CRANFIELD UNIVERSITY

Daniel Goodwin

From risk to safety management: Stakeholder engagement to inform the governance and design of water reuse schemes

School of Water, Energy and Environment (SWEE)
Cranfield Water Science Institute

EngD
Academic Year: 2017 - 2018

Supervisors: Dr Heather Smith & Professor Paul Jeffrey
December 2017

CRANFIELD UNIVERSITY

School of Water, Energy and Environment (SWEE)
EngD

Academic Year 2017 - 2018

Daniel Goodwin

From risk to safety management: Stakeholder engagement to inform the governance and design of water reuse schemes

Supervisors: Dr Heather Smith & Professor Paul Jeffrey
December 2017

This thesis is submitted in partial fulfilment of the requirements for the degree of EngD

Abstract

Water reuse is a feasible technological approach to addressing urban water management challenges. Whilst stakeholder acceptance is acknowledged as important for scheme success, less is known about how to interpret and influence stakeholder attitudes to water reuse, how preferences for risk mitigation influence scheme design, and what forms of engagement with risk work in what contexts. This thesis aims to understand the nature of stakeholder perceptions and expectations in the context of water reuse schemes, and to critically evaluate how stakeholder engagement with risk management can be used to enhance the governance and design of water reuse schemes. Through an embedded case study design and mixed-methods research, perceptions of water reuse as a feasible water management intervention in London are explored.

This study offers a number of contributions to the immediate field of research. Firstly, the findings highlight perceived benefits to engaging stakeholders through more collaborative learning-by-doing risk management. Secondly, the findings help to improve knowledge of methods for interpreting, informing and influencing stakeholders' perceptions through mediums such as online news and video animations. Thirdly, findings contribute to the understanding of the effectiveness of communication through showing an impact on public perceptions predicated on the focal characteristics of risk management messages. Fourthly, findings indicate that preferences for different recycled water uses and perceptions of certain scheme configurations could influence design decisions. Finally, findings support benefits of including stakeholders in multi-criteria evaluations of risk-based decisions.

A further contribution of this research is the identification of a number of thematic conditions necessary for enhancing scheme governance and design. These thematic conditions can assist in developing knowledge that focuses on overcoming the challenges of translating contemporary management and design theory into practice. In particular, this research highlights implication for advancing state-of-the-art risk management frameworks, specifically, through adopting more adaptive rationales informed through stakeholder engagement. This study contributes to the development of local and regional capabilities for water reuse risk management with implications for developing more strategic water reuse guidance and policy.

Keywords: Stakeholder engagement, risk management, water reuse, governance, design

Acknowledgements

And now, the end is near, and so it's time to write the acknowledgements. First, I will thank Dr Heather Smith, one of few unfortunate people who will ever read this thesis in its entirety. Not only read it, Heather has critically reviewed it and persistently encouraged me to re-examine and refocus my research and writing all along this four-year journey. I am grateful to Professor Paul Jeffrey for affording me his time, opinions and encouragement. Paul's academic achievements speak for themselves, perhaps less well acknowledged are his mentoring qualities. I would like to thank the Cranfield STREAM team, particularly Tania Rice for taking care of anything and everything. Next, I will thank the STREAM management team - where would we be without Challenge Week? Lastly, from the academic 'mob', I thank all the STREAM researchers and, particularly, Cohort V for their parts in my experience.

Thank you to the EPSRC and Thames Water for funding the research. From Thames Water, I would firstly like to take this opportunity to thank Dr Marie Raffin for recruiting me into the water reuse team and for supporting this project from start to finish. The list of people to acknowledge here is long, but in no particular order, I would like to extend my gratitude to Paul Rutter (thanks for the early project guidance), Lesley Tait and Richard Milton, and the Old Ford Team - Andy, Artur, Charlotte, Chris, Harpreet, John & Shaun, Libby, Martyn, Martyna, Mark (the apiarist), Matt, Paul Fewtrell, Pete & Wayne, Rachel, Ryland, Sian, Ted, and Waleed. Beyond the Old Ford team, I also thank those who have contributed to research at the 'coalface' through taking part in interviews and surveys, Nicki Dudley for assisting with transcribing interviews, and Michael Esler and Una Molyneux for statistics support.

Whilst co-authors get the more visible accolades, on the other side are those who must weather the emotional and physiological ups and downs of a weary student researcher. Foremost, I am grateful to Jo for her constant support, for giving me space to 'get on with research', for dealing with kids and pets (whilst I was away building water rockets or segwaying) – for everything really! Of course, I have to thank Evan for demonstrating the vastness of the human mind, Maya for her (occasional) kind words, the cats, and the dog (for all those 'peaceful' long walks on the beach). Finally, I am eternally grateful to my family – Philip, Geraldine, Jill and Beth - who have inspired and supported me to learn and because they're all more knowledgeable and wiser than I'll ever be. The final thank you is reserved for the postal delivery worker responsible for delivering this thesis on time – good luck.

Table of contents

List of Figures

Appendices

List of Tables

List of Abbreviations

AGWR	Australian Guidelines for Water Recycling
AHP	Analytic Hierarchy Process
BAU	Business as Usual
CEC	Contaminants of Emerging Concern
CR	Consistency Ratio
DALY	Disability Adjusted Life Years
DPR	Direct Potable Reuse
EPSRC	Engineering and Physical Science Research Council
FMEA	Failure Mode and Effects Analysis
FSDW	Framework for Safe Drinking Water (WHO)
GDWQ	Guidelines for Drinking Water Quality (WHO)
HACCP	Hazard Analysis and Critical Control Point
IDC	Industrial Doctorate Centre
IPR	Indirect Potable Reuse
ISO	International Standards Organisation
IUWM	Integrated Urban Water Management
LLDC	London Legacy Develop Corporation
MCDA	Multi-criteria Decision Analysis
MLD	Mega-litres per day
MTF	Management and Transition Framework
NPR	Non-potable Reuse
OFWRP	Old Ford Water Recycling Plant
Pppy	Per person per year
PROMETHEE	Preference ranking organization method for enrichment of evaluations
QEOP	Queen Elizabeth Olympic Park
QMRA	Quantitative Microbial Risk Assessment
SSP	Sanitation Safety Plan
SUWM	Sustainable Urban Water Management
TOPSIS	Technique for order performance by similarity to ideal solution
US EPA	United States Environmental Protection Agency
WCSP	Water Cycle Safety Plan

WFD	Water Framework Directive
WHO	World Health Organisation
WRMP	Water Resource Management Plan
WRSP	Water Reuse Safety Plan
WSP	Water Safety Plan

Chapter 1. Introduction

1.1 Challenges of water reuse

Water reuse is a feasible technological approach to addressing urban water supply challenges brought about by population growth, ageing infrastructure and climate change (Miller, 2006). Water reuse can increase the reliability of a water supply and the concept has been adopted in various international settings using a range of scheme designs for different applications (Wintgens et al., 2005). Wastewater is increasingly being repurposed for non-potable (e.g. irrigation) and potable uses, made possible by the evolution of both water treatment technologies and risk management procedures (Asano and Levine, 1996). However, whilst water reuse schemes have helped to close water supply deficits in some international settings (e.g. Windhoek, Namibia - van Rensburg, 2016), other localities have struggled with implementation (e.g. Toowoomba, Australia - Hurlimann and Dolnicar, 2010). Perhaps unsurprisingly, explanations for both strategic level and individual scheme implementation challenges have been attributed to a range of governance factors (Fawell et al., 2016; Furlong et al., 2016) that span experiences with policy making, regulation, financing, risk management, public participation and stakeholder engagement (Frijns et al., 2016).

Lacking stakeholder acceptance, at times amplified by regulatory (Oesterholt et al., 2007) or cost concerns (Friedler et al., 2006), has helped to explicate the abandonment of both potable (Hurlimann and Dolnicar, 2010) and non-potable (West et al., 2016) reuse scheme proposals. However, whilst the possible degree of personal exposure to recycled water can correlate with stakeholder acceptance, the salience of a scheme in a particular community is also important (Bruvold, 1988). Only through exploring governance factors in context (Frijns et al., 2016; Furlong et al., 2017) can explanations be developed for seemingly at odds experiences. For example, the high social acceptability of some potable reuse schemes (e.g. NeWater, Singapore - Mainali et al., 2011) can be contrasted with other socially unacceptable reuse schemes with much lower levels of indirect exposure to recycled water (West et al., 2016). Thus, the social context can interact with and influence decisions about scheme design configurations (Bell and Aitken, 2008), with consequences for a scheme's longer-term viability (West et al., 2016). Moreover, whilst short-term water management objectives might be satisfied by water reuse, inflexibility in the design configuration (Cook et al., 2010) or strategic policy (Browning-Aiken et al., 2011) may limit the capacity to satisfy future challenges.

Higher levels of stakeholder acceptance associate with lower perceived risks of water reuse and more trust in the water management organisations (Ross et al., 2014). Concomitantly, interpreting risk perceptions has provided a window into understanding how stakeholders vary in their views of water reuse schemes whilst also identifying potential areas of agreement for meeting management expectations (Baggett et al., 2006). Why individuals' evaluations of the risks of water reuse vary might depend, for example, on their worldviews (Price et al., 2012) or lived experiences (Leong, 2016). Moreover, some people might perceive a threat of something going wrong with the operation of a scheme whilst other might perceive an unacceptable impact to human health from exposure to the water (Nancarrow et al., 2009). Despite differences in how stakeholders might initially react to questions of risk, there may also be areas of common agreement, for example, on the uncertainty of longer-term health effects of exposure to low levels of contaminants (Khan and Gerrard, 2006). Presently, understanding how to meet the range of expectations for managing risks and promoting safety demarcates a frontier to contemporary knowledge. Moreover, there remain unanswered questions relating to how researchers, communication experts and water resource managers can engage a cross-section of stakeholders on the legitimacy of water reuse across varying scheme design configurations (Gikas and Tchobanoglous, 2009) and governance contexts (Frijns et al., 2016).

There are gaps in knowledge of the role stakeholders can play in the management of risks for water reuse schemes and the implications of their involvement in the design of schemes and their ongoing governance (Ferguson et al., 2013; Hanjra et al., 2012). Given the role risk mitigation has in the design (e.g. the selection of a treatment train) and ongoing operation of a water reuse scheme, it is desirable to improve knowledge of how agreeable decisions can be made among involved stakeholders (Attwater and Derry, 2005). There is scope, therefore, to explore the limits of the current state-of-the-art in risk management and to critically evaluate how existing knowledge might be extended to better understand the desirability, benefits and hurdles to accommodating a wider range of stakeholder expectations. Generating this knowledge would help to understand some of the challenges around translating contemporary management concepts into practice (Cook and Spray, 2012; Medema et al., 2008). Moreover, attempts to unpack the factors putting up barriers or bridges to inclusive risk management are likely to be context-sensitive (Boholm et al., 2012). These claims are supported by calls for more in-depth considerations of practical ways to interpret, inform and influence stakeholder attitudes to water reuse (Fielding and Roiko, 2014; Leong, 2010; Rozin et al., 2015; Russell et al., 2008) and to improve knowledge of the underlying mechanisms through which stakeholder attitudes evolve (Fielding and Roiko, 2014; Leong, 2016; Wester et al., 2016). Furthermore, these claims are underscored by limited knowledge of how stakeholders' preferences for risk mitigation might influence scheme design (Chen et al., 2014; Farrelly and Brown, 2011; Turner et al., 2016) and a lack of critically reported practical experience describing how water reuse might be incorporated into more strategic water management practice (Ferguson et al., 2013).

1.2 Theoretical perspective

People perceive risks differently and draw on a range of attitudes, values (Renn et al., 1992) and interpretive heuristics and biases (Tversky and Kahneman, 1974) to reflect on the interface of technology and society (Lupton, 1999; Sjoberg, 2000). For some, the modern fixation on technological has resulted in an undesirable accumulation of risks that are also open to social definition (Beck, 1992). For risk managers, however, the definition and assessment of risk is, more simply, a technical procedure that can be undertaken through rational calculations (Lupton, 1999). Risk perceptions create dissonance when, for example, risks are technically quantified as minor yet still elicit strong public concerns (Kasperson et al., 1988). Thus, there can be some disparity between technical definitions (the product of probability and magnitude) and the social experience (Renn et al., 1992). Furthermore, in the absence of technical knowledge, non-experts are more likely to draw on a wider range of considerations when reasoning about risk (Horlick-Jones and Prades, 2009). Wider considerations might relate to personal experiences (Feenberg, 2010) or opinions put forward by the media (Wahlberg and Sjoberg, 2000) that are used to help explain the uncertainty of a new technology.

A review of the theoretical approaches taken by the current corpus of water reuse studies (Table 1-1) illustrates an interaction with diverse risk perception theory. This review also highlights a tendency, throughout approaches traversing psychological and sociological viewpoints, to focus on attempting to explain why people perceive risks differently. There is, therefore, some porosity in this theoretical landscape, particularly around exploring ways of actively managing different risk perceptions and expectations (Sjoberg, 2000). These less well explored areas are associated with understanding how the circumstances in which information is communicated and interpreted might influence risk perceptions (Kasperson et al., 1988) and how the interpretation of perceptions (Goffman, 1986) might support the development of processes to accommodate different expectations (Dewulf et al., 2009).

