Chapter 21

The socio-technology of alternative water systems

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21.1 INTRODUCTION

Water reuse and rainwater harvesting systems provide water system managers and water users with technical alternatives for supplying water under conditions of scarcity and uncertainty. In changing the scale, source and use of water, alternative water systems also challenge long standing social, institutional, economic and environmental relationships that support conventional modes of provision of water infrastructure services. Engineers and decision makers commonly consider infrastructure provision to be a technical problem to be solved to support economic development. A broader analysis of infrastructure systems shows that they have co-evolved with society, politics, local environments and other factors (van Vliet *et al*. 2005). Infrastructure systems might therefore be considered to be socio-technical systems (Marvin & Graham, 2001; Hughes, 1989). The growth of new modes of water provision, such as reuse and rainwater harvesting, is likewise contributing to the co-evolution of alternative patterns of relationships between people, water, technology and their environment. The extent to which these new patterns of provision are more or less sustainable than current infrastructure systems will be the outcome of system design, governance and social change.

Everyday use of water by people in homes, businesses and public places in most developed countries has evolved in the context of continuous supply of clean water, irrespective of the weather, state of the environment or availability of water resources in the local catchment. As water use and populations have increased, water infrastructure has expanded to meet demand. Limits to water resources and the cost of implementing new supplies have prompted renewed interest in alternative water systems, including decentralised rainwater harvesting and non-potable reuse. However, these systems are not necessarily inherently more sustainable than existing water infrastructure. Moreover, in urban areas in developed countries these systems are usually used to supplement, rather than replace, existing supplies. Consequently, it is important to understand how alternative water systems are positioned in relation to conventional socio-technical infrastructure systems.

Sustainability assessment of infrastructure is usually based on indicators that address social, economic and environmental impacts. A socio-technical approach can help to deepen sustainability assessment by addressing interactions between different elements of sustainability indicators, and widening the analysis to include governance, regulation and other contextual factors. Analysis of infrastructure as socio-technical systems by scholars from a range of fields, including geography, history, sociology and science and technology studies, contributes to the development of a theoretical framework that can serve the basis for a more critical evaluation of sustainability than is usually achieved through indicator based approaches. Whilst this analysis is largely qualitative, it serves to inform the development of alternative water systems by showing how they both challenge and reinforce conventional approaches to water and infrastructure.

This chapter presents a framework for assessing the sustainability of water systems, based on critical perspectives on infrastructure and the relationship between society and the environment. General trends in infrastructure provision are summarised before reviewing recent theoretical developments in understanding the socio-technical nature of infrastructure. This forms the basis of a framework for assessing and comparing the sustainability of different forms of water provision. The framework is applied to conventional water systems, potable reuse, district scale non-potable reuse and rainwater harvesting. For each system the key socio-technical elements are analysed in general terms and then applied to specific case studies from South East England, UK and South East Queensland, Australia. The analysis highlights opportunities and challenges to sustainability with alternative reuse systems, as they both potentially reconfigure and/or stabilise conventional relationships between water, technology, society and the environment.

21.2 INFRASTRUCTURE, SOCIETY AND THE ENVIRONMENT

Infrastructure systems, such as those for water, transport, energy and communications, underpin modern societies and economies. These systems are essentially technical, but their existence and functioning depends upon political, economic, social and natural environments. Infrastructures also fundamentally change the environments and societies in which they operate. Thus the relationships between infrastructure, technology, society and the environment can be characterised as co-evolutionary (Shove, 2004; van Vliet *et al.* 2005).

For much of the twentieth century infrastructure provision was considered a function of the state, with major utilities owned and operated by government authorities (Marvin & Graham, 2001). The provision of these services and the need to establish institutions to finance, build and operate infrastructure had considerable influence in shaping the nature of municipal governance, balancing democratic oversight with technical expertise (Ben Joseph, 2011; Melosi, 2008; Halliday, 1999). The public provision of infrastructure reflected its importance in underpinning economic development and growth, as well as the modern social imperative to connect all members of society to essential services to improve public health and standards of living (Marvin & Graham, 2001).

