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The potential of water reuse as a management option for water security under the ecosystem services approach

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ABSTRACT

Focusing on the water–energy–food nexus, this paper revisits water reuse as a management option for water security under the ecosystem approach. The case of Singapore is presented as an example where water near self-sufficiency has been achieved through careful planning and leveraging of technology. Water reuse features prominently amongst other innovative integrated water management approaches. Although the application of water reuse technologies is very limited in the UK, there is a lot of potential both from a business and from an environmental point of view. The Anglian region, being extremely dry and hosting highly water-intensive economic activities, is classified as seriously water stressed. Water reuse is, therefore, of particular interest, especially considering the multiple benefits that are derived from ecosystems, i.e. ecosystem services, and how these depend on water availability and quality. Examples of technologies that deliver the highest grade water for reuse are ultra filtration, reverse osmosis and ultraviolet disinfection (often in combination). Findings demonstrate that water reuse can help in addressing water problems and challenges, particularly when decision-making is from a systems perspective. When ecosystem services are taken into account and are valued properly, water reuse is a sustainable practise that can also be financially profitable.

Keywords: Water reuse; Closing the loop; Ecosystem services; Water–energy–food nexus; Anglian region

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1. Introduction

The interdependency between the water, nutrients and carbon cycles could lead to shifts in water distribution that are difficult to predict. At the same time, there is a need to identify synergies in the water–energy–food nexus, whose components are evolving at different rates and are influenced by other sectors, in order to sustainably address water and environmental challenges in the near future [1]. The sustainable development and management of freshwater resources can only be brought about by commitment from the highest level of government to the lowest community level, involving significant investments, public education, legislative and institutional changes, technology and capacity building [2]. An example of such an approach is the recurring thesis in environmental and water resources engineering that it is feasible to treat wastewater to a high enough quality that it is a

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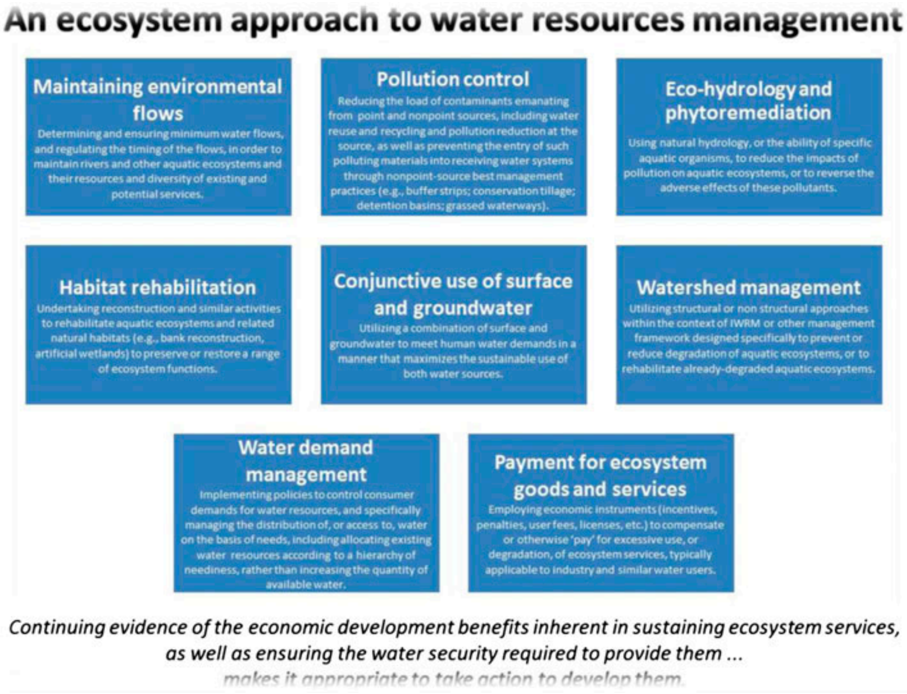
resource that could be put to beneficial use rather than wasted—a theory referred to as "closing the loop".