Table 1-1 Typology of theoretical approaches to risk perception research in water reuse studies (non-exhaustive)

Theoretical viewpoint	Theory and principal proponent	Example Studies		
		Reference	Context	Summary of findings
Social-psychological	'realist perspective' psychometric paradigm – voluntary, visible risks (Slovik)	Marks et al., (2008)	Seven Australian capital cities (n=2,504)	The theory was not consistent with results, for example, respondents were willing to see recycled water used, even if risks were not visible or voluntary.
	Magical contagion belief (Rozin, Nemeroff)	Rozin et al., (2015)	Two U.S studies, general (n=2,680) and students (n= 432) populations	Intuitive contagion-based thinking involved in reactions. A solution to the acceptability may be to gradually increase the amount of recycled water in the water supply
	Moral Foundation Theory (Haidt & Graham)	Wester et al., (2015)	U.S. population (n=207)	Isolated aspects of disgust sensitivity to predict discomfort with water reuse
	Modified Theory of Planned Behaviour (Ajzen)	Nancarrow et al., (2009)	IPR scheme for South-east Queensland (n=583)	Useful for understanding how various factors might influence consumers behavioural intentions
		Ross et al., (2014)	IPR Referendum, Toowoomba, QLD (n=380)	Higher levels of trust in the water authority associated with lower perceptions of risk and higher levels of acceptance
	Motivated Social Cognition (Jost)	Price et al., (2012)	Toowoomba after referendum, (n=17)	People motivated to process information to support their initial positions
	Elaboration Likelihood (Petty & Cacioppo)	Price et al., (2015)	South-east Queensland samples, two studies (n=415 and n=957)	Support increased after receiving more complex information. Trust in government was higher after information. Messages about the low risks resulted in higher support for some.
	Inoculation Theory (McGuire)	Kemp et al., (2012)	Australia – general population survey (n=978)	Their results indicated that communication strategies based on Inoculation Theory had limited effectiveness.
	Information deficit model (Miller, Ziman)	Fielding and Roiko, (2014)	South-east Queensland, students (n=63, n=141)	Information increased comfort with potable recycled water and, in general, improved positive emotions and support and

Theoretical viewpoint	Theory and principal proponent	Example Studies		
		Reference	Context	Summary of findings
			and general (n=305)	lowered risk perceptions.
Social-cultural theories	Risk society, reflexive modernity (Beck, Giddens)	Marks et al., (2008)	Seven Australian capital cities (n=2,504)	More consistent with results than realist perspective. However, results did not appear to be driven by respondents' greater concern with industrially produced hazards
	Social trust (Giddens, Sztompka)	Marks and Zadoroznyj, (2005)	Four case studies in U.S and Australia. Various qualitative data sources	A combination of technical and social structural elements will facilitate a sustained trust in, and acceptance of, water reuse.
	Actor-network theory (Latour)	Bell and Aitken, (2008)	IPR for London, literature review	Reconsidering IPR as a complex socio- technology could provide a grounding for devising processes and institutions for decision-making
	Relational theory of risk (Boholm & Corvellec)	Dobbie and Brown, (2014)	Literature review	For a water practitioner, a risk object (e.g. alternative water system or a technology) relates to an object at risk (e.g. public or environmental health, profitability)
	Socio-cultural approach (Kahan)	de Koster and Achterberg, (2015)	Data from Fielding & Roiko (2014),(n=299)	Only those comfortable with new technologies prove receptive to information about potable recycled water.
	Cultural theory (Douglas & Wildavsky)	Price et al., (2012)	Toowoomba following referendum, focus group (n=17 residents)	egalitarian and hierarchical 'policy stories' may be used in support of recycled water
		Marks et al., (2008)	Seven Australian capital cities (n=2,504)	Most consistent theoretical approach. A clearer order or water uses by their cultural need to ensure 'purity' with less pure uses transgressing normative, cultural boundaries

Risk can be technically defined as the effect of uncertainty on objectives (BSI, 2009). From this viewpoint, a risk-based philosophy aims to rationalise risk and prioritise management interventions through methods such as cost-benefit analysis (Kuklicke and Demeritt, 2016). This approach has been typified by the externalisation of social factors and attempts to reduce and control complexity, often through rigid and inflexible technical systems (Pahl-Wostl et al., 2007). The precautionary principle has similar goals to the risk-based rationale through advocating prudent handling of uncertain situations (Klinke and Renn, 2002). A criticism of both the risk-based and precautionary approaches is that they can attempt to close down management possibilities instead of remaining open to learning (Kuklicke and Demeritt, 2016). As an alternative, more adaptive-based management seeks to emphasise the role of learning and experimentation in making incremental management improvements (McDaniels et al., 1999). This perspective aims to encourage learning about different courses of action by experimenting and 'doing' (Folke et al., 2005). Rather than attempting to control change, the focus shifts to learning about the capacity to cope with change and to build system resilience (Folke, 2006).

Technically justified risk management decisions made in isolation of other stakeholders can lack legitimacy (Lebel et al., 2015). For instance, utilitarian rationalised decisions may be perceived as unfairly allocating project benefits or risk management responsibilities (Lebel et al., 2015). Thus, whilst the 'linear' focus on expert oversight of risk (command and control) was once a dominant management concept, more inclusive management styles are increasingly advocated (Pahl-Wostl et al., 2008). The accumulating evidence challenges the legitimacy of the linear rationale (Gearey and Jeffrey, 2006; Lebel et al., 2015; Pearson et al., 2009) and, alternatively, supports the principle of meaningfully engaging a range of views from an early stage. The advocacy for more stakeholder inclusion follows Habermasian 'communicative rationality', that is, people should seek to reach shared understandings and cooperate to solve common problems through discussion (Reed et al., 2009). Moreover, engaging a range of stakeholders is likely to encounter a fuller range of political, social, economic and administrative systems influencing the provision of the water service (Roger and Hall, 2002).

Despite the articulated benefits of stakeholder engagement, the process can be challenged through understanding which stakeholders should participate in what areas of management (Reed et al., 2009). Moreover, there are challenges to facilitating suitably engaging processes to avoid consultation fatigue (Kearnes and Motion, 2014) or frustration (Furlong et al., 2016). Ambitions for more inclusion might be scuppered by conflicts of interest, a lack of leadership, a lack of funding or fragmented roles and responsibilities (Akhmouch and Clavreul, 2016). Of promise, social learning can help stakeholder adapt to uncertainties and change (Pahl-Wostl et al., 2008b), particularly when they are enabled to act together in pursuit of shared objectives (Muro and Jeffrey, 2012). Following this trail of evidence, a number of gaps in existing knowledge emerge relating to how impacts of stakeholder engagement and learning initiatives are systematically documented and measured (van der Wal et al., 2014), understanding what works in certain contexts, how (Moglia et al., 2011; Ormerod and Scott, 2012) and why (Muro et al., 2012) and, the transferability of context-dependent findings to other similar situations (Pahl-Wostl et al., 2012).

1.3 Research context

This thesis presents work undertaken through the STREAM Industrial Doctorate Centre (IDC) and was sponsored by Thames Water and the Engineering and Physical Science Research Council (EPSRC). The research was carried out at Thames Water's Old Ford Water Recycling Plant (OFWRP) located at the Queen Elizabeth Olympic Park (QEOP) in London. This location provided a focus for developing a case study of risk management experiences with non-potable water reuse (NPR). The research was situated within the development of Thames Water's Water Resource Management Plan (WRMP) 2019 (which will document water resource management priorities for 2020 to 2045) and the consideration of a larger-scale indirect potable reuse (IPR) scheme and more extensive use of NPR in London. London's water resource management circumstances were considered the bounds of a case study to understanding stakeholder engagement with the management of risk for water reuse schemes.

Current water balance models for London predict an emerging public potable water supply deficit of up to 414 mega-litres per day (MLD) by 2040 (Thames Water, 2014). This growing deficit is being driven by projected climate change impacts, reductions of licensed abstraction volumes from the environment and population growth (Huskova et al., 2016). To help meet this water supply challenge, Thames Water is proposing a number of water management options including leakage reduction, demand management, smaller groundwater and water transfer schemes as well as water reuse (Thames Water, 2015). Water reuse options include an IPR scheme (approximately 150 MLD programmed for 2027) with advanced treatment of wastewater that is then returned to a river upstream of an abstraction point for a drinking water treatment plant (Thames Water, 2015). The second strategic water reuse option includes multiple local-scale NPR schemes for growth areas of Greater London, which could collectively contribute up to 33 MLD of non-potable water by 2040 (ARUP et al., 2017).

Alongside the developing water management challenge are recent reforms to the water industry's standpoint on stakeholder engagement and risk-based management. Stakeholder involvement is now an expectation for leading longer-term water resource planning and decision-making, as stipulated by the water industry's economic regulator Ofwat. To achieve this, the regulator allows water companies to decide how they undertake engagement but also stipulates engagement should be proportionate to the scale of a decision and supported by evidence (Ofwat, 2016). This shift in focus on stakeholder engagement is also visible in related areas of resource management. For example, the Water Framework Directive (WFD) emphasises the role of public consultation and engagement in river basin management (White et al., 2010). Whilst there is some focus on stakeholder engagement, less is known about how scheme designers and operators can develop effective engagement strategies to suit their local context (Jeffrey et al., 2014).

Water companies are also advised to adopt risk-based approaches to decision-making when developing WRMPs (UKWIR, 2016). This risk-based philosophy is common across the three water industry regulators inclusive of drinking water quality (Summerill et al., 2010b) and the management of the water environment (Kuklicke and Demeritt, 2016). The risk-based approach aims to guide activities that are proportionate to the scale of the challenge, preventative, system-wide (i.e. 'catchment to tap') and promote continual improvement (Fawell et al., 2016; Hall and Borgomeo, 2013).

1.4 Aims and objectives

To reiterate, knowledge gaps were identified in the existing corpus of research relating to (1) how to interpret, inform and influence stakeholder attitudes to water reuse, (2) how stakeholders preference for risk mitigation might influence scheme design, and (3) what forms of engagement with risk work in what contexts. To bridge these gaps, the aim of this research was to understand the nature of stakeholder perceptions and expectations in the context of water reuse schemes, and to critically evaluate how stakeholder engagement with risk management can be used to enhance the governance and design of water reuse schemes. The following objectives were used to inform the development of analytical methods and to guide the enquiry to address the aim. In turn, the objectives were addressed through research questions that are outlined in the relevant chapters of this thesis.

- Objective 1: To produce a critical review of the state-of-the-art risk management for water reuse.
- Objective 2: To evaluate how stakeholders perceive risk management and governance challenges and to understand their preferred solutions for addressing the challenges.
- Objective 3: To explore how perceptions of water management problems, risks and trust in the management of recycled water supply might be influenced.
- Objective 4: To explore methods of public communication and, particularly, to evaluate the impact of message framing on public attitudes towards non-potable water reuse.
- Objective 5: To explore how stakeholders' perceptions and preferences for risk management and recycled water end-uses might influence decision-making and scheme design.

1.5 Overarching methodology

In theory, an improved understanding of governance can be achieved through studying the richness of processes and through reconstructing causalities in detailed case studies (Pahl-Wostl et al., 2010). Case studies are important for helping to understand the socially situated dynamics of managing risks in practice (Boholm et al., 2012) and for improving water governance (Biswas and Tortajada, 2010). This is because the case study is suited to in-depth, inductive investigation of the factors informing decision-making and risk reasoning within a particular social context (Blaikie, 2000; Horlick-Jones and Prades, 2009). The selection of a case study framework for this research was guided by others exploring water reuse in different localities, such as in Tuscon, Arizona (Campbell and Scott, 2011); South-East Queensland (Hurlimann, 2007; Hurlimann and Dolnicar, 2016, 2010; Price et al., 2012; Ross et al., 2014); Singapore (Lee and Tan, 2016; Leong, 2016); Israel (Friedler et al., 2006), and; Windhoek, Namibia (van Rensburg, 2016). Moreover, case studies have been used to examine characteristics of water reuse governance including public perceptions (Smith et al., 2014), cost-effectiveness of water safety initiatives (Lindhe et al., 2011), microbial health risk management (Barker, 2014), public communications (Price et al., 2015), regulation and policy (Hanjra et al., 2012).

An embedded case study design was selected to guide the empirical enquiry and to help link qualitative and quantitative evidence (Yin, 2011). The benefits of drawing from multiple data sources (Ferguson et al., 2013), multiple cases studies (Mainali et al., 2011) and embedded cases studies (Farrelly and Brown, 2011; Marks and Zadoroznyj, 2005) are further demonstrated by water reuse studies, particularly for strengthening the results through replication and pattern matching techniques. Case studies can also be effective for exploring experimentation in design, for example through pilot projects (Ferguson et al., 2013), and in governance, for example, through contrasting case experiences with the norms of conventional practice (Bos et al., 2013). The bounds of the case study (including embedded sub-studies) for this research was the consideration of stakeholder engagement with aspects of risk management for water reuse schemes, both being planned and operating in London, United Kingdom (Figure 1-1). The details of the methods for each sub-study are included in the relevant chapters of this thesis.

Figure 1-1 Boundary of case study and embedded sub-studies

The case study used a mixed-method design and a number of quality assurance techniques (Table 1-2) that aimed to produce a 'thick description' with situationally-specific insights (Horlick-Jones and Prades, 2009). Through employing triangulation and pattern matching techniques (Trochim, 1989), this study attempted to explain some of the intricacies of feasible linkages between stakeholders' perceptions, preferences for managing risks and the implications for improving scheme governance and design. Moreover, this research sought to conceive whether the thematic constructs induced from the collective findings (Braun and Clarke, 2006) presented conditions that could be considered either necessary or sufficient (Dul, 2016) for enhancing scheme design or governance (Boholm, 2009; Pahl-Wostl et al., 2012). The methodological approach gave consideration to negative instances (Pawson, 2002) and plausible alternative explanations for any conceptual proposition stemming from the empirical observations (Bitektine, 2008; Yin, 2011). Finally, the evaluation of the evidence borrowed from the realist perspective which stresses that interventions are likely to work differently in different contexts (Pawson, 2002).