Infrastructure systems emerged on a model of centralised, universal provision. Centralised provision of services through large technical systems provided for levels of control and standardisation that were absent from earlier efforts to implement water and energy systems (Hughes, 1985). Public financing of large systems of universal provision also recognised the social and economic benefits of water, electricity, transport and other services (Marvin & Graham, 2001). Management and provision of infrastructure services grew on a predict-and-provide basis, with demographers and economists forecasting demand for services and engineers and utility managers expanding systems accordingly.

The expansion of infrastructure to meet ever increasing demand has had considerable impacts on the environment. Conventional models of infrastructure effectively assume that natural resources will be available to meet growing demand and that the environment is capable of absorbing waste and pollution. The continued expansion of infrastructure to abstract water, fossil fuels and other resources from the environment, and the impacts of pollution from burning fuels and disposing of wastewater and municipal waste, have had considerable impacts on local and global environments.

In the last two decades of the twentieth century ownership, management and financing infrastructure changed significantly. During the 1980s and 1990s privatisation of infrastructure was seen as the means to increase efficiency of operation and provide access to private capital to upgrade and expand networks. This also reflected wider political changes, which emphasised the role of markets and the individual preferences in development, rather than the role of the state and universal provision (Marvin & Graham, 2001; Swyngedouw, 1999). For individuals, access to infrastructure services, such as transport or communication, and to some extent water and energy, became more dependent on ability to pay. Thus changes in infrastructure systems reflect wider changes in society and politics at the end of the twentieth century.

The last decades of the twentieth century also revealed environmental limits to the continued expansion of infrastructure systems. Volatility in energy prices and their impacts on transport systems reflected constraints on fossil fuel supplies. Growing population and changing rainfall patterns contributed to water scarcity in cities including Sydney, Las Vegas, London and Athens (Kaika, 2006; Sofoulis, 2013). Climate change targets for reducing carbon emissions also provide constraints on continued expansion of infrastructure. These trends have contributed to increased focus on demand management as an alternative to continued expansion of infrastructure. Demand management programmes aim to reduce per capita consumption of resources by reducing distribution losses, improving efficiency of appliances and changing user behaviour, to enable existing systems to meet the needs of a growing population without increasing resource use, and to continue to meet the needs of current populations under conditions of resource scarcity (Butler & Memon, 2006).

Provision of infrastructure services, including energy, water and communications, has led to dramatic, unanticipated transformation of everyday life and social norms. Elizabeth Shove has shown the interaction between systems, technologies and social norms, in her 'co-evolutionary triangle' used to explain the 'racheting-up' of consumption of energy and water resources in homes (Shove, 2004). While provision of clean water and electricity provide unquestionable benefits to public health, these infrastructures have enabled the development of new domestic technologies, such as washing machines, that in turn contributed to changing social norms, such as wearing freshly washed clothes every day, or wearing a fresh change of clothes for different activities within the same day. Water and energy infrastructure were not built with constantly changing, clean clothes in mind, but social expectations have shifted as laundry has become more convenient.

Environmental and resource constraints have also prompted increased attention on decentralised technologies, in contrast to centralised infrastructure systems (van Vliet *et al.* 2005). Decentralised systems are often assumed by environmentalists to be more efficient than centralised systems by avoiding conveyance losses from large scale distribution networks. Local systems have also been promoted as being inherently more sustainable, encouraging people to live within their locally available, renewable resources. Such systems for self-sufficiency or local management of resources have been associated with the alternative technology movement, which promotes technologies that are able to be operated and maintained by local communities, with reduced requirement for centralised, expert led design and management (Schumacher, 1973).

21.3 SUSTAINABILITY, TECHNOLOGY AND WATER

A socio-technical perspective on infrastructure helps to identify the broader conditions and assumptions required in order for systems to exist and operate effectively. Modes of infrastructure provision reflect and stabilise assumptions about water, the environment, technology, society, governance and economics (van Vliet *et al.* 2005). Different technical options for water supply may require different economic and governance arrangements, and they might reflect different understandings about how people use water and relate to their local environment. Achieving sustainable water systems requires consideration of these wider socio-technical aspects of water supply and use. New technologies can be used in different ways to either reinforce unsustainable patterns of water supply and use, or to support the transition to more sustainable systems and lifestyles.