In Europe, the Water Framework Directive (WFD) (2000/60/EC) has introduced a legal framework to protect and restore the water environment across Europe and ensure its long-term sustainable use based on management at the scale of river basins, the natural, geographical and hydrological unit for freshwaters and sets specific deadlines for Member States to protect aquatic ecosystems [3]. The intent of WFD implementation is to achieve the sustainable management of water resources by taking due account of environmental, economic and social considerations. In doing so, the Directive establishes innovative principles for water management including public participation in planning and economic approaches, such as the recovery of the cost of water services.

At the same time, ecosystem services, the benefits people obtain from ecosystems, have received a lot of attention in recent years, for instance through the UN *Millennium Ecosystem Assessment* (MEA) [4] or *The Economics of Ecosystems and Biodiversity* (TEEB) initiative of the European Commission (through the European Environment Agency). The ecosystem approach, which originated from the Convention on Biological Diversity, provides a framework for looking at whole ecosystems in decision-making and for valuing the services they provide to ensure that society can maintain a healthy and resilient natural environment now and for future generations (Fig. 1). In the UK, the Ecosystems Approach Action Plan has defined the ecosystem approach as "A generic framework for incorporating the holistic consideration of ecosystem services and their value into policy, plan and decision-making" [5]. Ecosystem services, therefore, form part of the wider ecosystem approach.

Ecosystem services and the other benefits that we derive from the natural world are critically important to both the UK economy and human well being. Many of the most important ecosystem services provide values which are not reflected in market prices, services such as clean and regular water supplies, outdoor recreation and climate regulation [6]. Changes in freshwater ecosystems due to development pressures, exacerbated by climate change, could affect their capacity to provide sufficient and reliable quantities and qualities of water for people.

In the UK, about 22 billion m^3 of water is abstracted each year, 52% from rivers and lakes, 11% from groundwater and about 37% from tidal waters (mainly used for cooling) [7]. The UK Government's water strategy for England, "Future Water" [8], aims to reduce household water consumption by 13% by 2030, from 150 to 130 L/person/d. This could be achieved through more extensive water metering, tariffs and planning policies. The Walker Review report



An ecosystem approach to water resources management

Maintaining environmental flows
Determining and ensuring minimum water flows, and regulating the timing of the flows, in order to maintain rivers and other aquatic ecosystems and their resources and diversity of existing and potential services.

Pollution control
Reducing the load of contaminants emanating from point and nonpoint sources, including water reuse and recycling and pollution reduction at the source, as well as preventing the entry of such polluting materials into receiving water systems through nonpoint-source best management practices (e.g., buffer strips; conservation tillage; detention basins; grassed waterways).

Eco-hydrology and phytoremediation
Using natural hydrology, or the ability of specific aquatic organisms, to reduce the impacts of pollution on aquatic ecosystems, or to reverse the adverse effects of these pollutants.

Habitat rehabilitation
Undertaking reconstruction and similar activities to rehabilitate aquatic ecosystems and related natural habitats (e.g., bank reconstruction, artificial wetlands) to preserve or restore a range of ecosystem functions.

Conjunctive use of surface and groundwater
Utilizing a combination of surface and groundwater to meet human water demands in a manner that maximizes the sustainable use of both water sources.

Watershed management
Utilizing structural or non structural approaches within the context of IWRM or other management framework designed specifically to prevent or reduce degradation of aquatic ecosystems, or to rehabilitate already-degraded aquatic ecosystems.

Water demand management
Implementing policies to control consumer demands for water resources, and specifically managing the distribution of, or access to, water on the basis of needs, including allocating existing water resources according to a hierarchy of neediness, rather than increasing the quantity of available water.

Payment for ecosystem goods and services
Employing economic instruments (incentives, penalties, user fees, licenses, etc.) to compensate or otherwise 'pay' for excessive use, or degradation, of ecosystem services, typically applicable to industry and similar water users.

