droplets are released when a toilet is flushed and how much exposure to trace contaminants inhaling these aerosols creates. However, the CREW project concluded that overall using effluent for toilet flushing is unlikely to pose any significant health risk to humans in the UK. The concentration levels of microbial contaminants found in existing treated effluent discharges are already far lower than the level at which they would pose a threat if supplied for toilet flushing. Other studies have examined the in-house risks associated with contamination following diarrhoea or vomiting (contaminant levels significantly higher than found in treated effluent) and even these have not demonstrated clearly if aerosol inhalation transmits disease (Johnson *et al*., 2013). The main barriers and concerns are more likely to be the costs of installing such systems (requires dual-plumbing) and the potential of cross-contamination.

Drinking water

The fundamental difference between reusing treated effluent for non-potable and drinking water purposes is that drinking water has to meet the strict Drinking Water standards (DWI, 2009) regulated by the Drinking Water Inspectorate (Section 5). Whilst there are criticisms that the Drinking Water regulations do not specify detailed water quality limits for all potential contaminants the underpinning

requirement is that water companies provide wholesome water to customers. It is neither possible nor practical to attempt to specify limits for all potential contaminants as there are many chemical contaminants that remain undetected, for which detection and analytical methods have not been developed, and new chemical manufacturing process create new compounds and substances regularly. These issues typically lead water companies to adopt Drinking Water Safety Plans and precautionary treatment methods to ensure the water they put into supply is safe (Section 5).

3.4 Catchment Risks

As well as human health risks water reuse systems have the potential to impact negatively on the natural environment if they are not designed and managed appropriately. The most likely risks are to the hydrological regime (river flows) as diverting water back into supply systems can disrupt flow and velocities in watercourses, and this in turn can impact on water quality. Further due to the high concentration of many third party water abstractors and dischargers in UK river catchments, changes in hydrological regime has the potential to impact on third party operating conditions.

A study undertaken for UK Water Industry Research Limited (UKWIR) in 2015 examined the ability of the existing, non-reuse specific, water management regulatory framework to protect against these and other environmental water quality related risks (UKWIR, 2015). It concludes that the vast majority of [catchment] hazards are covered adequately by either existing legislation (such as the Water Framework Directive and its permitting programmes, the Urban Waste Water Treatment Directive and its regulations etc.) or other non-legislative tools (e.g. good practice guidance and recognised mitigation measures).

3.5 Types of Treatment

Section 3.3 highlights issues about non-potable water. For most purposes of use existing secondary treatment reduces concentrations of microbial, heavy metals, and other potential toxic elements to levels well below what is needed to make it safe for non-potable uses. This section highlights some of the main treatment processes involved.

Conventional Wastewater Treatment

Technology to treat wastewater continues to improve as water utilities demand ever more efficient processes driving treatment process manufacturers to innovate and design new technology. Wastewater treatment is not a single step process, it

consists of many separate and sequential stages (summarised in Table 3.2). One of the key requirements for wastewater engineers is to understand the many different processes and products that are available and design treatment trains that recognise the typical composition of incoming wastewater and the quality requirements on the effluent. Conventional wastewater treatment (i.e. treatment applied to municipal wastewater for discharge back to the environment) typically involves two stages: Primary and Secondary treatment, and in some situations where the volumes of water are high and/or the receiving waters in the environment are particularly sensitive to nitrogen or phosphorus, Tertiary treatment.

Table 3.2 Overview of the three stages of conventional treatment of municipal wastewater

Preliminary stage	Primary Treatment	Secondary Treatment	Tertiary Treatment
Screening: grit removal	Machination, sedimentation, sludge processing.	Stabilisation ponds, aeration, clarification, disinfection, activated sludge, secondary sedimentation.	Granular filtration, precipitating ions out of solution, additional disinfection, membrane technology, adsorption, advanced oxidation
What it does:	Physical processes that remove large biosolids (human waste) and separates it from the water. This is the process that takes place in the large circular open air tanks. In the UK this is typically used to prepare the water for secondary treatment rather than discharge. However, treatment works serving small populations and discharging into coastal or estuarine waters may be permitted to discharge primary treated wastewater (Defra, 2002).	Physical and biological processes that remove residual organic material and suspended solids. Aeration introduces oxygen which bacterial microorganisms use to convert the organic matter into inorganic end products (water, carbon dioxide, and ammonia). Secondary treatment is usually required to remove parasites	A final cleaning process that removes any remaining inorganic compounds. Processes adding hydrogen sulphide cause heavy metals which have low water solubility (e.g. cadmium, lead, mercury) to precipitate and then they can be removed. Similarly adding calcium or aluminium removes phosphate ions from the water.