Sustainability assessment usually focuses on the impacts of developments or technologies on the environment, economy and society. Pressure-state-response indicators expand this perspective to address the wider systemic interactions between different elements. A socio-technical analysis of sustainability provides more contextual, cultural and political knowledge about proposed systems. It reveals the deeper assumptions underpinning the development and operation of the systems, including assumptions about society and behaviour, values, the environment and the nature of water itself. For example, beyond the quantitative environmental impacts, a water reuse system is fundamentally based on an assumption that water is a limited resource, while conventional dam construction assumes that water can be captured and stored to meet social demands. Similarly, a tap connected to a conventional pipe network embodies a message that water is limitless, as the water keeps flowing unless user turns off the tap, while a water butt for garden watering presents water as a limited resource dependent on rainfall. Alternative water systems may present short term or small scale improvements in environmental performance or water resource conservation. However, if they reinforce behaviours based on an understanding of water as limitless then these improvements may be ultimately undermined.

The sustainability of infrastructure systems is also dependent on appropriate governance and financing arrangements. Regulation and ownership for alternative water systems can reinforce the role of centralised utility providers, or allow for wider participation in the water sector by different actors, including building owners and water technology and service providers. Different scales of technology and a diversity of service providers is a clear challenge for regulation and governance. In some cases, this may lead to greater public participation and deliberation in decision-making, in line with sustainability principles, whilst in others models of expert-led decision making are enhanced. The provision of water and sanitation services has shifted as political ideologies have changed. The introduction of alternative water systems provides opportunities for reform of infrastructure governance, but it may also re-enforce wider trends towards market and individualistic governance.

These themes are explored in the following sections, which analyse the socio-technology of conventional water systems, potable reuse, district scale reuse and rainwater harvesting. Each system is analysed in terms of its assumptions and requirements regarding water, the environment, technology, society, governance and economics. Comparison of different socio-technical arrangements for water highlights the challenges and opportunities for alternative water systems to contribute to sustainability.

21.4 CONVENTIONAL SUPPLY

Conventional water supply infrastructure is based on an assumption that supply will always be able to expand to meet demand. Thus, water is assumed to be a limitless resource. Consumers have developed uses for water accordingly, under the expectation that water will always flow from the tap.

Water supply and sanitation infrastructure developed largely to address significant public health risks (Halliday, 2001; Melosi, 2008). Clean water is produced and supplied under centralised management and dirty water is drained from homes as quickly as possible, before centralised treatment and discharge back to the environment. Water is thus either clean or dirty within conventional infrastructure, with no scope for water of multiple qualities for different uses. Centralised control of water infrastructure is essential to minimise risks to public health.

Conventional infrastructure provision assumes private control over water demand. Following the predict-and-provide model of provision, infrastructure managers traditionally anticipate demand but make no interventions in how people use water in the privacy of their own homes. In the exceptional circumstance of drought, water utilities may restrict outdoor water use, but indoor water use is usually assumed to be private and difficult to change (Allon & Sofoulis, 2006).

Provision of water infrastructure is capital intensive. Most water systems were initially constructed by the state, but in recent years the private sector has become involved in operating, maintaining and owning water infrastructure. Arrangements for funding water infrastructure and supply vary globally. Some jurisdictions fund water from centralised taxation revenues, but it is more common for revenue to be raised from users in the form or water rates or charges for water use. Water users are customers of water utilities, paying for the service of uninterrupted supply.

Governance arrangements for water infrastructure vary around the world. Large water utilities, whether privately or publically owned, are usually subject to regulation of water quality, abstraction from and discharge to the environment and the prices charged to customers. Regulation and governance of water utilities balances the needs for environmental and public health controls, with the economic impact on customers and investors. As the private sector has become more involved in provision of water infrastructure, the governance arrangements have become more complex, as water has moved from a public service to maintain good public health and economic development, to a source of profit for shareholders.

