Chapter 5

Water Reuse Trajectories

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Abstract

Water reuse is an obvious and important response to water scarcity in cities. It takes many forms – potable and non-potable, centralised and decentralised, direct and indirect, and planned and unplanned. How different forms of reuse emerge and stabilise depends on technical, economic, social, environmental and political factors, and specific local conditions. This chapter reviews trends in potable and non-potable reuse, including international examples of urban water reuse. The analysis shows that public acceptance, regulation, proven technology and support for innovation are needed to provide the conditions for water reuse systems to function. The diversity of approaches to water reuse in cities indicates that urban water infrastructure is diverging from the 20th century ideal of a centralised, universal supply of potable water. The different forms of water reuse present specific challenges for regulating and governing water infrastructure that require reform of existing arrangements and new institutions and management strategies.

5.1 Introduction

For most of the 20th century the development of urban water and sanitation infrastructure pursued an ideal model of centralised provision of drinking water and water-borne sanitation services (Graham and Marvin 2001). Universal, affordable access to potable water is a fundamental principle of good public health. Continuous water supply has also enabled modern lifestyles, gardens and standards of cleanliness that consume much more water than required to meet basic health needs (Shove 2003). Meeting the growing demand for water in cities is a major challenge for engineering, urban planning and governance. Conventional fresh water resources are renewable but limited, and in many parts of the world are unable to meet increasing urban demand.

Reusing water is an obvious and important measure for narrowing the gap between supply and demand. Water reuse takes many different forms, from simply using dishwashing water on kitchen pot plants, to recycling effluent from sewage treatment works for drinking water. Various techniques and systems for water reuse have different implications for cost, social acceptability, quality, energy consumption and governance. Reusing water at varying scales for different purposes introduces additional complexity into water infrastructure systems than conventional drinking water and sewerage systems (Bell 2012).

The chapter presents a typology of water reuse options, characterised according to scale (centralised or decentralised), strategy (planned or unplanned), end use (potable or non-potable) and the relationship to existing water resources (direct or indirect). The analysis highlights the socio-technical character of different types of reuse. As new technologies and infrastructures emerge to meet growing demand for water, they interact with and drive change in governance, social and economic systems.

5.2 Scale and Quality

Water reuse requires the existence of both a water supply system and a source of wastewater. The system which connects the two defines its form. There are typically four binary categories of water reuse systems: planned or unplanned, direct and indirect, potable and non-potable, and centralised and decentralised. Planned systems are those where a formal decision has been made to implement water reuse. Direct systems have no environmental barrier between discharging treated wastewater and the water supply system. Indirect reuse discharges treated wastewater into surface or groundwater sources, mixing it with conventional water resources, before abstracting it for reuse. Potable systems are used for drinking, food preparation and personal hygiene. Non-potable systems provide water for toilet flushing, irrigation, fire suppression and other low-risk uses. Centralised systems are organised at a municipal level, while decentralised systems operate on a building or neighbourhood scale.

In practice, few combinations of the four categories exist as the overall system form is dictated by the required water quality and the most appropriate scale at which to achieve this. Local economic, political, social and technological factors combine to determine the most appropriate form. Generally, system scale grows with increases in final water quality requirements.

Potable reuse systems can be both planned or unplanned, and direct or indirect. The level of water quality required for potable applications typically favours centralised systems to minimise risk to public health and achieve higher economic and energy efficiency required for high quality drinking water.

Non-potable systems are generally planned, direct and decentralised. The decision to use water for non-potable applications is inherently planned, an environmental barrier is not necessary to reach an appropriate level of water quality, and treatment can be achieved at smaller scales. System scale ranges from instant – sink to flush – to neighbourhood scale collection, storage and distribution. Examples of large scale non-potable reuse schemes are typically in industrial, environmental and agricultural rather than domestic applications.

The source of wastewater is a key factor in determining the cost, energy efficiency and scale of reuse. Energy use and cost increase with the amount of impurities that need to be removed – low-quality source water and high-quality final water requirements both lead to higher energy use. Most centralised reuse schemes are based on treating and redistributing municipal wastewater. Municipal wastewater is highly contaminated, and high levels of treatment, therefore energy and cost, are required prior to reuse.