Treatment Trains for IPR

Whilst the UK has a long history of unplanned indirect potable reuse (IPR) with many public water supply abstractions being downstream of (mostly secondary) treated effluent discharges, planned systems typically adopt a range of advanced processes, creating a ‘multi-barrier’ approach to ensure that the output water is free from contaminants hazardous to human health. The number of treatment technologies is vast and includes physical, chemical, and natural processes. Advanced processes are typically added on to conventional treatment trains. Table 3.3 lists some of the main processes and their impact on contaminants.

Table 3.3 Overview of Contaminants* Removed by Advanced Treatment Processes

Physical processes:	**Action and Removal**
Filtration	Removes suspended solids. Moderately removes protozoa and bacteria but only low removal of viruses. Low removal of metals. This could be considered to be a conventional treatment process.
Precipitation	Removes dissolved solids, as metal ions. A chemical dosing is required to create coagulation and flocculation.
Powdered Activated Carbon / Granulated Activated Carbon	Biological treatments that introduce active carbon to anaerobic or aerobic systems. Removes soluble organic compounds and some pathogens.
Micro / Ultrafiltration	Ultrafiltration separates out dissolved materials from the background water, it can remove particles as small as 1/300th the width of a human hair. It is very effective at removing protozoan pathogens and bacteria but less able to remove viruses. The capacity to remove steroid hormones is not yet fully understood (WHO, 2012) and hormones can accumulate on filtration membranes. Nanofiltration may not be a complete barrier to micro-pollutants such as hormones and this is an area of ongoing research (Ngheim *et al.,* 2004; and Koyuncu *et al.,* 2008).
Adsorption	Contaminants can be removed by passing untreated water though adsorptive granular media contained in a pressure vessel. As the water passes through the media, the charged ions are adsorbed onto the surfaces of the positively charged media particles. There are currently several adsorption media available: activated alumina (AA), titanium based media, zirconium based media, and iron based sorbents. The most common media include modified activated alumina and iron-based materials.
Nanofiltration / Reverse Osmosis	Filtered water is forced under pressure through microscopic pores in a multi-layered membrane. This separates pure water molecules from other dissolved substances that are 100 times smaller than those removed during ultrafiltration. It removes virtually all substances within water including organic compounds, nutrients, and salts.
Chemical processes:	
Chloramination	Chloramines are compounds that contain chlorine and ammonia. Monochloramine is added to water to kill bacteria. This is a different chemical from dichloramine and trichloramine which are most commonly found in swimming pools. Chloramination is sometimes used as an alternative to chlorination (CDC online).
Chlorination	Adding chlorine to water kills many pathogenic bacteria, but at normal dosage rates it does not kill all viruses, cysts, or worms. Chlorination is often combined with filtration at which point it becomes an excellent way to disinfect drinking water supplies.
Ozone	Ozone is an unstable gas that releases a free oxygen atom. When added to water it has an oxidising effect which is more effective against bacteria and viruses than chlorination. It also oxidises iron, manganese, and sulphur causing them to precipitate out of the water as insoluble particles which are then removed by further filtration.

Ultraviolet (UV) light disinfection	Typically applied after reverse osmosis, water is subjected to UV light which kills off any residual micro-organisms (such as bacteria and viruses).
UV/Hydrogen peroxide	In this process the water is dosed with hydrogen peroxide before entering the UV light chambers. The UV radiation converts the hydrogen peroxide into hydroxyl radicals which react with and destroy organic compounds. This is often followed by filtration over granular activated carbon (Water Research Foundation, 2011).
Natural systems:	
Soil Aquifer Treatment (SAT)	A natural process where water is applied to soil. Surface spreading facilitates initial decomposition by sunlight, filtration through soil particles removes suspended solids and bacteria, soil adsorbs organic contaminants, viruses, metals, and phosphates (Brown and Caldwell, 2013). The process removes organic compounds and nutrients, and pathogens.
Riverbank filtration	Riverbank filtration takes water (abstracted from close to the surface, i.e. shallow wells in riverbanks) and then applies it to land to infiltrate, similar to the SAT system. It can reduce or stabilise the microbial, organic matter, and particulate loads in the water but it does not remove all contaminants (Huelshoff *et al.,* 2009). This is generally viewed as a pre-treatment stage within the multi barrier approach in the overall treatment chain recommended by the World Health Organisation (2011).
Wetlands, Reservoirs	The role of environmental buffers in protecting human health in planned drinking water reuse systems is not documented definitively. Different types of buffer have different attributes that affect which contaminants they are able to remove, they provide different dilution levels, and the residence time of the water can differ considerably (NRC, 2012).