21.4.1 Case study: London, England

London and the Thames Valley are located in the water scarce region of South East England. Average rainfall is around 600 mm per year, with high population growth rates. Water provision in London has shifted between public and private ownership since the initial construction of the system in the nineteenth century. Before the 1890s water was supplied by private companies, between the 1890s and 1980s water was supplied by municipal authorities, and since 1987 water and sewerage services have been supplied by the privately owned Thames Water Utilities Limited. England and Wales are unique in the world in having a fully privatised water sector, regulated by three key regulators dealing with economics, environment and drinking water quality.

A number of important rivers and streams in the region are over-abstracted with the environmental regulator aiming to address over-licensing in vulnerable catchments. Addressing future water security for a growing population is a key concern for Thames Water and others. Key options include constructing a new reservoir to maintain environmental flows in the Thames during dry periods, expanding desalination capacity and potable reuse. The UK government has also set a target of reducing per capita water consumption from an average of 150 litres per person per day to 120 litres by 2030, which is reflected in a target for water companies to reduce daily customer demand by 1 litre each year. Most customers currently pay for water through a flat rate based on property values, with a programme underway to install water meters for all customers in coming decades.

21.5 POTABLE REUSE

Potable reuse involves treating wastewater to a very high standard, usually using membrane filtration and reverse osmosis, and returning it to the drinking water system rather than discharging to the environment. The treated water can be directly re-introduced to the drinking water system at the water treatment works, or indirectly introduced by aquifer recharge, discharge into raw water reservoirs or into rivers immediately upstream from abstraction points.

Technically, potable reuse involves a relatively minor adaptation of water supply infrastructure. Treated wastewater becomes another resource for conventional supply systems, with no changes required to water treatment and distribution systems or to how consumers use water. Potable water reuse maintains the water utility as a centralised owner and operator of the system, subject to the same water quality, economic and environmental regulations. Membrane technologies require much higher energy consumption to produce the raw water than abstraction of conventional water resources from the environment (Cooley & Wilkinson, 2012). Potable water reuse maintains centralised control of water quality. It presents the technical possibility for endless supply of water, as infinitely reusable, although this may be limited in practice to manage risks of recirculating micro-contaminants.

Socially, potable reuse has proved to be highly contentious (Hartley, 2006). Whilst potable reuse appears to present minimal changes to the overall structure of water supply networks, public acceptability of potable reuse has been a significant hurdle to implementation (Dolnicar & Schäfer, 2009). Public concerns with potable reuse include emotional 'yuck factor' responses, concerns about health risks associated with recirculating micro-contaminants, wider concerns about unknown risks associated with new technologies and the high energy consumption of water treatment (Dolnicar *et al.* 2011). Public backlash against potable reuse has been responsible for the failure of proposed systems, such as in Toowoomba, Australia and has delayed implementation in other cases, such as in San Diego, USA (Hurlimann & Dolnicar, 2010).

Public controversy about potable reuse highlights fundamental changes in the role of water utilities in society, as well as the relationship between consumers, infrastructure and water (Bell & Aitken, 2008; Colebatch, 2006). Whilst potable reuse represents minimal technical and institutional change to conventional water infrastructure, the impact of public opposition on proposed schemes and the strength of controversy shows that under conditions of water scarcity the public are no longer willing to accept expert decisions about water supply.

Potable reuse cannot succeed as a technical proposition, without taking account of social factors (Chilvers *et al.* 2011). This requires engineers and water managers to consider social factors in the design of systems and in decision making about water resource options. Deliberative decision-making processes have been proposed as a means of achieving a higher quality of decision about potable reuse and other water management options. This moves beyond public relations or education campaigns that aim to convince the public of the benefits and safety of potable reuse, to stronger engagement and involvement of the public in decision making. Involving the public at early stages of proposals and designs for potable reuse may lead to higher acceptability, but more importantly can help water utilities and regulators identify at an early stage if potable reuse is not a viable option for water supply (Bell & Aitken, 2008; Russell & Lux, 2009).