5.3 Unplanned Indirect Potable Reuse

Unplanned Indirect Potable Reuse (IPR) is the most common form of water reuse. It occurs wherever a water supply abstraction point exists downstream of a wastewater treatment discharge and the scheme is not formally recognised as being water reuse. It is common in urbanised catchments. In water stressed catchments, wastewater discharge can significantly contribute to river flows, enabling abstraction of water downstream whilst maintaining ecological functions.

In contexts where wastewater discharge and water supply quality is monitored and regulated, these are governed by the conventional standards for wastewater and water quality. Research into the treatment requirements for IPR and Planned Direct Potable Reuse (DPR) is becoming increasingly relevant for unplanned reuse as abstraction for potable applications regularly occurs from polluted water sources. In the future, it is possible that planned and unplanned potable reuse will be subject to the same regulatory scrutiny, public acceptance complications, and technological and infrastructural expense as the distinction between the two becomes blurred.

5.4 Planned Indirect Potable Reuse

Planned IPR schemes augment conventional sources of water in aquifers, rivers and reservoirs with treated wastewater to abstract higher volumes than would otherwise be sustainable. In IPR schemes, wastewater is usually treated to a much higher standard than is required for discharge to the environment. In addition to conventional sewage treatment, water for planned reuse in most cases is treated using membrane technologies. Technologies for tertiary wastewater treatment for potable reuse include reverse osmosis, micro-filtration, ultra-filtration and membrane bioreactors.

The most common treatment train for potable reuse systems is recognised by the California Department of Public Health (CDPH) as being microfiltration, reverse osmosis and an advanced oxidation process (CDPH 2011). The widespread implementation of this system is restricted by high capital, operational and maintenance costs, high energy consumption, limits on levels of water recovery, and effluent discharge. In response, a number of alternatives are emerging globally (Gerrity et al. 2013) such as ultraviolet disinfection, membrane bioreactors, chlorination, ozonation and biological activated carbon.

Membrane treatment technologies that are commonly used for potable reuse are expensive and energy intensive compared to conventional methods. Reverse osmosis is the same technique used in desalination, the most energy intensive method currently used to produce drinking water. Energy requirements for treating wastewater to potable standards can be a significant factor undermining the sustainability of potable reuse compared with other options (Cooley and Wilkinson 2012). However, in many cases potable reuse treatment trains are more cost effective and less energy intensive than alternatives such as water supply transfer schemes and desalination (Leverenz et al. 2011).

Regulation of IPR is well developed in the US, due to the development of schemes in Florida and California. Around half of US states have statutory requirements for IPR, and others use US Environmental Protection Agency (EPA) guidelines to assess individual cases (US NRC 2012; EPA 2004). California's regulation of its groundwater replenishment schemes is especially strong, addressing both reuse in general and groundwater recharge standards in particular (CDPH 2009; 2011).

The 'environmental buffer' provides additional informal treatment to the already highly treated wastewater, and enables mixing and dilution with conventional supply sources. Dilution with surface water and groundwater can cause the water quality to deteriorate if the treatment train achieves a particularly high standard, but have been thought to increase public acceptability of potable reuse.

Potable reuse of wastewater has proven to be controversial in recent decades. Indirect reuse is thought as more acceptable to the public than direct reuse. Mixing highly-treated wastewater with conventional water sources and the treatment provided by natural systems is thought to allay concerns about health risks associated with potable water reuse. Using treated wastewater to augment existing resources rather than directly reusing it as drinking water is also thought to reduce the 'yuck factor' associated with potable reuse, which is used to describe seemingly irrational public concern at drinking treated wastewater.

Nonetheless, public opposition to water reuse has been a significant factor in the failure of proposed projects and has delayed the implementation of others. The city of Toowoomba in Australia voted against IPR as a new source of water in a referendum in 2006 (Hurlimann and Dolnicar 2010). Public concerns focussed mostly on health risks and the 'experimental' nature of Australia's first IPR scheme. Implementing IPR in San Diego during the 1990s and 2000s was delayed due to public opposition, including concerns about environmental justice, with poorer neighbourhoods protesting about receiving more reused water than wealthier parts of the city.

Controversy about IPR has highlighted gaps in modern governance regimes for water infrastructure (Bell and Aitken 2008). The conventional expert-led management of water supply systems has been unable to adequately account for public interest and concerns about new sources of water. Responses have varied around the world. In Toowoomba, the referendum created an adversarial debate. A simple yes/no vote mitigated against meaningful public engagement in the decision-making process and debate about risks and benefits of the proposed scheme (Bell et al. 2011). Many schemes, particularly in California, have adopted a Decide-Announce-Defend (DAD) approach to implementation, in which engineering decisions are made without consulting the public, and sophisticated communication strategies deployed to convince the public of the benefits of IPR and counter concerns about risks.