Continuing evidence of the economic development benefits inherent in sustaining ecosystem services, as well as ensuring the water security required to provide them … makes it appropriate to take action to develop them.

Fig. 1. An ecosystem approach to water resources management.

[9] estimated that households with water meters used on average 10–15% less water than those without.

As freshwater supplies become more limited, desalination and water reuse provide a new water source to supplement fresh water supplies for a wide range of industrial, domestic and environmental needs. As such, meeting the increasing water challenges requires a combination of approaches including water conservation, recycling and treatment of impaired water from non-traditional resources to "create" new water.

This paper, therefore, focusing on the water–energy–food nexus, revisits water reuse as an integrated water management option for water security under the ecosystem services approach.

2. Integrated resources management for water security

A successful example of such an approach is the case of Singapore, which has achieved near self-sufficiency through careful planning and leveraging of technology. The Singapore example of water supply capacity developed by the Water Agency, since independence in 1965, is focused on capturing and storing surface water, as it does not have significant underground water supplies [2].

Innovative integrated water management approaches, such as the reuse of reclaimed water, the establishment of protected areas in urban rainwater catchments and the use of estuaries as freshwater reservoirs have been introduced along with seawater desalination in order to reduce the country's dependence on water imported from the neighbouring country Malaysia. Singapore's approach does not rely only on physical infrastructure, but it also emphasizes proper legislation and enforcement, water pricing, public education as well as research and development [10].

Singapore's success in integrated urban water management (IUWM) is unquestionable, with decreased domestic water consumption per capita, reduction in unaccounted-for-water (UFW) and a decrease in flood-prone areas. Its success is due to decades of sustained, methodical development of water policy, public support and institutional reform, all of which have played a crucial role. Singapore can go one step further to achieve greater sustainability if rooftop rainwater harvesting is also implemented as a decentralized, dual mode water supply system for non-potable use. There is no "one size fits all" solution to IUWM. Singapore's experience indicates that IUWM can be achieved with political will, good governance and a coherent water policy [2] (Fig. 2). Its integrated approach to water management has encompassed proper land use planning, judicial investments in infrastructure for water supply and used water, pollution control measures and use of technology and public education amongst others [11].

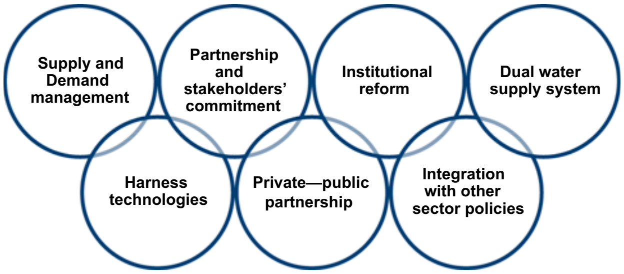


Fig. 2. Components of successful water resources management.

However, today Singapore is the exception rather than the norm, proving the prevailing world situation where the norm is far away from sustainable water and sanitation, and often at the expense of ecosystem services and the other benefits that we derive from the natural world.

As a result of water scarcity and increasing demand for freshwater, advancing the science of water purification is vital in the development of sustainable new technologies. "Nexus" thinking enables us to address water, food and energy issues more holistically. Integrated Water Resources Management (IWRM) under the nexus perspective becomes a cross-sectoral approach (Fig. 3) which places freshwater needs for human health and sanitation, next to demands on water for energy (e.g. hydropower) and food security (e.g. crop irrigation). Major concerns associated with technologies, such as seawater desalination include factors such as high cost and energy consumption, and for water reuse, institutional barriers and public perception.