21.5.1 Case study: South-East Queensland, Australia

A prolonged drought in the 2000s and continued population growth in the South East of Queensland resulted in reduced water storage in dams and the need to evaluate options for alternative water supplies. The Western Corridor Recycled Water Project (WCRWP) was implemented between 2007 and 2009 to provide reclaimed water to power stations and other industrial users and to allow for potable reuse during drought conditions. The WCRWP is wholly owned and operated by the government of Queensland, through independent entities. The project was funded by the Australian Federal Government through the National Water Commission. Funding and ownership of the project reflect conventional public interest and benefit from provision of water infrastructure.

The role of potable reuse in this region has been highly controversial. In 2007 an indirect potable reuse scheme proposed for the town of Toowoomba was rejected in a referendum of residents, after a highly adversarial campaign. Under worsening drought conditions the Premier of the State of Queensland announced that future potable reuse, through the WCRWP, would go ahead without further referenda, as a result of the seriousness of water shortages. A change in leadership of the government and a break in the drought led to a further change in direction, to the current arrangement that recycled water is used for industrial uses, except under conditions of extreme water shortage.

The changing role of recycled water in South-East Queensland and the changes in government decisions highlight the challenges that this new source of water poses for conventional institutional arrangements for delivering water infrastructure. The complex issues associated with the technical and social elements of this source of water are not amenable to conventional expert-led decision making that until recently has been largely free from public scrutiny or controversy. Efforts to involve the public through referenda failed to deliver robust decisions about water recycling, leading to changing positions for government decision making in order to achieve a socially acceptable outcome for water reuse.

21.6 DISTRICT NON-POTABLE WATER REUSE

Non-potable reuse at a district scale involves distributing treated municipal wastewater for landscape irrigation, toilet flushing and other non-potable uses. Early implementation of district scale reuse involved irrigation of sports fields and parks with primary or secondary treated effluent. More recently developments have involved dual reticulation of housing developments and public buildings to supply water treated to a high quality using membrane bioreactors or other advanced technologies. In such cases, non-potable water supply becomes a new infrastructure service, delivered through its own network, with separate systems for treatment and management.

As a new infrastructure service, non-potable water supply largely conforms to the conventional institutional arrangement for water supply. In most cases to date, the supplier of recycled water has been the incumbent water utility. However, in some jurisdictions it may be possible for new suppliers to enter the market providing non-potable water in competition with potable supply. Non-potable water is usually supplied to customers at a lower price than potable water, however this does not yet reflect the relative costs of supply, requiring economic subsidy.

The two sets of pipes for potable and non-potable water signify the multiple qualities of water and its scarcity in the environment. However, potable backup for non-potable supply can undermine recycling efforts and continue to support an understanding of water supply as limitless. Control of risk in non-potable reuse schemes shifts beyond the centralised authority, as customers, plumbers and others must take account of the different supply systems and manage risks of cross-connection of potable and non-potable systems, or misuse of non-potable water.

The energy balance of non-potable reuse schemes is comparable to conventional systems. Treatment of municipal wastewater and pumping through the local distribution network is usually comparable to conventional treatment and pumping for drinking and wastewater. The energy requirement for treatment is significant compared to conventional water treatment, but can be comparable with the combined energy required for both water and wastewater treatment, which are displaced by reuse (Hills & James, 2014).

Non-potable reuse has been shown to be more acceptable to the public than potable reuse. Use of water for landscape irrigation, fire suppression, agricultural irrigation and toilet flushing are more acceptable than for cleaning, bathing and drinking. Non-potable systems at the district scale are more likely to be publically acceptable than potable reuse. Thus entirely new infrastructure systems may be needed to enable water recycling within the current social arrangement, rather than simply incorporating recycled water into the existing potable supply.

21.6.1 Case study: Old Ford water recycling plant, London

The Old Ford water recycling plant was built to supply non-potable water to the Queen Elizabeth II Olympic Park for the 2012 Olympic and Paralympic Games, as well as for the legacy period during which the site is to be redeveloped for housing, community and sports facilities. This case study is explained in further detail in Chapter 15 in this volume (Hills & James, 2014). The plant abstracts water from a main sewer running close to the site and treats it using a membrane bioreactor to non-potable standards. The water is also chemically dosed to remove phosphorous, filtered through activated carbon to remove colour and disinfected using sodium hypochlorite before distribution to the site. Reclaimed water is used for landscape irrigation and toilet flushing in a number of venues on the park, with the intention of expanding use to additional venues and new developments.