Colebatch (2006) argues that decisions about IPR should be taken in a wider context of public consultation and engagement about water resources management and infrastructure. Rather than being presented as IPR as the preferred engineering solution to water shortages, the public should be engaged more widely in decision-making. A more deliberative approach to engaging the public in decisions about water reuse was proposed as an alternative expert led processes (Russell et al. 2008). Greater attention to public acceptability was a feature of recent proposals for IPR in Perth and London, including the use of deliberative methods of engagement (Aitken et al. 2014; Hills et al. 2013). Early results indicate that addressing social concerns about potable reuse from the outset of research and planning into new schemes reduces opposition and increases acceptance.

5.5 Planned Direct Potable Reuse

Planned Direct Potable Reuse (DPR) is the least common form of water reuse. In such schemes, treated wastewater is introduced directly into the drinking water system, without any environmental buffer between the wastewater treatment effluent discharge and water supply abstraction. DPR can consist of either a direct connection of the wastewater treatment discharge into the water supply distribution system or at the abstraction point for water supply treatment just before the normal drinking water treatment process. As in IPR, wastewater is subject to advanced treatment, usually membrane filtration. DPR must find alternative ways to provide the system security and public confidence that an environmental barrier provides.

The most famous example of DPR is in Windhoek, Namibia where the blending of treated wastewater with raw water sources has been available since 1968 to provide a more resilient supply in drought situations (Du Pisani 2006; Lahnsteiner and Lempert 2007; Menge 2007). The system includes extensive control and testing of the wastewater source to minimise the impact of industrial discharge and identify spikes in contaminants (Du Pisani 2006), and a treatment train designed to remove various contaminant classes consisting of chemical coagulation, sand filtration, ozonation, biological activated carbon, granular activated carbon, ultrafiltration, chlorination and sodium hydroxide stabilisation (Du Pisani 2006; Tchobanoglous et al. 2011). Extensive control and monitoring act as an alternative to an environmental or engineered buffer by providing sufficient time for quality testing, analysis and decision-making (Gerrity et al. 2013).

Two systems have recently been implemented in the US at Cloudcroft, New Mexico which uses a similar treatment train to Windhoek, and Big Spring, Texas which uses the traditional Californian model of microfiltration, reverse osmosis and advanced oxidation (Gerrity et al. 2013; Crook 2010; Khan 2014; Leverenz et al. 2011; NWRI 2010; Tchobanoglous et al. 2011). Further DPR systems are proposed for California as a solution to ongoing drought and water shortages (WRRF and WRCA 2014). Public acceptance of these schemes under extreme drought conditions has challenged previously held assumptions that DPR would be likely to face strong opposition due to concerns about health and the ‘yuck factor’ associated with the idea of ‘drinking sewage’.

DPR technology is between two and three times as energy efficient as desalination (Poussade et al. 2011; Tchobanoglous et al. 2011). It can be cheaper than IPR by avoiding pumping water to and from an environmental buffer. DPR can also be cheaper than centralised non-potable reuse as it avoids the need for a dual-reticulation network (Leverenz et al. 2011).

There are four barriers to the widespread implementation of DPR: the development of national regulation and global guidance; further research into the associated public health risks created by removing an environmental barrier; further development of cost and energy efficient treatment; and a change in the public perception of the risks associated with DPR.

5.6 Non-Potable Reuse

Non-potable reuse (NPR) has the possible advantage over potable reuse of less stringent end-use water quality standards, reducing the requirement for treatment. However, NPR requires a separate distribution network to the conventional potable system. This is a constraint on the scale of NPR schemes. Within a bathroom NPR can be as simple as redirecting shower outflow to fill a toilet cistern or irrigate the garden. NPR at a building or bigger scale requires more extensive plumbing systems, which practically duplicate the existing potable network.