*Residual after conventional secondary treatment. These advanced processes are already more commonly applied to industrial wastewater due to the additional range and higher concentrations of contaminants.

Figure 3.3 Reverse Osmosis Treatment Technology

Clockwise from left: close up of reverse osmosis membrane, membranes within the cases, entire reverse osmosis unit.

Photos: Sandra Ryan

Residual Risks and Risk Mitigation after Treatment

The treatment options that are available to produce non-potable and drinking water standard water from wastewater do provide high levels of assurance that the water is safe to use. However, as this review highlights there remain certain aspects where knowledge is still being developed or where inherent uncertainties are likely to prevail, particularly in the presence of new chemical compounds in industrial waters. The work undertaken for UKWIR in 2015 (UKWIR, 2015) identified that the inability to monitor incoming wastewater (and outgoing effluent) for all possible contaminants introduces uncertainty in the situation. This is normal and is not unique to water reuse systems.

The Drinking Water Inspectorate strongly supports the World Health Organisation's initiative in promoting water safety plans as the most effective means of consistently ensuring the safety of a drinking water supply. Water utilities in the UK are advised to fully utilise the mitigation measures covered by Drinking Water Regulations 15 and 27 (source risk assessment and drinking water

safety plans) to minimise risk of non-compliance with obligation to supply 'wholesome' water. This approach focuses on identifying and understanding the activities in a catchment that generate wastewater and therefore the likely substances and concentrations that will be present. This activity based approach supports the ongoing monitoring of a prescribed list of contaminants. The DWI has stated that a Water Safety Plan (WSP) is "*the most effective way of ensuring that a water supply is safe for human consumption and that it meets the health based standards and other regulatory requirements*" (DWI, 2005).

As uncertainty in the ability of treatment to remove hormones from water has prevailed and this is a key concern for stakeholders, the UK Endocrine Disruptor Chemicals National Demonstration Programme together with UK water company 'exposure' studies have generated further evidence on the capability of advanced wastewater and water treatment processes such as Granular Activated Carbon (GAC), Ozone, Reverse Osmosis (RO), and Chlorine dioxide to eliminate EDCs. Based on the outcomes of those investigations the Drinking Water Inspectorate confirmed that it "*can now be very confident that oestrogens are not present in [UK] drinking water*" (DWI, 2010)."

4. Energy and cost implications

Physical and chemical wastewater treatment are energy-intensive processes. Generally, the higher the level of treatment, the higher the energy requirement. In turn this translates into carbon emissions and higher operating costs. Therefore water utilities design their wastewater treatment trains to meet the exact water quality requirements of the destination. Underestimating the level of treatment that is required could have major human health implications and must be avoided. However, over-cautious planning, leading to unnecessary levels of over-engineered treatment may result in a very safe product with excessive costs.

Unfortunately for planners and engineers there is very little documented information on the unit costs of individual different treatment processes. Factors that impact on the energy and chemicals required to treat water to the desired standard include:

- The quality of the incoming wastewater. This varies spatially depending on the land use and industrial activity in the sewerage catchment. It can also vary significantly over time at the same treatment works. Heavy rainfall events can wash sediment into drains increasing turbidity levels, and over the longer term changes in population and industry can increase the loads and composition of water entering the treatment works;
- The water quality requirement of the intended reuse scenario (e.g. low grade non-potable for industrial cooling, slightly higher graded non-potable water for urban irrigation or low sensitive agriculture, or drinking water);
- The volume of water to be ‘reclaimed’ and reused;
- The availability of environmental water to dilute incoming effluent (e.g. estuarine waters);
- The specific combination of processes and their configuration in the treatment train;
- The availability to utilise ‘natural’ treatment methods including infiltration, wetlands, and blending the effluent with environmental water.