Water reuse is a sustainable practise that can be financially profitable in that context. Recycled water can satisfy most water demands, as long as it is

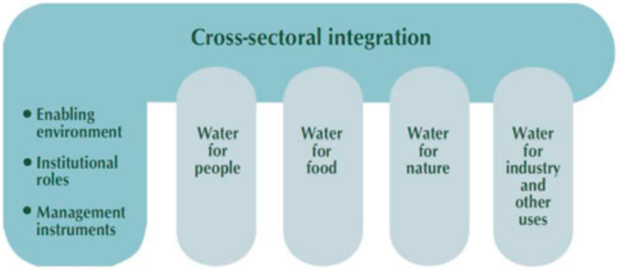


Fig. 3. IWRM and its cross-sectoral integration [12].

adequately treated to ensure water quality appropriate for the intended further use. Common industrial practice typically consists of end-of-pipe solutions that will allow the effluent to meet certain discharge standards before being released into the environment and the separate sourcing of clean water for their operations. Such linear modes of production are unsustainable and costly.

3. Anglian region case study

The Anglian region is a river basin district in the east of England. This region is extremely dry, receiving only two thirds of the UK's average annual rainfall (600 mm per annum) [13]. The Anglian region is mostly low lying with fens (artificially drained coastal and estuarine wetlands) comprising a large proportion of the area. This results in over one-fifth of the area being susceptible to coastal and surface flooding [14].

The climatic factors of the area, along with the highly water intensive economic activities of the area, result in the area being classified as seriously water stressed, with between 20 and 45% of the effective rainfall abstracted [14]. Therefore, water abstraction is a key environmental stressor. The Environment Agency (EA) [14] reports that 87% of groundwater and 21% of river length in the region are at risk or probably at risk from abstraction and flow regulation (Fig. 4). Moreover, 73% of surface water is at risk from groundwater abstraction and flow regulation and 68% of groundwater dependent terrestrial ecosystems are at risk from abstraction and flow regulation impacts [14]. Since 1990s, there have been five periods of drought officially declared in the region with the most recent between June 2011 and April 2012. The 2011 and 2012 drought period was a result of six months of exceptionally low rainfall and soil moisture deficit being at the highest recorded level [13]. This led to a domestic hosepipe ban from April to June 2012 [15]. The effects of water abstraction are exacerbated by a rapidly growing population and associated planned developments (e.g. 600,000 new homes planned before 2026) [14].

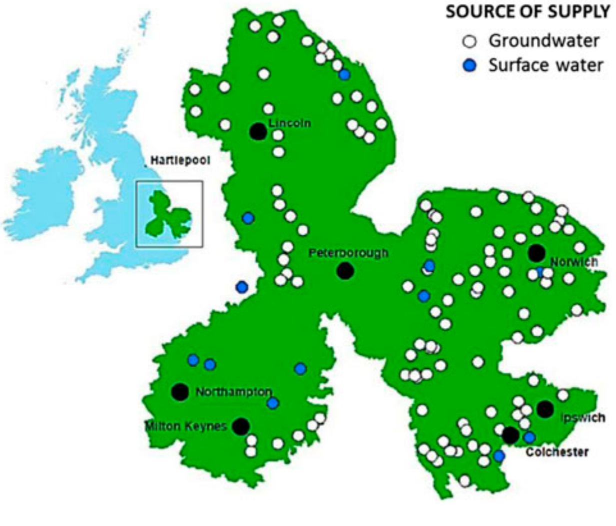


Fig. 4. Anglian water—water source [17].

Because of these pressures and the higher environmental standards required by the Water Framework Directive, only 18% of surface waters are currently classified as good ecological status or potential in the Anglian region; 33% of assessed surface water bodies are at good or better biological status now, although the EA expects this to change to 27% when all water bodies have been assessed [16]. The preferred option for water supply has traditionally been controlled by the availability of local groundwater and surface water sources [17]. As the demand for water increased and local supplies were exploited to their sustainable level, a network of raw and treated water transfers was developed along with strategic storage reservoirs, resulting in the extensive network that provides water services today.