Reuse of municipal wastewater for non-potable end uses should require less treatment than for potable use, but this can vary depending on the system configuration and risk management strategies. NPR schemes can also be based on local reuse of greywater, which is water from showers, washing machines, bathtubs, hand basins and low-risk industrial processes. NPR of greywater usually occurs on a household or building scale, with minimal requirements for treatment. However, the reduced cost of treatment for non-potable use must be balanced against the cost of building and operating a 'dual reticulation' system to distribute both potable and non-potable water as separate supplies.

Centralised NPR is perhaps the second least common form of water reuse after DPR. Its implementation requires considerably more planning, regulation and oversight than other forms as it requires the adoption or retrospective implementation of a dual reticulation network. Decentralised non-potable water supply systems can utilise a variety of water sources such as rainwater, storm-water, greywater and locally reclaimed wastewater (Moglia et al. 2011a) depending on the water quality requirements of the local context.

Non-potable urban reuse is a well-established practice in Japan due to policy requirements for dual reticulation networks in new buildings above $3000m^2$ in many urban areas (Asano et al. 1996). Perhaps the largest example of NPR is the 1979 Fukoaka City reclamation plant which supplies 9600 m^3/day for toilet flushing, park irrigation and commercial buildings (Funamizu et al. 2008). The system was implemented following an extreme drought in 1978 and uses a treatment train consisting of chemical coagulation and sedimentation, ozonation, granular filtration, and chlorination. This treatment train is comparable to those in potable applications. NPR applications are not limited to buildings and are typically used for landscape irrigation and garden watering.

Australia has led in researching and implementing decentralised NPR systems as a means to a diverse water supply to provide system reliability and flexibility (Cook et al. 2009; Moglia et al. 2011a; Sharma et al. 2008; Tjandraatmadja et al. 2005). In 2009, the Queensland government introduced mandatory on-site water reuse devices for new build homes, in addition to fitting water efficient appliances, to enable them to save 70,000 litres of mains water per year (DIP 2009; Mankad 2012).

There is now a recognised need to develop regulation and practice guidelines for constructing and using NPR (Moglia et al. 2011b; Sharma et al. 2010). Moglia et al. (2011b) suggest that there is a need for: governance development, operation and management models, engineering design codes, installation guidelines, risk assessments, and technology selection methods to support decentralised water reuse. In addition, they also suggest that adaptive governance mechanisms should be implemented to capture knowledge. These include performance monitoring, identifying key success factors, ongoing stakeholder discussion, the development of a multi-perspective complexity understanding, flexible institutional mechanisms to promote the industry, and intelligent and responsive policy-making in addition to industrial engagement (Moglia et al. 2011b).

Limited information from district NPR schemes suggest that they are not yet as economically or environmentally efficient as the combined footprint of traditional water supply and wastewater infrastructure (Verrecht et al. 2012). Initial estimates suggest that providing a dual reticulation network is more expensive than the treatment costs associated with treating wastewater to a high standard for potable reuse (Tchobanoglous et al. 2011). Results from BedZED, a zero-carbon housing development in London, (Verrecht et al. 2012) show that balances between public acceptance and water quality, staff maintenance and technological capital costs, treatment efficiency gains and capital storage costs, and storm-water, rainwater and wastewater integration have not been optimised.

Non-potable reuse of municipal wastewater at the Queen Elizabeth Olympic Park in London is considerably more expensive than conventional water and wastewater treatment. The reused water is intended for use in non-potable applications but the risk management strategy employed to avoid public health problems in the event of a misconnection or misuse of the water requires treatment to effectively potable standards. In this case the management of risk undermines the potential sustainability benefits of non-potable reuse by increasing the intensity and cost of treatment.

5.7 Socio-technical trajectories

Water reuse schemes in various forms are currently considered alternative, rather than mainstream options for water infrastructure. Our review of water reuse options shows that the key factors shaping the implementation of water reuse in cities around the world include public acceptance, regulation, technology and economic subsidy.

5.7.1 Public acceptance

The public perception of any water reuse scheme is integral to its success. Public acceptability of water reuse is particularly of concern for potable reuse. Effective public engagement in water resources decision-making can increase the acceptability of reuse. Recent experience in the United States also shows that acute water shortages are conducive to public acceptability of reuse, including DPR.

Without public support, schemes may be underutilised or abandoned as has been demonstrated in Toowomba. The main public concerns are the perceived public health risk, system failure, maintenance requirements, service parity with the incumbent system, water quality, and the environment (Dolnicar and Hurlimann 2010; Moglia et al. 2011a; Southern Water 2012). Objection to the use of reclaimed water increase as the application moves closer to the body (Dolnicar and Hurlimann 2010).