Unit costs of treatment processes and entire treatment trains (measured as £ per Ml - million litres) are therefore bespoke. Due to the potential financial implications of reuse there is interest in assessing costs relative to other alternative options. In the UK reuse systems are being considered as part of a diverse portfolio of options, alongside more traditional options such as reservoirs, transfers, leakage reduction, and other demand management. Reuse is therefore

often compared technically and financially against desalination, although depending on the circumstances these are not necessarily mutually exclusive.

The outcomes from case study investigations (ATSE, 2013) are that less energy is required to apply advanced treatment to wastewater than to desalinate seawater (notwithstanding reverse osmosis which can be applied in both systems). Another benefit of reusing treated effluent (treated to drinking water standard) is that it also reuses the existing water treatment and supply infrastructure connecting treatment works to demand centres. Reducing the level of capital expenditure to build new assets and operating a less energy intensive process makes water reuse a less carbon intensive and a less expensive process. In Singapore where the NEWater reuse system provides 30% of the water supply and desalination provides 25% the authorities have revealed that it is more expensive to desalinate water than it is to treat wastewater for reuse (PUB, online).

Technology development for both desalination and water reuse systems is rapid and inevitably there is interest in the opportunities that hybrid systems could offer. A recent study (Teusner *et al.*, 2016) has examined how a hybrid between sea water desalination and water recycling could work (a hybrid forward osmosis and reverse osmosis (FO–RO) plant). The article concludes that the hybrid method is comparable in cost to direct potable water reuse but is still cheaper than desalinating the same volume of water.

As stated, costs are highly variable and sensitive to many factors, one of which is the price of the technologies themselves (i.e. not just the operating energy costs). As technology continues to improve and more reuse systems come online the cost of treatment equipment will come down.

It is worth noting the wider economics of investing in new types of approach. Investment typically triggers additional investment. A focus in one area can generate spinoff industries in research, technology development, and manufacturing. Singapore is a prime example where its own investment in water management triggered several major international companies to invest in developing research centres in the country (e.g. US conglomerate General Electric, Germany's Siemens and Dutch firm Deltares). In addition to the immediate technology companies, creating a reliable water supply also gives confidence to water dependent businesses to invest in the locality.

5. Regulating Reuse

The status of water reuse as a mainstream drinking water or alternative non-potable supply is beginning to receive serious consideration, as demonstrated by Thames Water, Southern Water, and Anglian Water's 2014 Water Resource Management Plans. However, there is no national water reuse strategy and no specific regulations relating to strategic, centralised supply provision of treated effluent and this is seen as a barrier to implementing waste water reuse (UKWIR, 2015).

Elsewhere water suppliers and authorities face obstacles and delays mainly due to the lack of clear policies including defining treated wastewater as part of the water resource base, the lack of legal and institutional frameworks to help implement reuse projects, and the lack of support to train/inform farmers and the public about risk and available guidelines (TYPSA, 2013).

Countries and States facing chronic water stress, the USA (particularly California), Singapore, Australia, Israel, Japan, Saudi Arabia, China and the Mediterranean region, have developed reuse strategies (Hochstrat *et al.*, 2008) and regulations and guidelines to support mainstream uptake. The focus of these approaches to regulating reuse is primarily setting water quality standards relating to the purpose of use.

5.1 Existing Guidelines and Water Reuse Quality Standards

There is more than one way to regulate water quality. In 1989 the World Health Organization developed a set of guidelines that specify microbiological limits (WHO, 1989). This parameter based approach is popular, particularly in developing countries as it provides a straightforward system for ensuring safety and compliance. However, the parameters included and standards were considered too lenient to protect public health in more industrialised and more densely populated regions.

California, one of the leading areas of IPR, the California Department of Health Services developed the Californian Code Regulations, Title 22 – Division 4, an alternative approach that stipulates level of treatment rather than compliance with individual water quality parameters. The Title 22 Code does not specify which types of treatment process are required, but for a given purpose of use it does specify the level of 'log-removal' that treatment must achieve. This is a 'safety first' philosophy but it is inherently expensive, potentially over-cautious (carbon and financial cost implications), and disregards established traditional practices and socio-economic conditions present in many other parts of the world (UKWIR, 2014).