To address the European and national legislation and local concerns, the EA has indicated that possible abstraction reductions by Anglian Water (AW) plc of up to 70 Ml/d in the region might be required, in order to restore the abstractions programme to a more sustainable level. The amount of water supplied has stabilized over the last 20 years as a result of better leakage control, household metering and a decline in water used by industry. In 2008, 800,000 million litres of freshwater were abstracted in the Anglian basin, with approximately 60% of abstracted freshwater coming from surface water and 40% from ground water sources (Fig. 5). Ninety percent of the water abstracted was for public supply, while the agricultural sector accounted for 4% of the total freshwater abstractions [16].

Resulting from a combination of limited resources and high demand (both human and environmental), the region's water resources are already considered to be fully, if not over-committed [16]. Actually, 55% of the water resource units have been assessed as over-abstracted or over-licensed at low flows (Fig. 6). Where water is being over-abstracted, existing abstractions are causing unacceptable damage to the environment at low flows. Water may still be available at high flows, but with appropriate restrictions. Climate change will compound this further, as it will affect the amount and distribution of rainfall, impacting on flows and water levels and also the temperature of

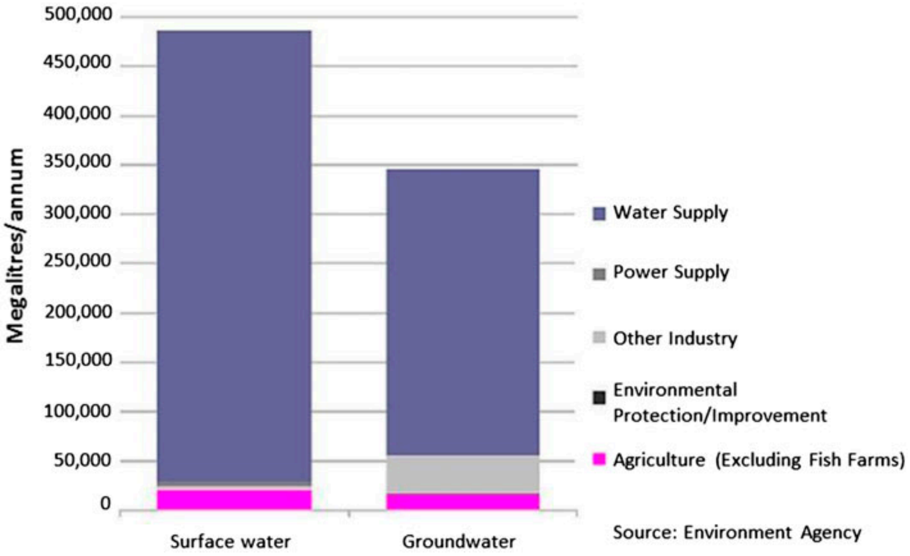


Fig. 5. Annual water abstraction in Anglian region 2008 [16].