Community involvement in the development of a scheme can take three forms: participation – where the community is actively involved in the development of a scheme they will adopt; influenced design – where the requirements and wishes of the community are considered by the system designers; and no alternative – where the system designers present the scheme as the only option to solve water scarcity (Bell 2012; Dolnicar and Hurlimann 2010). Higher levels of participation in water reuse and water resource decisions can make planning more complex and time consuming, but have been shown to underpin more robust decision-making and lead to higher levels of acceptance.

5.7.2 Regulation

The provision of national regulation and guidelines standards may enhance public confidence in water reuse as an alternative form of water supply. End use standards for potable and non-potable water should allow for flexibility in devising treatment trains in different applications. The establishment of any regulation and standards needs to find a balance between ensuring public health and avoiding an overly conservative standard which acts as a barrier to the implementation of water reuse schemes or requires energy and chemically intensive treatment (Nellor and Larson 2010). The development of guidelines and regulation is critical to the widespread implementation of water reuse schemes (Sharma et al. 2010).

5.7.3 Technology

Proven technology improves public confidence in water supply quality security and allows designers to implement systems, which are less energy intensive and more cost effective whilst having an appropriate level of process resilience. An increase in the technical capacity of water industry and its contractors and consultants in construction and maintenance of water reuse systems will be required for their widespread implementation (Moglia et al. 2011b). At present, inefficiencies associated with unfamiliarity are mitigated against through redundant process capacity providing system resilience to incoming contaminants and process failure (Gerrity et al. 2013).

Various treatment trains have been successfully implemented globally for both potable and non-potable applications. Reverse osmosis combined with micro/ultrafiltration is perhaps the most established and proven treatment train for potable applications (Thames Water 2013). Advances in online-monitoring will allow systems to be closely observed and process failure to be detected sufficiently quickly. Currently microbiological tests do not facilitate sufficiently quick pathogen identification for the removal of engineered or environmental barriers (Gerrity et al. 2013). This improvement will effectively optimise treatment trains – making them more energy efficient and cost competitive with alternative forms of water supply. Further monitoring of raw and effluent water quality is required to fully determine the design requirement and reliability of potable systems (Thames Water 2013).

5.7.4 Innovation support

Water reuse utilises technology and infrastructural arrangements which have not yet reached maturity. As a consequence, schemes may need to be implemented in protected market environments to allow water reuse to be competitive with traditional forms of water supply. To enable schemes to be economically feasible heavy subsidisation is often required (Hochstrat et al. 2007). Water reuse is usually more expensive than conventional supply. However, under conditions of water scarcity, water reuse may be costlier than other alternative water sources such as desalination and inter-basin transfers (Iglesias et al. 2010).

The water industry is often naturally conducive to the creation of protected markets to support developing technologies due to its monopolistic nature (Geels 2002). The lack of funding available for the trial of innovative technology and infrastructural arrangements is regarded to be a widespread barrier to implementing water reuse schemes (Bixio et al. 2008).

5.8 Conclusion

Water reuse offers a solution to water scarcity through the augmentation of existing water supplies to meet growing demand. Numerous water reuse examples exist globally with various applications, system scales, technologies and regulation. The determination of the optimum form of water supply will rely upon local economic, social and environmental conditions such as the cost of a marginal increase in water supply from existing or alternative sources; the availability and cost of energy for the treatment of wastewater; the required water quality for end use; the capital cost of installing a water reuse treatment system suitable for its applications; public acceptability and regulation.

Constraints on conventional supplies are an unavoidable physical challenge to the predominance of the 20th century model of universal, continuous provision of drinking water to cities (Bell 2015). The diversity of water reuse technologies and strategies exemplifies the complexity of trajectories of emerging water infrastructure systems. Balancing security of supply, public health risk, cost, environmental impacts and social acceptability in different options for water reuse demonstrates a shift away from universal, centralised provision. Water reuse systems are being deployed to meet demand in particular, local circumstances.

The emergence of alternative water reuse strategies demonstrates the interactions between the local and universal, as well as the need for social, political and economic reform alongside technological innovation in the context of environmental change. Alternative water sources and infrastructures do not exist as isolated, universal technological solutions to water scarcity, but are central to trajectories of development and reform in urban water systems.

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