Guidelines in other countries (such as Spain and Australia) usually define standards for microbiological hazards (focussing on pathogens and parasites) and are often specifically for water reuse in agriculture and aquaculture, rather than industry. It is impractical to monitor for all pathogens and so faecal indicator organisms (FIOs) (e.g. total coliform, faecal coliform and *Escherichia coli*) and nematode eggs are usually used to indicate overall pathogen level and set quality standards (Norton-Brandão *et al*., 2013). In many cases standards and regulations are specifically defined for the various crops (ready-to-eat, fodder, industrial etc.). For example, threshold values generally range between 100 – 1000 CFU/100 ml for unrestricted agricultural irrigation, while the threshold levels for some restricted irrigation uses can be more lenient up to 105 CFU/100 ml. Some also consider the influence of different irrigation options (i.e. subsurface drip irrigation versus spray irrigation) in reducing risks to human health (Becerra-Castro *et al*., 2015). More information explaining why different quality levels are acceptable for different uses is available in Section 3.3.

Existing guidelines in place in other countries on reuse of effluent do not specify threshold values for salmonella, Listeria, or Cryptosporidia. There are some guidelines specific to other types of use, for example using non-potable treated effluent for toilet flushing. In California the Title 22 microbial standard for toilet flushing with reclaimed water specifies that the median total coliform (pathogen) concentration must not exceed 2.2 coliforms*[8]/100 ml (based on a 7 day analysis). This is far more stringent compared to the microbial standard in Japan, which is defined as 1000 coliforms/100 ml of reclaimed water (Ogoshi *et al*., 2001).

The 1989 WHO guidelines were updated in 2006 (WHO, 2006) setting stricter quality limits, and these are generally accepted to represent a minimum water quality requirement. Many non-potable reuse systems set WHO 2006 guidelines as their minimum but develop their own bespoke quality and therefore treatment levels in accordance with their own situation.

In 2012 the European Commission issued its '*Blueprint to safeguard Europe's water resources'* (European Commission 2012) in which it identified that reusing treated effluent offers sufficiently significant potential to reduce the stress on Europe's freshwater resources that action to accelerate uptake is required. The Commission has explored a variety of regulatory and non-regulatory instrument options to proactively increase water reuse across Member States. The scope of this has been restricted to non-potable reuse systems and the Commission is currently working with its technical working groups to confirm an appropriate set of standards that will be applicable to and support water suppliers across the different States.

[8] MPN – Most Probable Number

5.2 UK Regulatory Situation

Neither the UK nor European Union have legislative regulations concerning strategic centralised wastewater reuse other than the Urban Wastewater Treatment Directive (91/271/EEC - UWWTD) which advises to reuse wastewater "*whenever appropriate*". Where reuse systems have been developed in Europe this has been carried out "under country specific national or even regional guidance" (Hochstrat, 2006). The 2015 investigation into the ability of the existing framework of water management related regulations to effectively regulate water reuse systems (UKWIR, 2015) examined 17 relevant EU directives and 38 pieces of domestic UK legislation. Within this framework there are sufficient controls permitting water abstraction and discharge, control of substances and pollution, and drinking water requirements to protect against the majority of potential risks that the study identified.

Drinking Water

Regulations on the quality requirements of drinking water are very clear. The Water Resources Act 1991 imposes the duty on water companies to supply wholesome water, and this is regulated by the Drinking Water Inspectorate. The legal standards in the UK[9] are those which are set in Europe in the Drinking Water Directive 1998 together with national standards set to maintain the high quality of water already achieved (DWI, 2009 and DWI, 2010a).

The main outstanding gap in legislation relates to the absence of a clear regulatory mechanism to allocate some form of ownership on water that is discharged into the environment but intended to be re-abstracted (Indirect Potable Reuse). This creates a commercial rather than health or environmental risk for those operating and relying on the water reuse process.

Arguably one of the biggest issues that could inhibit large scale uptake of water reuse systems is the uncertainty caused by how the UK has transposed the Urban Waste Water Treatment Directive into domestic legislation. Whilst the UWWTD itself advocates reusing wastewater, the UK Environmental Permitting Regulations (EPR) implies that treated effluent is classified as waste (rather than resource) unless it is discharged into controlled waters (e.g. a river). This severely limits what that water could then be used for and has the potential to inhibit all but variations of Indirect Potable Reuse (IPR).

There is no expectation or requirement to retrospectively begin applying additional regulatory measures to the large number of existing indirect and unplanned *de facto* water reuse situations across the country. Whilst there is a growing appetite

[9] the Water Supply (Water Quality) Regulations 2000 (as amended in 2007 and 2010)

to increase the role of reuse as a water resource/supply solution there is agreement across the regulators and the water companies that the most appropriate way to ensure human and environmental health are not compromised will be through the use of Water Safety Plans as advocated by the Drinking Water Inspectorate.