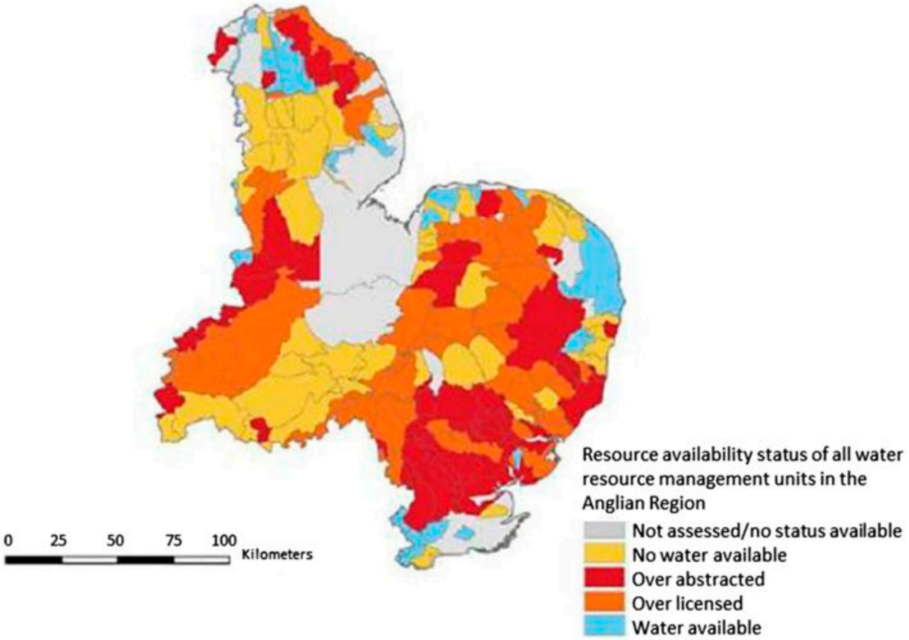


Fig. 6. Water available for abstraction (all water resource management units).

water. This will, in turn, affect where plants and animals can survive the quality of their habitats and their abundance. The rate and scale of change will affect different species in different ways as they try and adapt to changing habitats. Some of the sites of nature conservation interest that are being protected today may be increasingly vulnerable to irreversible change of habitat and species [7].

The UK’s Climate Projections (UKCP09) show that the Anglian region is likely to experience hotter drier summers, warmer wetter winters and rising sea levels [18]. This is likely to have a significant effect on environmental conditions and will increase the impact of human activity on the water environment.

It is suggested that consideration of ecosystem services in the decision-making process can lead to well-informed decisions, strengthening the economic and environmental argument of actions that can deliver environmental quality [19].

Overall, the current status as well as the outlook for ecosystem services in the Anglian region does not show a marked improvement. Given increased impacts from climate change as well as economic and population increase over the next 25 years, water availability for use by the environment is seriously under strain. Respective population, domestic and commercial demand growth by water resource zone over the next 25 years will cause additional pressure on water resources. AW expects a total of 560,000 new properties (amounting to approximately 800,000 people) over a 25 year time period in the region [17].

On the other hand, the full implementation of the Urban Waste Water Treatment Directive (91/271/EEC) in the region has resulted in treated wastewaters of quite high quality that could be reused for certain applications or improved by polishing steps for uses with higher quality requirements. Even though reclaimed water reuse is currently implemented in many European countries, mainly for irrigation, its potential has not yet been exploited in many areas.

4. The potential for water reuse

Water reclamation and reuse provides a unique and viable opportunity to augment traditional water supplies (Fig. 7). As a multi-disciplined and important element of water resource development and management, water reuse can help to close the loop between water supply and wastewater disposal [20]. But the real reason this option is revisited is the energy costs firstly in collecting, extracting, conveying and distributing water to end-users and secondly in treating and disposing of the wastewater once the end users have finished with it [21]. Although it requires additional energy to treat wastewater for recycling, the amount of energy required to treat and/or transport other sources of water is generally much greater [22].

From a systems point of view, closing the loop is a way of reducing interdependencies and an opportunity for optimizing a self-contained part without negative impacts to other parts or the whole. One of the most profound failures of our industrialized society is the way in which our production processes are so entirely linear. While this approach is perhaps “efficient” in the traditional sense (more product, less time, fewer inputs), when we consider the larger costs of production—those that are most often seen as externalities (e.g. wastewater discharge, air emissions, depleted soils and razed forests), it is harder to demonstrate the overall net benefit from many of our practices [23].

Therefore, the option of water reuse is becoming more attractive. Technologies that deliver the highest grade water for reuse, such as ultra filtration, reverse osmosis and ultraviolet disinfection have become cheaper and more effective [24]. The public is becoming more environmentally concerned. Recycling water seems as natural as any other recycling and more environmental friendly than big dams, diverted rivers and desalination. The economics are, therefore, to develop water reuse strategies in the developed world [25]. Many cities are running out of options and they are realizing that high grade urban water reuse is