The plant is owned and operated by Thames Water, the privately owned water utility supplying water and sewerage services to London and surrounding regions. The plant is also financed by Thames Water, whose investment plans and customer charges are regulated by the Office for Water (Ofwat, The Water Services Regulation Authority). The recycled water is charged at a lower cost than potable water, but the operating costs of the plant are higher than conventional water and wastewater treatment and distribution. The UK does not have regulations for non-potable water quality and the plant is designed and managed according to the US EPA standard for use of reclaimed water for landscape irrigation. The system is backed up by the potable mains, so that supply of water through the non-potable water network is not disrupted when demand is high or the plant is out of operation. Outside the Olympic period, demand has been driven largely by requirements for landscape irrigation, with very low demand during winter months. The overall energy intensity for treatment of the non-potable water is comparable to the combined energy intensity of potable and wastewater treatment through the conventional infrastructure system. Water is supplied mostly to public buildings and used for public landscaping, with one housing development currently supplied, and future housing developments being targeted for supply. The water is treated to a high standard, including disinfection, to reduce health risks from cross connection to the potable supply on customers' premises.

21.7 RAINWATER HARVESTING

Rainwater harvesting is a decentralised form of non-potable water supply, ranging from simple water butts for garden watering to building scale systems with dedicated pipe networks and automated control systems (Hassell & Thornton, 2014). As a non-potable source of water, rainwater harvesting is mostly used for landscape irrigation, toilet flushing and fire suppression. Harvested rainwater is relatively clean, allowing for the development and implementation of decentralised treatment systems to produce potable water in remote locations (Adler *et al.* 2014; Thayil-Blanchard & Mihelcic, 2014).

Rainwater harvesting is a significant departure from conventional water supply systems operated by water utilities. The systems are usually owned and operated by building owners, with suppliers providing management and maintenance support in some cases. Thus the ownership and operation of water supply systems are decentralised, as well as the technology and the water source.

Rainwater harvesting systems recognise that water resources are limited. They present the opportunity for users to maintain current patterns of water use by providing an alternative source, rather than directly driving changes in consumption behaviour. Where rainwater harvesting systems are backed up by potable supply, this can undermine water savings potential, particularly during dry weather. This can be addressed by applying restrictions during drought events on outdoor use from all water sources, including rainwater harvesting, in order to avoid individualist perceptions that rainwater harvesting allows users complete control over their water supply and use.

Regulation of rainwater harvesting challenges conventional institutional arrangements for water supply. Standards for water quality and technology have developed to manage public health risks, which have contributed to increasing complexity of technology and increasing energy consumption. Requirements for pumping for supply and recirculation of water through distribution systems contribute to high energy demands. In the UK, some types of rainwater harvesting system have been shown to be more energy intensive than mains supply, due to the relative efficiencies of pumping. Rainwater harvesting has been driven by policy interventions in several jurisdictions, as described by Ward *et al.* (2014).

21.7.1 Case study: Pimpama Coomera, Australia

The Pimpama Coomera development in Australia incorporates rainwater harvesting as well as dual reticulated district scale reuse. Rainwater is harvested from individual houses into tanks owned and managed by home owners. Rainwater tanks are above ground and external to the houses, and are built according to two mandatory minimum sizes (5 m^3 for detached homes, 3 m^3 for semi-detached homes and townhouses). Pumping requirements are minimised by above ground storage and due to most houses being single storey bungalows.

Rainwater is used for outdoor irrigation and for cold water supply to washing machines. The rainwater system is backed up by potable supply and is subject to the water restrictions for outdoor use during drought events. Rainwater harvesting is promoted as part of the stormwater management for the development, which also includes swales and other elements of water sensitive urban design. Rainwater harvesting at Pimpama Coomera is also integrated with non-potable supply and stormwater management and is compulsory for all homes, with standard requirements for tank size. The overall strategy for water management is delivered by the municipal water utility, Gold Coast Water and the individual water user has minimal involvement in technology choice, management or other decisions. Water supply is maintained, but with restrictions during drought. Individual consumers who use more than the rainwater supply during normal (non-drought) periods are not restricted, due to the potable backup. Rainwater harvesting is effectively a buffer for the non-potable and potable supply networks, providing an additional source of water with relatively low energy requirements, but with limited impact on user experience or behaviour.