Table 1-2: Quality assurance methods used for the research (from Trochim, 1985 & Yin, 2011)

Tests	Techniques used for this thesis
Construct validity	The various observations from the sub-studies were inductively brought together to build up observational constructs. Multiple sources of evidence were drawn on to triangulate and enhance the validity of constructs.
Internal validity	Patterns of replication across the sub-studies were used to help build explanations and infer causal relationships, such that certain conditions could be inferred to lead to other conditions related to the specific context of the study. Mixed methods were used including quantitative methods for hypothesis testing and exploring causes and effects. Inductively building constructs and matching patterns of replication were used towards developing a conceptual proposition.
External validity	Multiple embedded case studies were used and patterns of replication were assessed across the evidence produced to help establish the transferability and generalisability of the findings beyond the specific context of the case study.
Reliability	Case study protocol was followed for qualitative and quantitative data collection. This included interview guides for semi-structured interviews and documentation of questions used in questionnaires. Inter-coder reliability was used for qualitative data analysis and established measures of reliability for groups of questions used to form dependent variables in questionnaires (e.g. Cohen's internal consistency). Thus the data collection and analysis procedures are repeatable.

1.6 Thesis plan

This thesis is presented as a series of chapters formatted as journal papers (Table 1-3

Table 1-3). The research activities were carried out in sequence, such that findings from one activity helped informed the next. Coordinating with the objectives outlined in the previous section, the first research activity was a review of the state-of-the-art in risk management for water reuse (Chapter 2). Following this, the research adopted interpretative research methods to develop a more in-depth understanding of stakeholders' management expectations for water reuse schemes in London (Chapters 3 & 4). Qualitative methods were also used to investigate the impact of the news media's framing of potable water reuse on public perceptions (Chapter 4). Next, quantitative methods were employed to evaluate the impact of communicating with the public about water safety management for non-potable reuse (Chapter 5). Following this, stakeholder risk management and scheme design preferences were explored through a multi-criteria evaluation (Chapter 6). The final thesis chapter (Chapter 7) summarises the research findings with respect to the aims and objectives and discusses the implications.

Table 1-3 Summary of thesis structure and status of papers

Chapter	Obj.	Title	Journal	Status
2	1	Applying the water safety plan to water reuse: towards a conceptual risk management framework	Environmental Science: Water Research and Technology	2015, 1 (5), 709 -722
3	2	Collaboration on risk management: the governance of a non-potable water scheme in London	Journal of Hydrology	In press
4	3	Evaluating media framing and public reactions in the context of a water reuse proposal	International Journal of Water Resource Development	In press
5	4	Informing public attitudes to non-potable water reuse – the significance of message framing	Water Research	Under review
6	5	Multi-criteria stakeholder evaluations of risk interventions for new non-potable recycled water end uses	Science of the Total Environment	Ready for submission
Appendix C	5	Evaluating urban non-potable water reuse opportunities - Costs and benefits of risk management interventions	Institute of Water Journal	2017; 1; 6-13

1.6.1 Sequence and interaction of chapters

Chapter 2 reviews the state-of-the-art in practice-based approaches to managing risks for water reuse schemes. The review focused on the Water Safety Plan concept and its variations to understand the feasibility of capturing a fuller spectrum of possible water reuse applications and governance contexts. This review engaged with the broad typology of risk assessment, management and decision support techniques evaluated in the water reuse literature. The findings highlighted gaps in current risk management guidance for water reuse schemes and provided a foundation for the research activities carried out for the subsequent chapters of this thesis.

Chapter 3 explores the theme identified in Chapter 2 of how broader objectives might be consolidated in risk management processes. This chapter considered the role of risk perceptions in a scheme governance context and explores the challenges of involving multiple stakeholders in the management of risk. This research utilised a qualitative case study of non-potable reuse to help unpack stakeholders' views on water reuse governance challenges and solutions for the Old Ford Water Recycling scheme in London. Alongside Chapter 3, Chapter 4 also explores perceptions of water reuse schemes in London through a second qualitative case study of an indirect potable reuse proposal for London. This second case study, using data from news articles, online comments and social media, also probes a second theme identified in Chapter 2 of exploring methods for supporting communication and engagement activities.

Chapter 4 investigates the constraints and benefits of communicating with the public through online news and social media. This chapter explores the influence of the news media in shaping public opinion to understand attitudes to potable water reuse and risk and how they might be influenced. This sub-study employed thematic analysis of online comments and news articles to compare themes between the sources of data. Chapter 5, informed by findings from Chapters 3 and 4, builds on the communication theme and considers that there may be different ways risks can be perceived and safely managed. This chapter summarises survey data that captured participants' reactions to a number of video animation communications that varied the description of safety management for non-potable water reuse.

Findings from the previous chapters helped inform the final study described in Chapter 6. This chapter explores multiple stakeholder decision evaluations that consider the prioritisation of risk management scenarios through attempting to balance a number of objectives. This study used a questionnaire to elicit stakeholder's priorities for a number of different recycled water uses and risk management scenarios related to the OFWRP case study. This chapter linked to a third risk management theme identified in Chapter 2 - the need to explore ways to facilitate decision making, scheme design and management prioritisation amongst multiple stakeholders that can account for uncertainty and sometimes complex risk interactions.

Finally, Chapter 7 summarises research findings, discusses them with respect to the aims and objectives and identified knowledge gaps, and discusses the implications for scheme governance and design. This chapter is concluded with a discussion of some limitations to this research, the identification of future research opportunities followed by the conclusions.

1.7 References

Akhmouch, A., Clavreul, D., 2016. Stakeholder Engagement for Inclusive Water Governance: "Practicing What We Preach" with the OECD Water Governance Initiative. Water (Switzerland) 8, 1–17. doi:10.3390/w8050204

ARUP, AECOM, SHSWS, Aquality, 2017. Thames Water non-potable water reuse strategy, Marine Pollution Bulletin. London, UK. doi:10.1016/S0025-326X(01)00267-3

Asano, T., Levine, A.D., 1996. Wastewater reclamation, recycling and reuse: past, present, and future. Water Sci. Technol. 33, 1–14.

Attwater, R., Derry, C., 2005. Engaging communities of practice for risk communication in the Hawkesbury Water Recycling Scheme. Action Res. 3, 193–209. doi:10.1177/1476750305052144

Baggett, S., Jeffrey, P., Jefferson, B., 2006. Risk perception in participatory planning for water reuse. Desalination 187, 149–158. doi:10.1016/j.desal.2005.04.075

Barker, S.F., 2014. Risk of norovirus gastroenteritis from consumption of vegetables irrigated with highly treated municipal wastewater-evaluation of methods to estimate sewage quality. Risk Anal. 34, 803–817. doi:10.1111/risa.12138

Beck, U., 1992. Risk Society: Towards a New Modernity. SAGE Publications Ltd, London and Newbury Park, CA.

Bell, S., Aitken, V., 2008. The socio-technology of indirect potable water reuse. Water Sci. Technol. Water Supply 441–448. doi:10.2166/ws.2008.104

Biswas, A.K., Tortajada, C., 2010. Future water governance: Problems and perspectives. Int. J. Water Resour. Dev. 26, 129–139. doi:10.1080/07900627.2010.488853

Bitektine, A., 2008. Prospective case study design - Qualitative method for deductive theory testing. Sage - Organ. Res. Methods 11, 160–180.

Blaikie, N., 2000. Designing Social Research: The Logic of Anticipation. Polity Press, Cambridge.

Boholm, Å., Corvellec, H., Karlsson, M., 2012. The practice of risk governance: lessons from the field. J. Risk Res. 15, 1–20. doi:10.1080/13669877.2011.587886

Boholm, M., 2009. Risk and Causality in Newspaper Reporting. Risk Anal. 29, 1566–1577. doi:10.1111/j.1539-6924.2009.01296.x

Bos, J.J., Brown, R.R., Farrelly, M.A., 2013. A design framework for creating social learning situations. Glob. Environ. Chang. 23, 398–412. doi:10.1016/j.gloenvcha.2012.12.003

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3, 77–101. doi:10.1191/1478088706qp063oa

Browning-Aiken, A., Ormerod, K.J., Scott, C. a., 2011. Testing the Climate for Non-Potable Water Reuse: Opportunities and Challenges in Water-Scarce Urban Growth Corridors. J. Environ. Policy Plan. 13, 253–275. doi:10.1080/1523908X.2011.594597

Bruvold, W.H., 1988. Public Opinion on water reuse options. J. Water Pollut. Control Fed. 60, 45–49.

BSI, 2009. BS ISO 31000 (2009) Risk management — Principles and guidelines. British Standards Institute, London.

Campbell, A.C., Scott, C. A., 2011. Water reuse: policy implications of a decade of residential reclaimed water use in Tucson, Arizona. Water Int. 36, 908–923. doi:10.1080/02508060.2011.621588

Chen, Z., Ngo, H.H., Guo, W., Lim, R., Wang, X.C., O'Halloran, K., Listowski, A., Corby, N., Miechel, C., 2014. A comprehensive framework for the assessment of new end uses in recycled water schemes. Sci. Total Environ. 470–471, 44–52. doi:10.1016/j.scitotenv.2013.09.061

Cook, B.R., Spray, C.J., 2012. Ecosystem services and integrated water resource management: Different paths to the same end? J. Environ. Manage. 109, 93–100. doi:10.1016/j.jenvman.2012.05.016

Cook, S., Sharma, A., Batten, D., Burn, S., 2010. Matching alternative water services to industry type: an eco-industrial approach. Water Sci. Technol. Water Supply 10, 969. doi:10.2166/ws.2010.640

de Koster, W., Achterberg, P., 2015. Comment on "Providing information promotes greater public support for potable recycled water" by Fielding, K.S. and Roiko, A.H., 2014 [Water Research 61, 86-96. Water Res. 84, 372–374. doi:10.1016/j.watres.2015.05.067

Dewulf, A., Gray, B., Putnam, L., Lewicki, R., Aarts, N., Bouwen, R., van Woerkum, C., 2009. Disentangling approaches to framing in conflict and negotiation research: A meta-paradigmatic perspective, Human Relations. doi:10.1177/0018726708100356

Dobbie, M.F., Brown, R.R., 2014. A framework for understanding risk perception, explored from the perspective of the water practitioner. Risk Anal. 34, 294–308. doi:10.1111/risa.12100

Dul, J., 2016. Necessary Condition Analysis (NCA). Organ. Res. Methods 19, 10–52. doi:10.1177/1094428115584005

Farrelly, M., Brown, R., 2011. Rethinking urban water management: Experimentation as a way forward? Glob. Environ. Chang. 21, 721–732. doi:10.1016/j.gloenvcha.2011.01.007

Fawell, J., Le Corre, K., Jeffrey, P., 2016. Common or independent? The debate over regulations and standards for water reuse in Europe. Int. J. Water Resour. Dev. doi:10.1080/07900627.2016.1138399

Feenberg, A., 2010. Between reason and experience. The MIT Press, London, UK.

Ferguson, B.C., Brown, R.R., Frantzeskaki, N., de Haan, F.J., Deletic, A., 2013. The enabling institutional context for integrated water management: lessons from Melbourne. Water Res. 47, 7300–14. doi:10.1016/j.watres.2013.09.045

Fielding, K.S., Roiko, A.H., 2014. Providing information promotes greater public support for potable recycled water. Water Res. 61, 86–96. doi:10.1016/j.watres.2014.05.002

Folke, C., 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. Glob. Environ. Chang. 16, 253–267. doi:10.1016/j.gloenvcha.2006.04.002

Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive Governance of Social-Ecological Systems. Annu. Rev. Environ. Resour. 30, 441–473. doi:10.1146/annurev.energy.30.050504.144511

Friedler, E., Lahav, O., Jizhaki, H., Lahav, T., 2006. Study of urban population attitudes towards various wastewater reuse options: Israel as a case study. J. Environ. Manage. 81, 360–370.

Frijns, J., Smith, H.M., Brouwer, S., Garnett, K., Elelman, R., Jeffrey, P., 2016. How governance regimes shape the implementation of water reuse schemes. Water (Switzerland) 8. doi:10.3390/w8120605

Furlong, C., De Silva, S., Gan, K., Guthrie, L., Considine, R., 2017. Risk management, financial evaluation and funding for wastewater and stormwater reuse projects. J. Environ. Manage. 191, 83–95. doi:10.1016/j.jenvman.2017.01.007

Furlong, C., Gan, K., De Silva, S., 2016. Governance of Integrated Urban Water Management in Melbourne, Australia. Util. Policy 2002, 1–11. doi:http://dx.doi.org/10.1016/j.jup.2016.04.008

Gearey, M., Jeffrey, P., 2006. Concepts of legitimacy within the context of adaptive water management strategies. Ecol. Econ. 60, 129–137. doi:10.1016/j.ecolecon.2006.02.014

Gikas, P., Tchobanoglous, G., 2009. The role of satellite and decentralised strategies in water resources management. J. Environ. Manage. 90, 144–150.

Goffman, E., 1986. Frame Analysis: An Essay on the Organization of Experience. Northeastern University Press.