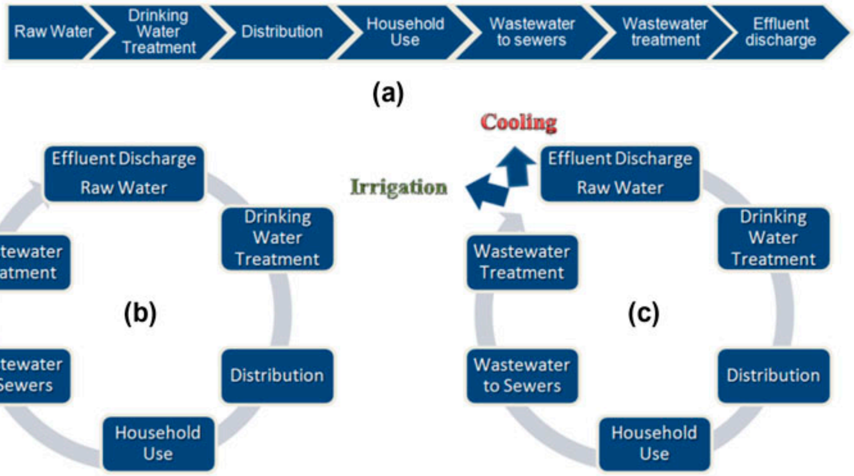


Fig. 7. From linear water use (a), to closing the loop either as a self-contained system (b), or though the water–energy–food nexus (c) [1].

much cheaper than the alternatives. If we take into account that the quality of raw water for drinking water production is often worse than effluent discharge and that the cost of wastewater treatment is as high as for drinking water [26], then it makes sense to close the loop. Rather than releasing high-quality wastewater effluent back into the environment and then paying to retreat it for drinking water purposes, it is more sustainable and energy efficient to close the loop.

Water treatment technologies are applied to produce high-quality drinking water that meets the quality standards for domestic (drinking) water supply. Conversely, municipal and industrial water use tends to degrade water quality by introducing chemical or biological contaminants. The quality changes necessary to upgrade the wastewater then become the basis for wastewater treatment. In practice, treatment is carried out to the point required by regulatory agencies for protection of the aquatic environment and other beneficial uses. Ultimately, as the quality of treated water approaches that of unpolluted natural water, the practical benefits of water reclamation and reuse are evident. As more advanced technologies are applied for water reclamation, such as carbon adsorption, advanced oxidation, and reverse osmosis, the quality of reclaimed water can exceed conventional drinking water quality by most conventional parameters and it is termed repurified water [20].

In developing its Water Resources Management Plan (WRMP), AW has followed the "twin-track approach" of using demand management alongside water resource development [17].

AW has included demand management proposals through further targeted leakage control, enhanced metering, pressure reduction schemes, the installation of water-efficiency devices and water audits. These options are normally selected in preference to larger resource development options and AW plans for a significant increase in investment in demand management in its business plan for 2010–2015 [17]. Over the longer term, AW is targeting a 90% penetration of domestic water meters by 2035 and this will be achieved by the continued metering of all new homes built and pro-active customer campaigns.

It is important to note the differences between demand management and resource development options in terms of certainty of quantification of water saved or provided. Whilst the output of a new water resource—e.g. water transfer or desalination—can be relied upon with some certainty throughout its design life, the savings from demand management are subject to changes in the water usage of products and customers' behaviour in using them.

By reusing water, a number of benefits can be achieved in the region: contribution to alleviating water scarcity problems, pollution prevention through decreased effluent discharge, enhancement of the status of wetlands and other habitats, water conservation from the reduced need to extract and treat freshwater, reduced energy costs from the separate treatment of freshwater and wastewater and a business opportunity from exporting the recovered water to other end uses (agricultural and landscape irrigation, cooling water for power plants and oil refineries, other industrial uses, drinking water, boiler make-up water, etc.), enhanced self-sufficiency for water, reduction of wastewater discharge costs, elimination of business risks related to water availability and possible future regulatory changes on wastewater discharge and management (that could entail additional costs), and "greening" of the business and increasing its brand value. Examples of technologies that deliver the highest grade water for reuse are ultra filtration, reverse osmosis and ultraviolet disinfection (often in combination).