21.8 DISCUSSION

A socio-technical analysis of alternative water systems enables comparison with existing infrastructure to assess the extent to which they reinforce or challenge conventional arrangements for relationships between technology, society and water. A framework for sustainability analysis is presented in Table 21.1: categories in the column on the left and criteria in the columns to the right. Whilst alternative systems present opportunities for improving the sustainability of urban water infrastructure, this is not inevitable. Indicator-based comparison provides useful data on environmental impacts and economic costs and benefits, whilst more qualitative socio-technical analysis, such as that presented here, reveals underlying assumptions and values that are embodied in different infrastructure arrangements.

Conventional water supply systems are adapting to resource constraints and population growth, and ownership and regulation arrangements vary around the world. Despite demand management efforts, the essential assumption of water as an endless resource to be provided by expert-led decision making is maintained in most efforts to adapt to changing social and environmental conditions. Potable reuse of water is effectively a supply side solution for conventional water infrastructure. However, controversy surrounding public acceptability demonstrates that governance arrangements for conventional supplies must adapt to changing public expectations and concerns about risks associated with new technologies and contaminants. Expert-led decision making has moved tentatively towards more democratic forms of decision making about infrastructure, but the structures and governance arrangements are still being confirmed and in most jurisdictions remain to be stabilised.

Table 21.1 Comparison of conventional and alternative water infrastructure systems.

	Conventional supply	Potable reuse	District non-potable reuse	Rainwater harvesting
Water	Limitless Pure or contaminated Dangerous	Endlessly recyclable Industrial product Water cycle can be short circuited	Scarce	Scarce
Environment	Resource Sink for waste Must be controlled	For human use Energy is limitless Outside city	Humans part of water cycles	Humans part of water cycles
Technology	Universal standards Big systems Requires expert knowledge	Complex Engineer control Centralised	Simple to intermediate complexity Lay to engineer controlled Simple to complex Decentralised and intermediate scale	Simple Lay expertise Designer and community led Decentralised and intermediate scale
Society	Consumption is private Infrastructure serves society	Consumption is private Accepts technology	Consumption is private	Consumption is private
Governance	Expert led decision making Large utilities (public and private) Independent regulation	Regulated utility Municipal to national governance Technocratic, with some recognition of public concerns	Expert led decisions municipal governance Regulated utility	Minimal regulation or governance beyond installation Municipal scale
Economics	Capital intensive	Centralised Public and private Capital intensive	Capital intensive, ownership dominated by utilities, with potential for diverse ownership and management	Decentralised Minimal capital requirement Initial investment by household, municipality or other funded programme

District scale non-potable reuse and rainwater harvesting shift conventional assumptions about water to recognise multiple qualities for multiple uses. However, to date most significant cases of non-potable reuse at district scale have been owned and operated by conventional water utilities. Governance arrangements for non-potable reuse are still being formulated to allow the entrance of a wider range of providers for non-potable water. Although it is recognised that water for non-potable use can be of a lower quality than potable water, standards have not yet been confirmed and countries such as the UK have relied on the US EPA standards for landscape irrigation. Managing risks of cross connection mean that non-potable reuse water is treated to a much higher standard than required for its intended end uses, increasing energy and chemical requirements and undermining its sustainability potential. The embodied energy and resources in the distribution network must also be accounted for in assessing the overall sustainability of reuse compared to other water resource options.

Rainwater harvesting most clearly shifts responsibility for water provision to householders and building owners, as owner and operators of non-potable water supply systems. Whilst this provides an additional distributed source of water, where rainwater tanks are backed up by piped supply, they maintain and even amplify the expectation that water is a constant resource. Regulation of rainwater systems also presents challenges to public health and local government authorities, with the need to balance health risks with technical complexity.