Hall, J.W., Borgomeo, E., 2013. Risk-based principles for defining and managing water security. Philos. Trans. A. Math. Phys. Eng. Sci. 371, 20120407. doi:10.1098/rsta.2012.0407

Hanjra, M.A., Blackwell, J., Carr, G., Zhang, F., Jackson, T.M., 2012. Wastewater irrigation: Implications for water governance and public policy. Int. J. Hyg. Environ. Health 215, 255–269. doi:10.1016/j.ijheh.2011.10.003

Horlick-Jones, T., Prades, A., 2009. On interpretative risk perception research: Some reflections on its origins; its nature; and its possible applications in risk communication practice. Health. Risk Soc. 11, 409–430. doi:10.1080/13698570903180448

Hurlimann, A., 2007. Recycled Water Risk Perception - A Comparison of Two Case Studies, in: 4th IWA Specialist Conference on Efficient Use and Management of Urban Water Supply., pp. 181–193. doi:10.2166/WPT.2007068

Hurlimann, A., Dolnicar, S., 2016. Public acceptance and perceptions of alternative water sources : a comparative study in nine locations. Int. J. Water Resour. Dev. 32, 650–673. doi:10.1080/07900627.2016.1143350

Hurlimann, A., Dolnicar, S., 2010. When public opposition defeats alternative water projects - The case of Toowoomba Australia. Water Res. 44, 287–297. doi:10.1016/j.watres.2009.09.020

Huskova, I., Matrosov, E.S., Harou, J.J., Kasprzyk, J.R., Lambert, C., 2016. Screening robust water infrastructure investments and their trade-offs under global change : A London example. Glob. Environ. Chang. 41, 216–227. doi:10.1016/j.gloenvcha.2016.10.007

Jeffrey, P., Ryan, S., Smith, H., 2014. Establishing a Robust Case for Final Effluent Reuse. Report 14/WR/29/3.

Kasperson, R.E., Renn, O., Slovic, P., Brown, H.S., Emel, J., Goble, R., Kasperson, J.X., Ratick, S., 1988. The Social Amplification of Risk: A Conceptual Framework. Risk Anal. 8, 177–187. doi:10.1111/j.1539-6924.1988.tb01168.x

Kearnes, M., Motion, J., 2014. Project Report Water Recycling and Media: Guidelines for Community Engagement.

Kemp, B., Randle, M.J., Hurlimann, A., Dolnicar, S., 2012. Community acceptance of recycled water - can we inoculate the public against scare campaigns? J. Public Aff. 12, 337–346.

Khan, S.J., Gerrard, L.E., 2006. Stakeholder communications for successful water reuse operations. Desalination 187, 191–202. doi:10.1016/j.desal.2005.04.079

Klinke, A., Renn, O., 2002. A new approach to risk evaluation and management: Risk-based, precaution-based, and discourse-based strategies. Risk Anal. 22, 1071–1094. doi:10.1111/1539-6924.00274

Kuklicke, C., Demeritt, D., 2016. Adaptive and risk-based approaches to climate change and the management of uncertainty and institutional risk: The case of future flooding in England. Glob. Environ. Chang. 37, 56–68. doi:10.1016/j.gloenvcha.2016.01.007

Lebel, L., Sinh, B.T., Nikitina, E., 2015. Adaptive governance of risks: climate, water and disasters, in: Shaw, R., Pulhin, J.M., Pereira, J.J. (Eds.), Climate Change Adaptation and Disaster Risk Reduction : Issues and Challenges. Emerald Group Publishing Limited, Bingley, pp. 115–142.

Lee, H., Tan, T.P., 2016. Singapore's experience with reclaimed water: NEWater. Int. J. Water Resour. Dev. 32, 611–621. doi:10.1080/07900627.2015.1120188

Leong, C., 2016. A lived-experience investigation of narratives : recycled drinking water. Int. J. Water Resour. Dev. 32, 637–649. doi:10.1080/07900627.2015.1126235

Leong, C., 2010. Eliminating " Yuck ": A Simple Exposition of Media and Social Change in Water Reuse Policies. Int. J. Water Resour. Dev. 26, 111–124. doi:10.1080/07900620903392174

Lindhe, A., Rosén, L., Norberg, T., Bergstedt, O., Pettersson, T.J.R., 2011. Cost-effectiveness analysis of risk-reduction measures to reach water safety targets. Water Res. 45, 241–53. doi:10.1016/j.watres.2010.07.048

Lupton, D., 1999. Risk and sociocultural theory, Risk and sociocultural theory: New directions and perspectives. Cambridge University Press, Cambridge. doi:10.1017/CBO9780511520778

Mainali, B., Ngo, H.H., Guo, W.S., Pham, T.T.N., Wang, X.C., Johnston, A., 2011. SWOT analysis to assist identification of the critical factors for the successful implementation of water reuse schemes. Desalin. Water Treat. 32, 297–306. doi:10.5004/dwt.2011.2714

Marks, J., Martin, B., Zadoroznyj, M., 2008. How Australians order acceptance of recycled water: National baseline data. J. Sociol. 44, 83–99. doi:10.1177/1440783307085844

Marks, J., Zadoroznyj, M., 2005. Managing Sustainable Urban Water Reuse: Structural Context and Cultures of Trust. Soc. Nat. Resour. An Int. J. 18, 37–41. doi:10.1080/08941920590947995

McDaniels, T.L., Gregory, R.S., Fields, D., 1999. Democratizing risk management: Successful public involvement in local water management decisions. Risk Anal. 19, 497–510. doi:10.1023/A:1007060931193

Medema, W., McIntosh, B.S., Jeffrey, P., 2008. From Premise to Practice : a Critical Assessment of Integrated Water Resources Management and Adaptive Management Approaches in the Water Sector. Ecol. Soc. 13, 29. doi:29

Miller, G.W., 2006. Integrated concepts in water reuse: managing global water needs. Desalination 187, 65–75. doi:10.1016/j.desal.2005.04.068

Moglia, M., Alexander, K.S., Sharma, A., 2011. Discussion of the enabling environments for decentralised water systems. Water Sci. Technol. 63, 2331–2340. doi:10.2166/wst.2011.443

Muro, M., Hrudey, S.E., Jude, S., Heath, L., Pollard, S., 2012. Making It Real: What Risk Managers Should Know About Community Engagement. J. Environ. Assess. Policy Manag. 14, 1–21. doi:10.1142/S146433321250010X

Muro, M., Jeffrey, P., 2012. Time to talk? How the structure of dialog processes shapes stakeholder learning in participatory water resources management. Ecol. Soc. 17. doi:10.5751/ES-04476-170103

Nancarrow, B.E., Leviston, Z., Tucker, D.I., 2009. Measuring the predictors of communities ' behavioural decisions for potable reuse of wastewater. Water Sci. Technol. 60, 3199–3210. doi:10.2166/wst.2009.759

Oesterholt, F., Medema, G., van der Kooij, D., Martijnse, G., 2007. Health risk assessment of non-potable domestic water supplies in the Netherlands. J. Water Supply Res. Technol. 56, 171. doi:10.2166/aqua.2007.043

Ofwat, 2016. Ofwat's customer engagement policy statement and expectations for PR19.

Ormerod, K.J., Scott, C.A., 2012. Drinking Wastewater : Public Trust in Potable Reuse. Sci. Technol. Human Values 1–23. doi:10.1177/0162243912444736

Pahl-Wostl, C., Holtz, G., Kastens, B., Knieper, C., 2010. Analyzing complex water governance regimes: the Management and Transition Framework. Environ. Sci. Policy 13, 571–581. doi:10.1016/j.envsci.2010.08.006

Pahl-Wostl, C., Lebel, L., Knieper, C., Nikitina, E., 2012. From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. Environ. Sci. Policy 23, 24–34. doi:10.1016/j.envsci.2012.07.014

Pahl-Wostl, C., Sendzimir, J., Jeffrey, P., Aerts, J., Berkamp, G., Cross, K., 2007. Managing Change toward Adaptive Water Management through Social Learning. Ecol. Soc. 12.

Pahl-Wostl, C., Tàbara, D., Bouwen, R., Craps, M., Dewulf, A., Mostert, E., Ridder, D., Taillieu, T., 2008. The importance of social learning and culture for sustainable water management. Ecol. Econ. 64, 484–495. doi:10.1016/j.ecolecon.2007.08.007

Pawson, R., 2002. Evidence-based Policy: The Promise of `Realist Synthesis'. Evaluation 8, 340–358. doi:10.1177/135638902401462448

Pearson, L.J., Coggan, A., Proctor, W., Smith, T.F., 2009. A sustainable decision support framework for urban water management. Water Resour. Manag. 24, 363–376. doi:10.1007/s11269-009-9450-1

Price, J., Fielding, K.S., Gardner, J., Leviston, Z., Green, M., 2015. Developing effective messages about potable recycled water: The importance of message structure and content. Water Resour. Res. 51, 2174–2187. doi:10.1002/2014WR016514.Received

Price, J., Fielding, K.S., Leviston, Z., 2012. Supporters and Opponents of Potable Recycled Water : Culture and Cognition in the Toowoomba Referendum. Soc. Nat. Resour. 25, 980–995. doi:10.1080/08941920.2012.656185

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. J. Environ. Manage. 90, 1933–1949. doi:10.1016/j.jenvman.2009.01.001

Renn, O., Burns, W.J., Kasperson, J.X., Kasperson, R.E., Slovic, P., 1992. The Social Amplification of Risk: Theoretical Foundations and Empirical Applications. J. Soc. Issues 48, 137–160.

Roger, P., Hall, A., 2002. Effective Water Governance. TEC Backgr. Pap. Glob. Water Partnership, Stock. Sweden. 7.

Ross, V.L., Fielding, K.S., Louis, W.R., 2014. Social trust, risk perceptions and public acceptance of recycled water: Testing a social-psychological model. J. Environ. Manage. 137, 61–68. doi:10.1016/j.jenvman.2014.01.039

Rozin, P., Haddad, B., Nemeroff, C., Slovic, P., 2015. Psychological aspects of the rejection of recycled water: Contamination, purification and disgust. Judgement Decis. Mak. 10.

Russell, S., Lux, C., Hampton, G., 2008. Beyond "Information": Integrating Consultation and Education for Water Recycling Initiatives. Soc. Nat. Resour. 22, 56–65. doi:10.1080/08941920801910666

Sjoberg, L., 2000. Factors in risk perception. Risk Anal. 20, 1–11. doi:10.1111/0272-4332.00001

Smith, H.M., Rutter, P., Jeffrey, P., 2014. Public perceptions of recycled water: a survey of visitors to the London 2012 Olympic Park. J. Water Reuse Desalin. 1–7. doi:10.2166/wrd.2014.146

Summerill, C., Smith, J., Webster, J., Pollard, S., 2010. An international review of the challenges associated with securing " buy-in " for water safety plans within providers of drinking water supplies. J. Water Health 8, 387–398. doi:10.2166/wh.2010.047

Thames Water, 2015. Thames Water Water Resources Management Plan 2015 - 2040 - Executive Summary. Reading, UK.

Thames Water, 2014. Revised Draft Water Resources Management Plan (2015-2040) - Section 6: Baseline Supply Demand Position. Reading, UK.

Trochim, W.M.K., 1989. Outcome pattern matching and program theory. Eval. Program Plann. 12, 355–366. doi:10.1016/0149-7189(89)90052-9

Trochim, W.M.K., 1985. Pattern Matching, Validity, and Conceptualization in Program Evaluation. Eval. Rev. 9, 575–604. doi:10.1177/0193841X8500900503

Tversky, A., Kahneman, D., 1974. Judgment under uncertainty: heuristics and biases. Sci. New Ser. 185, 1124.

UKWIR, 2016. WRMP 2019 methods – risk based planning.

van der Wal, M., De Kraker, J., Offermans, A., Kroeze, C., 2014. Measuring Social Learning in Participatory Approaches to Natural Resource Management. Environ. Policy Gov. 24, 1–15. doi:10.1002/eet.1627

van Rensburg, P., 2016. Overcoming global water reuse barriers: the Windhoek experience. Int. J. Water Resour. Dev. 32, 622–636. doi:10.1080/07900627.2015.1129319

Wahlberg, A., Sjoberg, L., 2000. Risk perception and the media. J. Risk Res. 3, 31–50.

West, C., Kenway, S., Hassall, M., Yuan, Z., 2016. Why do residential recycled water schemes fail? A comprehensive review of risk factors and impact on objectives. Water Res. 102, 271–281. doi:10.1016/j.watres.2016.06.044

Wester, J., Timpano, K.R., Çek, D., Lieberman, D., Fieldstone, S.C., Broad, K., 2015. Psychological and social factors associated with wastewater reuse emotional discomfort. J. Environ. Psychol. 42, 16–23. doi:10.1016/j.jenvp.2015.01.003

Wester, J., Timpano, K.R., Cek, D., Broad, K., 2016. The psychology of recycled water: Factors predicting disgust and willingness to use. Water Resour. Res. 52, 3212–3226. doi:doi:10.1002/2015WR018340

White, I., Kingston, R., Barker, A., 2010. Participatory geographic information systems and public engagement within flood risk management. J. Flood Risk Manag. 337–346.

Wintgens, T., Melin, T., Schäfer, A., Khan, S., Muston, M., Bixio, D., Thoeye, C., 2005. The role of membrane processes in municipal wastewater reclamation and reuse. Desalination 178, 1–11. doi:10.1016/j.desal.2004.12.014

Yin, R.K., 2011. Applications of Case Study Research: Third Edition. SAGE Publications Ltd.

Chapter 2. Applying the Water Safety Plan to water reuse: Towards a conceptual risk management framework

D. Goodwin[1], M. Raffin[2], P. Jeffrey[1], H. M. Smith[1]

[1]Cranfield Water Science Institute, Cranfield University, Bedfordshire, UK, MK43 0AL

[2]Thames Water Utilities Ltd, Innovation, Reading STW, Island Road, Reading, UK RG2 0RP

Abstract

The Water Safety Plan (WSP) is receiving increasing attention as a recommended risk management approach for water reuse through a range of research programmes, guidelines and standards. Numerous conceptual modifications of the approach – including the Sanitation Safety Plan, the Water Cycle Safety Plan, and even a dedicated Water Reuse Safety Plan – have been put forward for this purpose. However, these approaches have yet to encapsulate the full spectrum of possible water reuse applications, and evidence of their application to reuse remains limited. Through reviewing the existing evidence base, this paper investigates the potential for adapting the WSP into an approach for water reuse. The findings highlight a need for the management of risk to reflect on, and facilitate the inclusion of, broader contexts and objectives for water reuse schemes. We conclude that this could be addressed through a more integrated approach to risk management, encapsulated within an overarching risk management framework (adapted from the WHO's Framework for Safe Drinking Water) and operationalised through the Water Reuse Safety Plan (WRSP). We also propose that the WRSP should be based on modifications to the existing WSP approach, including an increased emphasis on supporting communication and engagement, and improvements in decision support mechanisms to better account for uncertainty, risk interactions and risk prioritisation.