Non-potable Water

For non-potable systems there are currently no legislative controls prescribing water quality standards for the use of non-potable water, e.g. for agriculture. However, there are regulations that apply to the use of water in the food industry:

1. The Drinking Water (Undertakings) (England and Wales) Regulations 2000 (SI 2000/1297) as amended by the Water Supply (Miscellaneous Amendments) (England and Wales) Regulations 2010 (SI 2010/996). This relates to legally binding water quality improvement programmes to meet drinking water standards;
2. The General Food Regulations 2004 (SI 2004 / 3279 as amended) and Council Regulation 178/2002;
3. Council Directive 98/34/EC - The Technical Standards and Regulations Directive. This requires member states to tell the European Commission, and other member states, about their technical regulations, at a draft stage;
4. Security and Emergency Measures (Water and Sewerage Undertakers) Direction 1998;
5. The Security and Emergency Measures (Water Undertakers) Direction 2006. This updates the 1998 Direction in light of Water Act 2003 and provisions for licensees.

There are no controls to prevent cross-contamination of private drinking water supplies by non-potable reuse supplied water. The Water fittings Regulations could be extended to address this but it may well be easier to manage this via appropriate bespoke contract conditions.

6. Forward Look

Across Europe, including the UK, it is well recognised that traditional sources of water (abstracting environmental water from the ground and rivers etc) may have reached their limits in terms of how much water they can continue providing for drinking water and other non-potable abstractions. In fact as the climate continues to change and regulations to protect the water environment become more stringent even existing resources are expected to diminish. This is a real problem as populations continue to increase and urbanise. In combination with action to reduce and manage demand for water, options to reuse water will become increasingly more attractive and economically feasible.

The existing 'drought resilience' water reuse system in Essex (Section 2) and the major drinking water support reuse scheme planned for London (150 Ml/d by 2027) are likely to be followed by many other reuse systems. They will not necessarily all be driven by arid or semi-arid climatic conditions, nor will they all be to provide drinking water. Already reuse 'working groups' are forming including in Scotland where despite high annual rainfall levels, the mountainous terrain and competing demands for water are increasing the difficulties of providing cost-effective supply infrastructure using traditional water resources and the opportunities of non-potable reuse are being explored.

The European Commission recognizes that the potential to relieve pressure on stressed freshwater systems is huge but concerted and targeted action is required to actively increase uptake. In 2010 it published a 'roadmap' for how the European Union should manage its water resources. That document, *A Blueprint to safeguard Europe's water resources* (European Commission, 2012) makes clear that reuse for irrigation or industrial use is the main alternative supply option requiring extra attention to increase its application. A study in 2006 reported that only 2.4% of wastewater was being actively reused (AQUAREC, 2007) and the vast majority of that was for agricultural irrigation in Spain and Italy. Other countries which use a lot of treated wastewater to irrigate crops include Cyprus, Greece and Israel. Israel is one of the leading countries in terms of the proportion of wastewater that it actively reuses. Elsewhere the industrial and municipal demands of the rest of Europe continue to put pressure on the limited freshwater resources.

The reuse landscape in the UK is expected to change during the next 10 to 15 years. Water resources in the South and East of England are under intense pressure due to very large populations (forecast to continue growing significantly) occupying the driest part of the country. Water companies are forecasting continued increase in demand for water whilst at the same time being forced to

reduce the volume of water they abstract from the environment where this is found to be the main cause of diminished flow, and degraded ecology. Most water companies in that region have started to consider the option of reuse but it is Thames Water that has identified the most urgent need to find a solution to a forecast supply deficit. Thames Water is currently pursuing a research programme to investigate and design a robust reuse system to support its other sources supplying London.

Widespread implementation beyond existing agricultural reuse and the emerging systems in the south-east of England may take many years, and the rate of change will undoubtedly be influenced by the occurrence (or not) of drought putting the spotlight on the pressure that water resources are under.

Other policy and cultural attitudes could influence the rate of change such as the ‘Zero Waste’ agenda and the ‘Circular Economy’ which advocate the economic as well as the environmental benefits of reusing resources. Water reuse systems could become much more mainstream as the need to reuse becomes more pressing, human health and environmental risks become better understood, and the costs of developing and operating water reuse systems continue to come down.

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