The case studies presented in this chapter demonstrate the extent to which alternative systems re-enforce conventional arrangements for water infrastructure and the degree to which they limit their potential contribution to more sustainable water systems (Table 21.2). Widening participation in decision making in relation to the provision of services and infrastructure has the potential to improve the overall sustainability of alternative systems, but requires more complex and adaptable governance arrangements and risk management. Whilst integration of urban water systems is desirable, backup of non-potable water systems with potable water systems undermines their potential to transform social norms of water use. Reuse and rainwater harvesting systems can reinforce the idea of water as a limitless resource to be delivered by technical systems and managed by technical experts. Encouraging a shift in behaviour to live within local water resources and environmental conditions may require rethinking the integration of potable and non-potable systems.

21.9 CONCLUSION

Alternative water systems present fundamental challenges to conventional modes of infrastructure provision. Successful implementation of alternative water systems requires development of new economic, social and governance arrangements, as well as the design and commercialisation of technologies. In order for these systems to be sustainable, it is important to consider their environmental and social

Table 21.2 Case studies of conventional and alternative supply.

	London, UK	**Western Corridor, Australia**	**Old Ford, UK**	**Pimpama Coomera, Australia**
Water	Resource for human benefit produced and delivered by large infrastructure system Water is either pure of dirty	Resource for human benefit produced and delivered by large infrastructure system Water is scarce but recyclable	Resource for human benefit produced and delivered by large infrastructure system Water is scarce Water quality is fit-for-purpose	Resource for human benefit. Fresh water is scarce. Local supplies supplement centralised provision. Water quality is fit-for-purpose
Environment	Constraint on options for future development	Resource for human benefit. Environment is unpredictable, requiring infrastructure systems to buffer extreme events	Constraint on development, providing limits to energy and water	Resource for human use. Multiple sources of water provide resilience against extreme events
Technology	Complex, centralised control of technology, requiring high levels of expertise	Complex, centralised control of technology, requiring high levels of expertise	Complex, centralised control of technology, requiring high levels of expertise	Domestic scale systems backed up by centrally controlled supply. Higher risk water recycling managed by experts

(*Continued*)

Table 21.2 Case studies of conventional and alternative supply (*Continued*).

	London, UK	**Western Corridor, Australia**	**Old Ford, UK**	**Pimpama Coomera, Australia**
Society	Limited capacity to chance social expectations and demand for water	Public acceptability of technology is a risk to development Technology can be reconfigured to address public concerns, within environmental constraints	Limited capacity to chance social expectations and demand for water Environmental credential of Olympic Games were important to local and international community	Shared responsibility for ownership and management of water supply technology Higher risk managed by expert authorities. Social demand for alternative water sources
Governance	Private water company regulated for price, environment and quality. Limited public engagement.	Public ownership of independent company	Private water company regulated for price, environment and quality. Limited public engagement.	Planning and urban development processes used to drive uptake of alternative water systems
Economics	Capital intensive, monopoly provision, price and investment plans subject to regulation	Water infrastructure is of national importance. Government investment and ownership	Price of water subsidised Demonstration site not economically feasible under normal conditions	Individual ownership of alternative water systems

implications, as well as conventional concerns about supply and demand and costs and benefits of investment. A socio-technical approach to water infrastructure and alternative technologies helps to highlight the potential for different supply options to contribute to sustainability, or to re-enforce unsustainable relationships between people, technology and the environment.

Infrastructure systems stabilise relationships between people, technology, institutions and the environment. Alternative water systems such as rainwater harvesting and non-potable reuse introduce new technical elements into urban water systems, which renegotiate these relationships. The extent to which these system are incorporated into existing institutional arrangements will influence their sustainability in the long term. Alternative systems backed up by a mains potable supply maintain the user expectation of unlimited continuous supply of water, independent of weather and hydrological conditions, which is ultimately unsustainable.

Water reuse and rainwater harvesting systems have the potential to contribute to a fundamental restructuring of the relationships between people and water, to support the transition to sustainability. However, these technologies may not be inherently sustainable. The technical configuration of alternative water systems and their integration with existing systems is central in determining whether they contribute to a transformation of urban water systems or further stabilise conventional infrastructure systems and social norms.

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