2.1 Introduction

The management of risk is a significant challenge for the development and operation of water reuse schemes. Risks in water reuse schemes arise from a variety of hazards, which can lead to a wide range of consequences. Understanding of risk has led to the development and use of a number of risk-based management approaches and governing frameworks. The resulting view is that, for water reuse schemes, system wide risk-based management can be more effective than reliance on end product compliance alone (Hamilton et al., 2006; Hochstrat et al., 2010).

Experience has been gained through applying a number of risk management approaches to water reuse schemes, at both scheme appraisal and operational stages. The principle examples involve derivations of the Australian Guidelines for Water Recycling (AGWR), the Hazard Analysis and Critical Control Point (HACCP), the Water Safety Plan (WSP) and ISO guidelines (Dewettinck et al., 2001; Dominguez-Chicas and Scrimshaw, 2010; Law et al., 2014; Muston, 2012; NRMMC EPHC & AHMC, 2006; Page et al., 2008; Power, 2010a; Salgot and Priestley, 2012; SEQWater, 2013; Swierc et al., 2005). Documented evidence of using these approaches illustrate the benefits of risk management processes (e.g. to minimise the chance of failure through mistakes or omissions) and illuminate specific water reuse risk management needs. That said, risk management approaches are not immune to challenges, particularly from institutional arrangements, public engagement and broader uncertainties associated with risk identification and assessment.

An increasing number of water reuse standards, guidelines and projects are promoting the Water Safety Plan (WSP) risk management approach. For example, the latest edition of the US EPA Guidelines for Water Reuse (USEPA, 2012) promotes the use of a risk management system such as the WSP. Despite this growing interest, only a limited number of schemes have documented the application of a WSP-based approach to water reuse schemes (Dominguez-Chicas and Scrimshaw, 2010; Godfrey et al., 2005; Hills, 2013; Weemaes, 2011). These limited and context specific examples are currently not sufficient to fully understand the broader suitability of this risk management process for water reuse.

In Australia, a significant number of water reuse risk management plans have been developed, through the application of the Australian Guidelines for Water Recycling (AGWR). While they don't implement the WSP approach per se, the AGWR present an overarching risk management framework that (like the WSP) is based on HACCP principles. Some of the plans that have emerged from the AGWR framework have been referred to as safety plans (Hamilton et al., 2005; Thompson, 2005). Outcomes from applying the AGWR suggest that the development of country specific guidance is desirable, obtainable and advantageous (Apostolidis et al., 2011; Muston, 2012). However, a number of limitations have also been documented, including a lack of consistency in the validation of technology and the scope of the risk management framework being too narrow (Huxedurp et al., 2014; Law et al., 2014). Nonetheless, experience from Australia provides valuable insight for examining how a risk management approach can be extended to water reuse.

The WSP approach operationalises the World Health Organisation's (WHO) overarching risk management framework – the Framework for Safe Drinking Water (FSDW). This framework is applied system-wide from catchment to tap and is designed primarily to meet health-based targets (WHO, 2011). For non-potable water reuse, the WHO's Guidelines for the Safe Use of Wastewater, Excreta and Greywater (WHO, 2006) apply to wastewater and greywater reuse in aquaculture and agriculture. The WHO has developed a modification of the WSP – the Sanitation Safety Plan (SSP) approach – to implement these guidelines, albeit for a limited number of source water and end use options (WHO, 2015). The availability of both WSP and SSP manuals helps promote their application and ensure consistency and confidence in the process (Bartram et al., 2009; WHO, 2015). Both of these existing guidelines establish a foundation framework for applying a WSP-based approach to water reuse, but are also limited in their scope.

Other WSP-based approaches have also emerged, such as the Water-Cycle Safety Plan and the Urban Drainage Safety Plan, which highlight's the WSP's appeal and broad international applicability (do Céu Almeida et al., 2014; Möderl et al., 2015). What is currently lacking is a better understanding of how a WSP-based approach can be comprehensively applied to water reuse schemes, and what specific modifications might be required for this. Whilst water reuse is incorporated to some extent in existing WSP-based approaches, none address the full scope of reuse schemes, nor do they appear to have engaged meaningfully with the specific literature base, associated best practice guidance, and industry experience associated with reuse. Other studies (Sanz and Gawlik, 2014) have proposed a Water Reuse Safety Plan (WRSP) as a WSP-based approach that is applicable to a range of water reuse systems and incorporates risks to the environment. However, the relative lack of documented examples of applying such a WSP-based approach to reuse, along with evolving water reuse risk management requirements, suggests that further investigation is required.

This paper aims to help develop and operationalise a WRSP approach applicable across urban, industrial, agricultural, environmental and potable reuse applications. In doing so, this paper examines how the WSP could be adapted most effectively for water reuse. The paper also explicitly considers the need to develop an overarching risk management framework, alongside (and adapted from) the FSDW, in which to situate a WRSP approach. To achieve these aims, we will first examine the nature of the FSDW and the WSP and consider what gaps exist in its ability to address water reuse. Next, we draw from a review of the water reuse literature and identify some key risks that warrant particular consideration for water reuse schemes. We then examine how these key risk considerations might be addressed with the WSP approach, and within its overarching framework (the FSDW). This provides the basis for discussing how the WSP and its framework might be adapted into a comprehensive risk management approach for water reuse – namely a WRSP approach situated within a broader management framework.

2.2 Steering the Water Safety Plan towards reuse

Emerging from the principles of the Stockholm Framework, the WHO's Guidelines for Drinking Water Quality (GDWQ) (WHO, 2011) take an integrated approach to risk assessment and risk management to control water-related disease. The GDWQ is a preventative management approach described by the Framework for Safe Drinking Water (FSDW) that consists of three components (Figure 2-1): (1) establishment of health-based targets, (2) Water Safety Plans; and (3) a system of independent surveillance (WHO, 2011). The FSDW is the risk management framework and the WSP is the applied risk management process. The WSP is essential to operationalising the risk management framework in a consistent and transparent way. Within the WSP component are three elements. These are: (i) System Assessment, (ii) Monitoring, and (iii) Management and Communication.

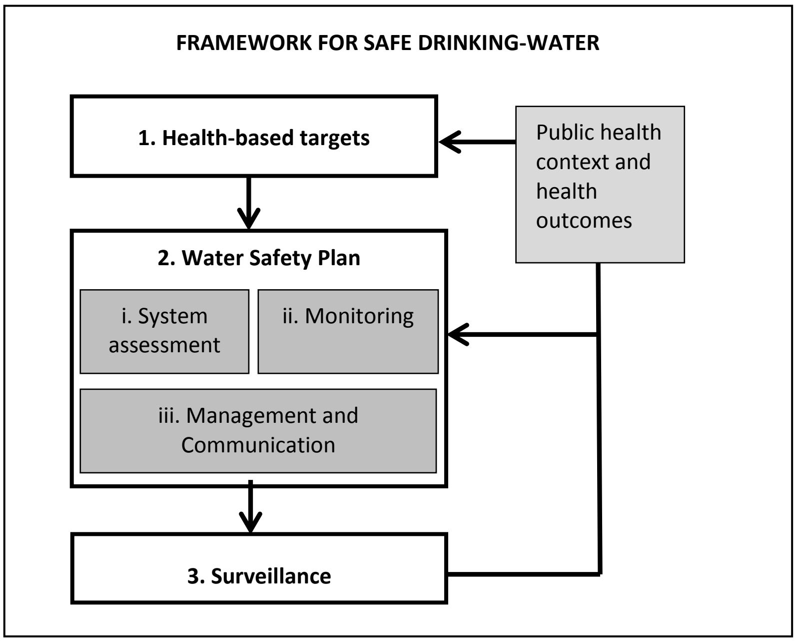


Figure 2-1 WHO's Framework for Safe Drinking-Water (adapted from WHO, 2011)

The WSP and its three elements are further divided into eleven modules designed to assist with the development and implementation of risk management. The eleven modules and their relationship to the three WSP elements are shown in Figure 2-2. These modules should be followed to make preparations for normal operating and emergency situations. The system assessment is conducted by a WSP team who describe the catchment to tap system by identifying hazards, characterising the risks, determining controls and developing an improvement plan.

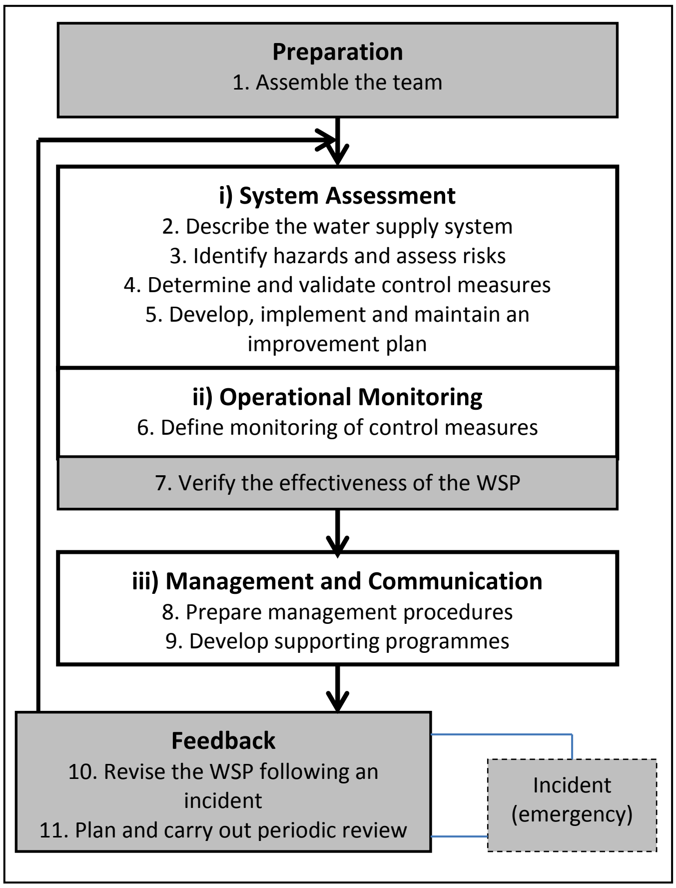


Figure 2-2 How to Develop and Implement a WSP (11 Modules) (adapted from Bartram et al., 2009)

The basis of the WSP is the Hazard Analysis and Critical Control Point (HACCP) method. HACCP was developed by the food industry to provide a systematic analysis of hazard within a process to “ensure food is safe and suitable for human consumption” (CAC, 2009). Through a process of hazard analysis; critical control points identification; establishment of critical limits; monitoring; taking corrective actions; recordkeeping; and verification, risk managers can understand the relationship between hazard and process and thus take preventative action against threats. This approach has been adopted by the water industry and modified to accommodate elements such as risk assessment, community involvement, non-critical control points, multiple barriers and Disability Adjusted Life Years (Dewettinck et al., 2001; NHMRC & NRMMC, 2009; Page et al., 2008; Salgot and Priestley, 2012; Swierc et al., 2005). Such a risk management process provides a structured system to identify, prioritise and control risk and to minimise the chance of failure through error, oversight or lapse of management (Davison et al., 2005). The WHO's WSP is an internationally recognised, well-established and trusted method for managing potable water supply schemes and is a regulatory requirement in a number of countries (Edgar et al., 2010). Such an approach is now often considered necessary for managing water reuse schemes (Hochstrat et al., 2010).

The WSP can be adapted to specific contexts for different drinking water supplies. Such examples include assessing risks associated with supply security, water pressure and aesthetics (eg. taste, colour) (do Céu Almeida et al., 2014; Rosén et al., 2007; Viljoen, 2010). Still, there is a recognised need for more research and capacity building to implement the WSP, particularly for small water supplies (Perrier et al., 2014; van der Hoek et al., 2014). There is also a recognised need to integrate better risk management tools and to address some non-technical operational and human factors (Kot et al., 2014; Lindhe et al., 2013; Summerill et al., 2010b). One attempt to achieve these aims is the Water Cycle Safety Plan (WCSP) approach that extends the WSP to the urban water cycle. The WCSP extends the scope of the WSP beyond public health hazards to consider public safety (flooding) and protection of the environment (do Céu Almeida et al., 2014). The WCSP framework was developed as part of the PREPARED project (do Céu Almeida et al., 2013), and was designed to include all aspects of the urban water cycle, including water reuse (e.g. greywater reuse and rainwater harvesting (Baban et al., 2011)). Other adaptions of the WSP include the Water and Sanitation Safety Plan, the Urban Drainage Safety Plan and the Building Water Safety Plan (Cunliffe et al., 2011; Möderl et al., 2015; Rapala, 2014; WECF, 2014).

Water reuse guidelines, standards and research programmes are increasingly referring to and promoting the use of the WSP or a Water Reuse Safety Plan (WRSP) for both potable and non-potable water reuse schemes. This is particularly the case in North America (Ashbolt, 2014a, 2014b; Gelting et al., 2015; ILSI, 2013; NRC, 2012; USEPA, 2012) and Europe (Bixio et al., 2008; BSI, 2013, 2011; Fawell et al., 2005; Hochstrat et al., 2010; Jeffrey et al., 2014; Sanz and Gawlik, 2014; Weemaes, 2011). To date, however, there are relatively few documented examples of the application of a WSP-based approach (based on the WHO guidelines) to water reuse. One example, by Dominguez-Chicas and Scrimshaw (2010), evaluated the first three WSP modules (1. Assemble the team; 2. Describe the water supply system; and 3. Identify hazards and assess risks) for a pilot scale IPR scheme. They describe these initial steps of the process as being essential and capable of prioritising hazards. However, they also found that high levels of uncertainty and precaution resulted in an over estimation of high-risk parameters. Other applications of the WSP to reuse include focusing on benefits of risk communication and stakeholder engagement (Godfrey et al., 2010, 2007, 2005; Hills, 2013; Hills and James, 2015).