Although the application of water reuse technologies is very limited in the UK, there is a lot of potential from establishing such practices, both from a business point of view and from an environmental one. Managing impacts of production activities alone is not enough. Innovation is required in the form of water reuse. If we take into account that the quality of raw water for drinking water production is often worse than effluent discharge and that the cost of wastewater treatment is as high as for drinking water, then it makes sense to close the loop. Rather than releasing high-quality wastewater effluent back into the environment and then paying to retreat it for drinking water purposes it is more sustainable and energy efficient to close the loop.

5. Discussion

A decisive factor in achieving a higher percentage of water reuse is the establishment of effective incentives, which in many instances will be of either an economic or a regulatory nature. The limiting factor for water reuse can in many cases be the quality of the water available linked to the treatment processes (technical options) and potential hazards for secondary users. In any case, its economic viability needs a careful cost-benefit analysis for the various parties involved to be carried out.

A wide range of applications of this approach can be found in the literature with some companies having a very strong presence in this field. Intel

Corporation (Intel) has developed water sustainability measures to reduce fresh water consumption which is inherently high for its operations (e.g. need for large amounts of ultra pure water for washing silicon wafers). The resulting water savings have been estimated at three billion gallons of water annually [27]. Water reuse technologies have significantly contributed to this outcome. Intel's facility in Albuquerque, New Mexico is an example of water reuse practice. Depletion of groundwater reserves in Albuquerque's primary aquifer had created strong pressures for businesses to minimize water use. By installing a high-recovery reverse osmosis water purification process, improving chip washing and rinsing techniques and using water-efficient landscaping, the Intel facility has reduced water use by 47% since 1994. Intel also reuses water from semiconductor rinsing in other industrial processes. In addition, the company pre-treats wastewater and returns it directly to the city treatment facility. Seventy-five to eighty-five percent of all water Intel uses in manufacturing at this facility is eventually returned to the Rio Grande River [28]. Similarly, in its Ocotillo Campus, Intel applies Reverse Osmosis to treat production effluent in order to recharge the underground aquifer. It is estimated that more than 3.5 billion gallons of drinking quality water to the underground aquifer are for eventual reuse since project inception [29].

However, some water reuse implementation projects have failed because some other key factors, such as social awareness and public perception or associated ecological effects were not taken into account. Thus, the consideration of regulatory, economic, technological, social and environmental factors seems essential to successfully accomplish a reclaimed water reuse project.

Feasibility studies can contribute towards obtaining the success in the implementation of a water reuse project [30]. For example, this is evident in Singapore's case, where success in integrated urban water management with a focus on water reuse has delivered additional benefits, such as decreased domestic water consumption per capita, reduction in leakages, and a decrease in flood-prone areas. Such integration requires political will, good governance and a coherent water policy. Singapore's integrated approach to water management has encompassed open land use planning, judicial investments in infrastructure for water supply and used water, pollution control measures and use of technology and public education amongst others [11]. Singapore's success is due to decades of sustained, methodical development of water policy, public support and institutional reform, all of which have played a crucial role [2].

Again it comes down to systems thinking. The need for interdisciplinary understanding of what the problem entails, focusing on linkages between the sectors and a holistic investigation to establish integrated solutions that acknowledge that events are separated by distance and time and that small catalytic events can cause large changes in complex systems, are all part of a well-designed effort to understand before we take action. Because an improvement in one area of a system can adversely affect another area of the system, organisational communication at all levels is necessary to avoid any unintended consequences Systems thinking, for any kind of system—natural, scientific, engineered, human or conceptual, provides a very useful framework for really solving problems rather than just taking decisions. It is the complexity of natural systems that creates the real challenge for environmental problem solving and the reason why, for example, further research on systems analysis tools could provide further opportunities for interdisciplinary, integrated and holistic solutions to water management.

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