The review has highlighted that the WSP approach is focused primarily on hazards that could impact human health. Though this focus might consider the role of unplanned, indirect potable reuse (IPR), agricultural non-potable reuse of greywater and wastewater, it is not effective for addressing hazards non-specific to human health (e.g. diffuse nutrients). The literature pertaining to risk management for water reuse, best practice guidance and industry experience is extensive. However, the authors are not aware of examples that integrate principles from this body of work into existing WSP-based concepts. This is developed further in the following sections.

2.3 Risk considerations for water reuse

This section draws from an extensive review of water reuse literature. This review identified a number of key risk considerations for water reuse: 1) risk characterisation and decision support tools to interpret uncertainty; 2) integration and prioritisation of risks, risk controls and operational monitoring; 3) understanding technological performance and the capabilities of water professionals; and 4) communication and engagements with regulators, stakeholders and the public.

2.3.1 Risk characterisation

The probabilistic nature of risk assessment introduces uncertainty to the process, which can limit the capacity of risk managers to identify hazards (NRMMC EPHC & AHMC, 2006; Roux et al., 2008). Factors that can contribute to uncertainty include: lack of available information on catchment hazards (including a lack of understanding on what hazards to include in the assessment) lack of information on the quality of source or receiving waters, and variability in the technical and operational data for treatment systems (Anderson et al., 2001; Dominguez-Chicas and Scrimshaw, 2010; NRMMC EPHC & AHMC, 2006; NRMMC EPHC & NHMRC, 2008). Hazard identification for water reuse can be aided through the identification of common hazards across different projects (e.g. twelve common hazards are identified in the AGWR for managed aquifer recharge (NRMMC EPHC & AHMC, 2009)).

Uncertainty will also exists within risk control and operational monitoring and the understanding of public support and stakeholder expectations (Chen et al., 2013; Debroux et al., 2012; NRMMC EPHC & AHMC, 2009; Salgot et al., 2006). In addition, scheme- or technology-specific hazardous events need to be considered. For example, Van den Akker et al. (2014) discuss public health hazards that could be introduced to a systems via membrane cleaning. Water treatment can generate hazardous by-products, such as disinfection by-products (eg. THMs, NDMA) or greenhouse gases (Chang et al., 2010; NRMMC EPHC & AHMC, 2009; Weber et al., 2006).

There is perhaps a tendency to overestimate risks though the assumptions required during both qualitative and quantitative risk characterisations (Chen et al., 2013; Ryu et al., 2007). For example, conservative margins of safety can be used which may result in overestimating the significance or magnitude of risks (Dominguez-Chicas and Scrimshaw, 2010; Schäfer and Beder, 2006; Storey et al., 2007). This can be true for Quantitative Microbial Risk Assessment (QMRA) (Mok et al., 2014). However, even with limited available data, the benefit of QMRA and other quantitative risk assessment techniques is that they can serve to interpret uncertainty, assess treatment options and highlight the need for risk controls (Chen et al., 2013; Mok et al., 2014). The water reuse literature outlines a number of potential improvements that could support decision making during hazard identification and risk characterisation. However, as Salgot & Priestley (Salgot and Priestley, 2012) note, despite advances in the tools available, simplifications are often required for practical application.

2.3.2 Risk integration and prioritisation

Integrated risk management processes should consider a wide range of risks across the entire scope of water reuse (Huxedurp et al., 2014). Water reuse risk management plans typically relate to microbial and chemical hazards and their potential consequences for human health and environmental end points (NRMMC EPHC & AHMC, 2006; Sanz and Gawlik, 2014). These hazards can be interdependent and the realisation of a single event might trigger a cascade of secondary or tertiary consequences that will have far ranging effects (refer to Figure 2-3) (Rayne and Forest, 2009), specifically within an operational context (Swartz, 2010). Thus, initial consequences could escalate to threaten commercial, contractual, reputational or broader water resource planning and policy objectives (Campbell and Scott, 2011; Hurlimann et al., 2007; Huxedurp et al., 2014; Institute for Sustainable Futures, 2013a; Muston, 2012; NRMMC EPHC & AHMC, 2006; Pickering, 2013; Urkiaga et al., 2008; USEPA, 2012).

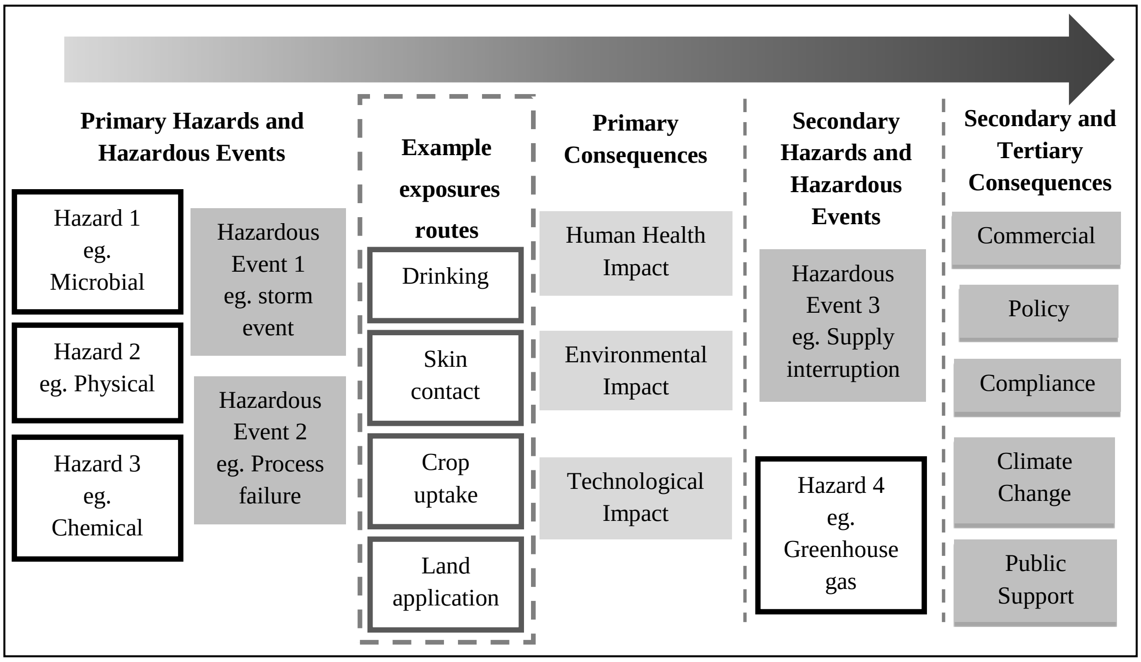


Figure 2-3 An illustrative example of possible risk interactions for water reuse with primary, secondary and tertiary consequences

A more integrated risk assessment process would extend beyond consideration of health and environmental effects to include other aspects like technology and process performance impacts (Listowski, 2009; Nandha et al., 2014), which might, for example, impact operating costs, supply pressure or availability (Rosén et al., 2010). How hazards, risks or technologies are perceived might also impact on the acceptability of a supply and thus the objective of building public support and confidence (Hurlimann, 2007; Wu et al., 2012). Other factors to consider include system scale and complexity. Smaller schemes with well understood catchments and low risk end uses could use simplified risk management processes (Godfrey et al., 2010; Power, 2010a). Risk management schemes need not be overly complicated (NRMMC EPHC & AHMC, 2006), however, failure to integrate all elements of a system can diminish the effectiveness of scheme performance (Institute for Sustainable Futures, 2013a).

Risk-based decision making requires that hazards and consequences are prioritized and that a broad range of issues are assessed and compared alongside one another. For example, health risks must be considered alongside availability of supply and, depending upon the objective of the decision maker, compromise between water quantity and quality may be considered (Rodriguez et al., 2009). Individual hazards may relate to a number of consequences and therefore certain outcomes and water quality targets may need to be prioritised. However, the prioritization process will be affected by uncertainty. For example, the impact of endocrine disrupting compounds in fish has been documented, yet the implications for human health remains inconclusive (Ying et al., 2004), so the relative priority of the hazard is difficult to establish.

2.3.3 Technological performance & water sector experience

The performance of the system can affect the quality of the product water (Thoeye et al., 2003). Multi-barrier systems are recommended for reuse to address the fact that individual process elements and barriers can fail (Hass and Trussel, 1998). The water reuse system comprises different treatment technologies and performance of these technologies may decrease over time or can also introduce additional risk to the system (Rodriguez et al., 2009). For example, nitrosamines are shown to increase after ozonation and chloramination (Hatt et al., 2013; Pisarenko et al., 2013). Validation of treatment process log reductions is another important consideration (WHO, 2011). Indicative log reduction and actual validated system performance reductions are recommended considerations for the risk management process for reuse (Law et al., 2014; Muston and Halliwell, 2011; NRMMC EPHC & AHMC, 2006; USEPA, 2012).

The performance of water treatment technologies, and the potential for them to introduce risk to the system, can be monitored via performance targets (Muston and Halliwell, 2011). This approach may be beneficial for systems where experience with water reuse schemes is low (Bartrand et al., 2013; Nandha et al., 2014). Example performance targets can include: reliability (eg, pressure), operational running costs, energy consumption, and customer satisfaction (Bartram et al., 2009; NRMMC EPHC & AHMC, 2009; Rosén et al., 2007; USEPA, 2013). Operator capabilities are another important consideration, particularly in the absence of industry experience (NRMMC EPHC & AHMC, 2006). Individual human errors or broader system faults can lead to hazardous events occurring (Woo and Vicente, 2003). For indirect potable reuse schemes, environmental buffers may be utilised “to provide ‘time to respond’ to treatment malfunctions or unacceptable water quality” (Khan, 2013). There is a potential for a lack of organisational experience with water reuse schemes to increase the perceived burden of management and documentation requirements and this may impact on investment in water reuse (Halliwell, 2014; Institute for Sustainable Futures, 2013b).

2.3.4 Communication and engagement

Risk communication is susceptible to issues of ambiguity that are often due to perceived difficulties in communicating scientific concepts (Bichai and Smeets, 2013; Doria, 2010; Russell and Lux, 2009). Often these problems are due to differences in social values or how individuals perceive risk (Ormerod and Scott, 2012). Effective communication is therefore valuable to reduce uncertainty and build public support and this can be achieved by improving awareness through constructive and continual engagement with water reuse stakeholders (Baggett et al., 2006; Derry et al., 2006; NRMMC EPHC & NHMRC, 2008; Stenekes et al., 2006). One way of achieving this may be to involve members of an effected community more closely in the risk management process (Derry, 2011).

When communicating risk, it is important to understand that risks might affect stakeholders throughout the system (eg. catchment, treatment plant) (do Céu Almeida et al., 2014; Rosén et al., 2007). Understanding stakeholder attitudes across the system can be helpful for reducing uncertainty and improving risk characterisation, particularly around potable reuse (Campbell and Scott, 2011; Nancarrow et al., 2009). Poor understanding of both stakeholder and public attitudes can also have a negative impact on how governing administrations promote water reuse (Domènech and Saurí, 2010). Uncertainty in both attitudes and governance may also influence water practitioner’s perceptions of risks, their assessment of risk and decisions around the role of water reuse in water resource planning (Baggett et al., 2006; Dobbie and Brown, 2014b; Tchobanoglous et al., 2011).

2.4 Mapping risk considerations onto the WSP

This section maps the key considerations from the water reuse literature review onto the WSP’s three main structural elements: system assessment, operational monitoring, and management and communication. This is done to evaluate how the WSP addresses these risk considerations, and identity how these it might be best adapted into a risk management approach for reuse.

2.4.1 System assessment

The WSP acknowledges uncertainty in risk assessment but it does not provide specific guidance or tools to help address it. As identified in the literature, challenges to system assessment might include: a lack of knowledge and guidance on the hazards to consider, the conditions that might trigger a hazardous event, and the variance inherent in probabilities and consequences. Both qualitative and quantitative assessment methods can be used to characterise risk. A typical technique is the semi-quantitative matrix that can be used to prioritise risks and vulnerabilities (WHO, 2011). Comparing different risks presents a challenge due to subjectivity, for example, Hrudey et al. (2011) describe the challenges in comparing health risks from inadequate disinfection with possible risks of cancer or adverse reproductive outcomes arising from disinfection by-products.

Water reuse risk assessment requires guidance on how to make better decisions in the presence of uncertainty. Whilst WSP documentation identifies the need to account for variability and uncertainty, little advice is provided for the practitioner. In the WSP manual, Bartram et al., (2009) suggests using “significant” and “not-significant” as a simplified approach where risks are difficult to characterise. Similarly, whilst QMRA is recommend by the WHO, is it suggested that the strength of the approach (and other quantitative assessments) lies in the interpretation of model uncertainties in decision making (Cook et al., 2009; Khan and Roser, 2007; Ryu et al., 2007; Smeets et al., 2010). Other tools identified in the WSP literature, such as multi-criteria decision analysis (MCDA), can enable uncertainty modelling to prioritise safety measures and this may bring benefits to WRSP guidance (Lindhe et al., 2013).

A number of recommendations arise in the water reuse literature for dealing with variability and knowledge uncertainty. Chen et al. (2013) suggests fuzzy sets or hybrid fuzzy-stochastic modelling and Khan (2013) recommends Monte Carlo based probabilistic assessments for optimising multiple process treatment performance. These approaches can help to reduce the propagation of conservative assumptions in deterministic approaches. However, such approaches may have limited appeal to water reuse scheme assessors or operators who may not have time or resources to undertake detailed modelling. Therefore, more research and guidance on such analyses is needed before they can be used routinely in place of simpler deterministic analyses (NRMMC EPHC & AHMC, 2006).

“The WSP approach should be considered as a risk management strategy or umbrella which will influence a water utility’s whole way of working towards the continuing supply of safe water.” (Bartram et al., 2009). For this reason, any water reuse risk management guidance may need to consider potential risk interactions and the related risk controls, particularly for schemes with multiple and mixed end use requirements (potable and non-potable). Though suggested, no guidance for how to accommodate more complex and system wide risk interactions is provided.

Failure Mode and Effects Analysis (FMEA) can be used to analyse water systems, including those incorporating reuse systems (Hwang et al., 2015; MacGillivray et al., 2006). Dominguez-Chicas and Scrimshaw (2010) identify a number of indicators that could be used to determine failure modes and the potential effects for IPR. Although this may be advantageous to the management of a system as part of a WSP, such an initial and conceptual model currently has little practical application. Further development of FMEA would be beneficial to water reuse risk management as part of a WSP based approach. Other techniques such as fault tree and event tree analysis may be advantageous to water reuse, particularly for understanding and assessing relationships between events and consequences (Swartz, 2010).

These findings highlight a need for risk assessment to consider cumulative effects arising from the interaction of multiple hazards or exposure pathways (Alves et al., 2012; Suter et al., 2005). As with risk assessment, risk controls will also need to consider risk interactions. Heterogeneous risk controls may be required for some schemes with multiple end uses and this is not an explicit consideration of the WSP pro-forma. Additionally, technology may be relied on to treat the water to a certain quality, however, risks can also be controlled through non-technical barriers such as restricting exposure or behaviour change, particularly for non-potable reuse (McIlwaine and Redwood, 2010). Thus the benefits of non-technical barriers would supplement a WSP for water reuse.

2.4.2 Operational monitoring

Operational monitoring refers to the definition and validation of control measures, the establishment of procedures to demonstrate that the controls are working and corrective actions are undertaken (Bartram et al., 2009). Operational monitoring may be challenged by regulatory requirements, cost, levels of detectability and scientific knowledge in new and emerging chemicals (what to monitor) (Debroux et al., 2012). Cost-benefit analysis can be introduced to the WSP framework to help decision makers prioritise monitoring needs. Operational monitoring typically includes measurement of parameters at control points across the system (WHO, 2011). However, observational monitoring techniques can also be beneficial to water reuse, particularly where suitable analytical capabilities are unavailable. Qualitative techniques can include audits of signage and visual inspection of irrigation systems and vegetation health for non-potable reuse (NRMMC EPHC & AHMC, 2006). Qualitative monitoring can also enable operators to become more familiar with operational and risk management processes through regular and critical interaction with them.

WSP documentation provides guidance on the use of faecal indicator organisms such as E. coli in providing safe drinking water. The benefit of using surrogate indicators is identified by Godfrey et al. (2010), again, particularly where there are limited analytical facilities or where the detectability of particular hazards is challenging or expensive. Other surrogates may be useful for reuse, for example, dissolved oxygen can be used to monitor for trade waste discharge, however, this requires careful management to avoid false alarms (Fairbairn, 2006). The use of surrogates and qualitative monitoring for water reuse is covered in some detail in the AGWR, however, a comprehensive summary is not provided in the WSP based guidance or emerging concepts such as the WCSP.

2.4.3 Management and communication

Management and Communication is the third WSP element and includes supporting programmes. WSP supporting programmes are described as actions that are important to ensuring water safety but are not control measures and do not directly affect water quality treatment (WHO, 2011). Supporting programmes include training, research and quality assurance such as process validation. What is highlighted in the literature is that the documentation needs to be efficient and actually contribute to improving risk management without being overly bureaucratic. This is not so much a question for the structure of the WSP and relates more to the effectiveness of implementation guidelines and organisational capabilities, culture and support (Summerill et al., 2010a).The benefit of adapting the WSP to water reuse is that support can be derived from resources such as the WSP and SSP manuals, templates, case studies, networks and a substantial body of literature.

Communication is a suggested supporting programme for the WSP. The WSP team should therefore set out to promote a continual dialogue with stakeholders and the public. Although the WSP contains a communication element, more emphasis on this can be required for water reuse. The AGWR and ISO 31000 are examples of a more encompassing approach to communication within the risk management process. Bringing engagement into the system assessment would allow for external concerns of risks to be more suitably addressed and this may lead to improvements in public support and scheme design efficiencies.

2.5 Broader framework considerations

The WSP does not stand alone and is situated within its broader risk management framework – the Framework for Safe Drinking Water. The FSDW was developed from the WHO's harmonised risk framework. This is an iterative process that links the assessment of risk with risk management using the definition of health targets and the assessment of health outcomes (Bartram et al., 2001). This section of the paper evaluates how the FSDW addresses the key risk considerations for reuse identified previously. The focus of this section is on components 1 and 3 of the FSDW - as we have addressed component 2, the WSP in the previous section (Figure 2-1). This section also considers the context of acceptable risk which helps establish the targets (health-based) for the FSDW. This provides the basis for examining how the FSDW might be adapted into a complementary risk management framework for water reuse, within which a WRSP could be situated.

2.5.1 Acceptable risk context

The acceptability of water reuse risks will depend upon the end use of the water and the diversity of stakeholders (Chen et al., 2013, 2012a; do Céu Almeida et al., 2014; Pickering, 2013; Power, 2010b). Acceptability may also vary where vulnerabilities exist within communities such as with immunocompromised groups, this is particularly the case for non-potable reuse (Muston and Wille, 2006). As a result, how risks are measured will need to vary with the context (Hunter and Fewtrell, 2001; Rodríguez et al., 2012). The DALY, used to measure disease burden, is used in the WSP and AGWR frameworks, however, this might not be flexible enough to account for the different contexts in which water reuse is applied. In addition, this measure does not account for environmental risks (e.g land salinity or eutrophication of a receiving water), nor does it address concerns about odour, colour, taste or supply reliability (Lindhe et al., 2009; Wu et al., 2012).

Broader consideration needs to be given to the selection of technology and the design of water reuse schemes. This can be hampered by a lack of available performance data or a limited understanding as to how certain technology will perform within a given cultural or organizational context. The local context and experience may favour certain technology. For example, dual membrane process trains incorporating reverse osmosis are essentially default for many indirect potable and non-potable urban reuse schemes (particularly in Australia and California). However, this may not be the most cost effective or sustainable solution to provide safe water (Law et al., 2014). The views of the public and their attitudes to risk may also differ to water industry practitioners (Meehan et al., 2013; Price et al., 2012). Negative public attitudes can be enough to render a scheme unviable, particular for potable reuse (Hurlimann and Dolnicar, 2010). Non-potable reuse is also subject to negative attitudes and views on acceptable levels of risk. Negative experiences with cross-contamination in the Netherlands led to the Dutch government discouraging large scale non-potable schemes (Oesterholt et al., 2007). Such attitudes and concerns need to be taken seriously in the given context and cannot be overlooked when defining what is acceptable, the water supply targets and for developing water reuse risk management framework requirements.

2.5.2 Targets

For the FSDW the targets are health-based, but the risk context for reuse shows that targets may need to be broader. Internationally, water quality requirements for identical water reuse applications can vary in both the number of parameters used to assess risk and the target values (Wintgens and Hochstrat, 2006). These differences can be explained by the availability (or lack) of data (eg. toxicological), views on acceptability, and the extent to which the precautionary principle is applied (Rodríguez et al., 2012). Depending on the scheme, targets will also vary depending on the characteristics and sensitivity of the receiving environment and intended end use (Janbakhsh, 2012; NRMMC EPHC & AHMC, 2006; USEPA, 2012). This will be a reflection of the acceptable risk context.

Targets for microbiological quality remains paramount yet there remains some epistemic uncertainty around the range of chemicals that may be present in reclaimed water, particular for potable but also for a number of non-potable reuse applications (NRMMC EPHC & NHMRC, 2008). Guideline water quality targets for water reuse may differ from standard potable water targets, particularly through the consideration of environmental guideline values and contaminants of emerging concern (CEC) (Khan, 2013; NRMMC EPHC & AHMC, 2006). CEC targets may be considered for potable reuse. However, this is more an issue of public and regulator perception when advanced treatment is used (Tchobanoglous et al., 2011). Such contaminants are being given increasing attention in non-potable reuse application, particularly for agricultural and environmental uses. In some cases, the level of advanced treatment may be minimal and there exist various knowledge gaps around the impact of a number of chemicals (Fatta-Kassinos et al., 2011; Grassi et al., 2013).

2.5.3 Review and surveillance

Review of the WSP is essential and should be carried out periodically or following any incident, while surveillance is required to "continuously and vigilantly assess and review the safety and acceptability of water supplies" (Bartram et al., 2009; WHO, 2011). Surveillance will include monitoring potential changes to the system such as the possibility of cross-connections being introduced when non-potable networks are modified (Hambly et al., 2012; Oesterholt et al., 2007; Sinclair et al., 2010). The responsibility for such auditing will need to be clarified when stakeholders commit to a scheme. As would auditing methods, where dye testing and fluorescence analysis are suggested (Hambly et al., 2012; Storey et al., 2007).

Observable outcomes may not always be immediately apparent at an individual project level. A review of international IPR schemes by Rodriguez et al. (2009) suggests that despite variations in scheme design, no health impacts in the communities served have been observed. Sinclair et al. (2010) make a similar finding for dual reticulated neighbourhoods. Although the sensitivity of such studies has been questioned, they do provide benefits such as the confirmation that there is no substantial problem (Khan, 2013). The broader implication of this is that methods need to be considered in the framework that can assess a scheme's effectiveness against outcomes. Key knowledge gaps include developing a better understanding of the health effects of some long term exposures (particularly to low chemical concentrations) and the mixture effects of chemical (for which cell based bioassays can be employed) (Escher et al., 2014; NRMMC EPHC & AHMC, 2006).

Using surrogate indicators may be a way to assess outcomes and this can be supported by the observation of changes in institutions, operations, investment or policy (Lockhart et al., 2014; Mudaliar, 2012). Critical success factors may be employed to validate outcomes against objectives by identifying activities that support the defined goals (Keremane and McKay, 2009; Mainali et al., 2011). As with any surrogate indicator, it needs to be clear how their measurement correlates with the parameter of interest (Birks and Hills, 2007). Review is required to monitor for newly detected chemicals, changes in legislation, advancements in technological capabilities and changes in social attitudes (Muston and Halliwell, 2011; Nancarrow et al., 2009; Rodriguez et al., 2009; Salgot et al., 2001). A key challenge to a risk management framework for water reuse is to facilitate social learning and to find new ways to discuss risk and uncertainty (van Asselt and Renn, 2011).

2.6 Towards a WRSP and a risk management framework for reuse

The sections above have highlighted the potential for the WSP, and its overarching risk management framework, to be modified to more effectively address key risk considerations for water reuse. These modifications will help further develop the Water Reuse Safety Plan (WRSP) approach as an effective tool for all applications of water reuse. A WRSP is not a new proposal. What this paper proposes is how to further operationalise the WRSP based on modifications to the existing WSP, and also suggests conceptual requirements for a governing risk management framework for a WRSP.

Previous work on WRSPs illustrates the need to address both human and environmental health risks (Ashbolt, 2014; Sanz and Gawlik, 2014), however, this paper suggests a need to engage with broader dimensions of risk. Sanz and Gawlik (2014) propose WRSP modules, however, these do not include supporting programme, stakeholder engagement or communication requirements, despite evidence showing the benefits of these elements for water reuse (Godfrey et al., 2010; Hills and James, 2015). Secondly, this current proposal does not attempt to situate the WRSP within a governing framework and therefore does not facilitate an integrated approach to the understanding of acceptable risk or risk responsibilities. Finally, through emphasising a need for reliable data to undertake risk assessment, this proposal does not engage with aspects of variability and knowledge uncertainty. We suggest that interpreting aspects of uncertainty is important for water reuse risk management to aid decision making and to reduce the propagation of conservative assumptions that may result in an over estimation risk (Chen et al., 2013; Dominguez-Chicas and Scrimshaw, 2010).

One of the WSP's strengths is that it provides a structured, standardised approach that can be applied across project stages from feasibility to implementation. This is supported by the WSP manual, numerous case studies, templates and empirical evidence. The WSP benefits from adoption within the water sector for drinking water supply in a number of countries and regions. Therefore applied methodologies and organisational capabilities already exist in many water industries. This adoption is extended to a regulatory requirement in some countries, such as the UK. Conversely, other settings may have alternative preferences for risk management – or no formal approach at all. A WRSP framework could be seen as competing with other established approaches in some instances.

HACCP (from which the WSP evolved as an application specifically for the water industry) is still promoted in the water reuse literature (Salgot and Priestley, 2012; Tchobanoglous et al., 2011). This continued use of HACCP may be because it provides a generic and familiar approach to the systemic assessment of risk. HAACP can also be accredited for water supply and water reuse (Law et al., 2014). The AGWR is another risk management framework that is becoming influential beyond Australia and has been tested on recognised international schemes like Windhoek's DPR scheme (Health Canada, 2010; Law et al., 2014). We do not propose that a WRSP-based risk management framework should replace these existing approaches, but rather that it can serve as a complementary framework that could prove particularly suitable for those areas where the WSP is already widely used.

An overarching water reuse risk management framework (derived from the FSDW) could promote an integrated systems approach to risk, operationalised through the WRSP (Figure 2-4). A WRSP would build on existing WSP modules to help: 1) characterise risks and provide decision support tools to interpret uncertainty; 2) integrate and prioritise risks, risk controls and operational monitoring; 3) progress the understanding of technological performance and improve the capabilities of water professionals; and 4) support engagement and communication with regulators, stakeholders and the public. A broader systems approach to the risk management framework may help planners and practitioners anticipate potential threats and opportunities for water reuse schemes. The aim would be to facilitate decisions that address longer-term risks and costs (Muston, 2012). Inclusion of performance targets for both processes (validation of log reductions) and services (customer satisfaction) would help integrate water reuse risk analysis across multiple objectives.

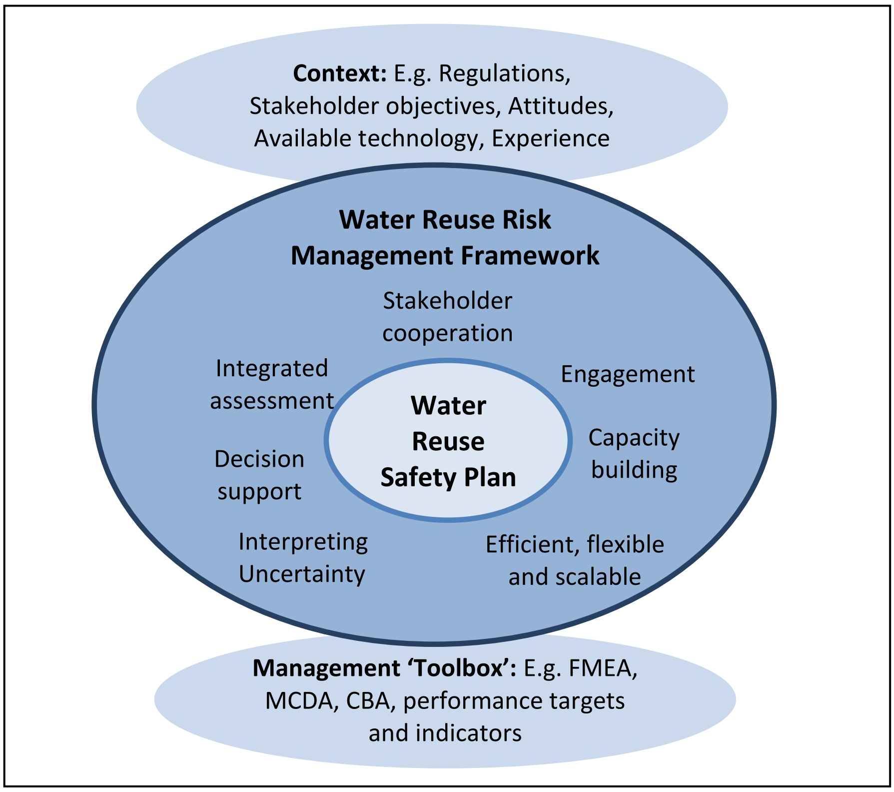


Figure 2-4 A conceptual water reuse risk management framework, operationalised through a WRSP approach

Human dimensions of water reuse risk management are diverse. This includes understanding the needs and expectations of multiple stakeholders and satisfying the concerns and needs of reclaimed water users (including the public). Human factors can trigger hazardous events through design and operational decisions. The findings of this review suggest that better understanding and integration of stakeholder and public attitudes would help to improve confidence in water reuse decisions and the overall risk management. The use of conservative margins of safety and interpretations of public perception may, in some cases, lead to over engineered systems. Thus, a more integrated approach to risk management may assist in optimising context specific scheme design and operation.

In keeping with other studies and guidelines, this review finds that guidance on developing and implementing a WRSP should include emphasis on gaining regulatory commitment (do Céu Almeida et al., 2014; Hills and James, 2015; NRMMC EPHC & AHMC, 2006). Regulatory engagement is necessary to define roles and responsibilities for managing risk. Regulatory cooperation will help achieve clarity on water reuse requirements, particularly around developing targets, operational monitoring and reporting requirements. An overarching risk management framework for reuse requires a level of flexibility in order to be able to consider a range of schemes, regional and national policies, legislation and standards. Maintaining water safety often requires inputs from multiple organisations. To address this complexity, an open audit system could be made available to all relevant agencies (Cook et al., 2009). Such an aspiration is consistent with other research that demonstrates water reuse technology should be joined with institutional arrangements that involve the public and provide more transparent governance (Marks and Zadoroznyj, 2005).

Risk assessment processes must consider the effect that different technologies can have on a system. The use of performance targets could encourage the integration of a WRSP with other business areas and could create benefits from the mobilisation of existing operational and technical experience. A current limitation to the Australian approach is a lack of consistency in the validation of technology (Law et al., 2014). A key benefit to a WRSP approach would therefore be the inclusion of indicative log reduction values to assist with multi-barrier design. This would also include standardised requirements for validating technology. Inclusion of other performance targets such as reliability, operating costs, energy consumption (per quantity supplied) and customer satisfaction would help to link system performance with other business areas and across different stakeholder objectives. Broadening the use of performance indicators could also help to facilitate the realisation of other water reuse benefits such as nutrient and energy recovery.

Water reuse also requires improved engagement and communication. Communication needs to go beyond the provision of information, and include understanding of community attitudes, and expectations (Campbell and Scott, 2011; Nancarrow et al., 2009). Attempts to understand attitudes should also extend to stakeholders and water practitioners whose perspectives on certain risks and uncertainties will vary (Baggett et al., 2006; Dobbie and Brown, 2014b). A WRSP approach can look to other risk management processes such as the AGWR and ISO 31000 to help integrate communication improvements that aim to facilitate equitable deliberation and social learning (Baggett et al., 2006; Russell and Lux, 2009). Integrating stakeholders and affected communities in the risk assessment, control and management may prove to be advantageous. This would require minor restructuring of the WSP pro forma and supporting programmes. This may bring improvements to scheme design, particularly as it is recognised that decisions are often made to mitigate perceived public perceptions (Khan, 2013). A contribution of this review is to suggest the need to integrate socio-technical considerations and human factors into the risk management framework.

The findings of this study highlight a need to consider multi-dimensional risk interactions involved with water reuse schemes. This is particularly the case for non-potable and indirect reuse where a range of risk pathways and receptors becomes possible. DPR scheme management may in fact be somewhat simpler without the need to consider intermediate environmental risks, for example. Whilst the challenges of risk interactions are not unique to water reuse, any WRSP guidance would benefit from drawing on research and developments in these areas. Aspects to consider might include hazard interactions, triggers, and cascades of hazardous events with multiple primary and secondary consequences. Although the safety plan may benefit from restricting the scope of operational risk management (particularly to human health and environmental impacts), the overarching risk management framework should consider a broader systems approach (to integrate commercial and regulatory risks, for example). This in turn reflects on the requirements for integrating risk controls and operational monitoring. This integrated approach to risk should also address best practice advice on interpreting uncertainty to enable decision making.

Integrating decision support tools such as cost-benefit analysis, MCDA and FMEA into the WRSP approach would prove advantageous. This is to assist with risk prioritisation and optimisation at various stages of the process. Project feasibility can include identifying the scope of risk assessment required. Simplified assessments are recommended for domestic scale, low risk schemes and detailed assessments for more complex schemes (NRMMC EPHC & AHMC, 2009; Power, 2010a). The scope of the targets and risks will depend on the nature and complexity of the catchment to tap system. As a result, the overarching risk management framework needs to facilitate flexibility in its scope and application with an aspiration that the WRSP risk management process can improve efficiency and outcomes. Current risk management processes are demonstrated to be flexible. This is shown in the literature with HACCP, the WSP and the AGWR all being adapted and modified to meet the particular needs of both decision makers and end users.

The FSDW incorporates the WSP and is a risk management framework designed for drinking water supplies. Although the WSP may in some respects be suitable to operationalise aspects of water reuse risk management, the requirements for a governing framework are less clear. While we have proposed the development of a standalone risk management framework for water reuse, it is important not to overlook the AGWR and the WCSP as existing risk management frameworks capable of fulfilling this role. The AGWR are applicable to a range of water reuse configurations and for this reason they are seen as a significant risk management framework with potential for international implementation (Apostolidis et al., 2011; Law et al., 2014; Nandha et al., 2014; Sanz and Gawlik, 2014). However, the AGWR are tailored to the Australian regulatory system, and may therefore present a less coherent approach in other international settings. This is particularly the case for scheme approval and operational management where jurisdictions in Australia have alternative documentation and risk management requirements (Power, 2010a; SEQWater, 2013). Whilst experience from Australia provides valuable insight for water reuse risk management learnings, the loss of the 'safety plan' identity may not leverage the necessary organisational and stakeholder buy-in in some international contexts. The AGWR are also limited in their consideration of broader system risk interactions.

Specific requirements for water reuse schemes currently fall between existing WHO guidelines on drinking water and wastewater management. A WRSP approach would complement and extend the SSP and provide a stand-alone risk management process for all variants of non-potable water reuse. Such an approach could also be applied to potable reuse, either as a standalone process for a particular scheme (from catchment to tap) or as a complement to existing drinking WSPs, where they are presently adopted. A more integrated approach to assessing potable and non-potable water supplies is particularly required for schemes involving dual-reticulation, where some aspects of risk assessments may be duplicated for each distribution network – particularly around matters of cross contamination. Similarly, for indirect potable reuse (IPR) schemes, there may be overlaps in how catchment risks are considered where a WRSP supplements existing drinking water risk management processes. Careful integration between the two processes would help avert unnecessary duplication.

The Water Cycle Safety Plan (WCSP) approach may account for these overlaps by including all aspects of an urban water cycle. However the WCSP concept does not currently account for many of the key risk considerations for water reuse. Future work should examine the potential for harmonising the WCSP approach with the WRSP approach to better facilitate water reuse within the urban water cycle. Further work will also be needed to ensure harmonisation of WRSPs with existing WSPs or alternative risk management processes currently used for potable reuse.

2.7 Conclusions

This paper has highlighted a number of key risk considerations for further developing the WRSP approach. Proposed modifications to the existing WSP approach and its overarching risk management framework, in order to adapt them for water reuse, include aspects such as supporting communication and engagement with the public, stakeholders and governing bodies, and improving decision support mechanisms to better account for uncertainty, risk interactions and risk prioritisation. These aspects are not unique to water reuse, but require a greater degree of attention than what is currently afforded in existing WSP guidance. Other modifications of the WSP (such as the WCSP), as well as the AGWR, are currently limited in their ability to address all applications of water reuse across multiple contexts. However, they do provide valuable insights which can inform the further development of the WRSP approach.

As with the WSP, a WRSP approach should be encompassed within a broader risk management framework. This will help establish risk management principles and ensure objectives are suitable for the context. Like the WHO's Framework for Safe Drinking Water, the risk management framework for reuse would guide scheme managers in setting targets and routinely assessing management performance. The AGWR, the WCSP approach and ISO 31000 are important references for broader framework requirements. For water reuse, important risk considerations extend beyond public health outcomes, and an overarching risk management framework must therefore reflect and facilitate broader contexts and objectives for water reuse schemes. The findings of this study highlight that a more integrated systems approach to risk management for water reuse, encapsulated within a risk management framework and operationalised through the WRSP, would help scheme managers to better anticipate potential risks and opportunities.

2.8 Acknowledgements

This research was co-funded by the UK's Engineering and Physical Science Research Council (EPSRC) and Thames Water through the STREAM Industrial Doctorate Centre. The authors are also grateful for the advice and input provided by Dr George Prpich of Cranfield University.

2.9 References

Alves, S., Tilghman, J., Rosenbaum, A., Payne-Sturges, D.C., 2012. U.S. EPA authority to use cumulative risk assessments in environmental decision-making. Int. J. Environ. Res. Public Health 9, 1997–2019. doi:10.3390/ijerph9061997

Anderson, J., Adin, A., Crook, J., Davis, C., Hultquist, R., Jimenez-Cisneros, B., Kennedy, W., Sheikh, B., Van Der Merwe, B., 2001. Climbing the ladder: A step by step approach to international guidelines for water recycling. Water Sci. Technol. 43, 1–8.

Apostolidis, N., Hertle, C., Young, R., 2011. Water Recycling in Australia. Water 3, 869–881. doi:10.3390/w3030869

Ashbolt, N., 2014a. Matching Water Quality to Reuse : A systems approach to manage public health, in: Alberta Water Council Symposium. Calgary, pp. 1–17.

Ashbolt, N., 2014b. Developing Safe Sustainable Water Reuse Application in Alberta: Rationale and Framework, in: Alberta Land Insitute - Water Reuse Workshop.

Baban, A., Goktas, O.C., Hocaoglu, S.M., Atasoy, E., Akalın, N.G., 2011. Demonstration in Istanbul- conceptual scheme for rainwater harvesting and grey water management. Istanbul.

Baggett, S., Jeffrey, P., Jefferson, B., 2006. Risk perception in participatory planning for water reuse. Desalination 187, 149–158. doi:10.1016/j.desal.2005.04.075

Bartram, J., Corrales, L., Davison, A., Deere, D., Drury, D., Gordon, B., Howard, G., Rinehold, A., Stevens, M., 2009. Water Safety Plan Manual: Step by Step risk management for drinking-water supplies. Geneva.

Bartram, J., Fewtrell, L., Stenström, T., 2001. Harmonised assessment of risk and risk management for water-related infectious disease : an overview. Geneva.

Bartrand, T., Rosen, J., Mieog, J., Hargy, T., 2013. Characterizing Influent Water Quality for a Water Reuse Operation, in: Water Quality Technology Conference and Exposition 2013.

Bichai, F., Smeets, P.W.M.H., 2013. Using QMRA-based regulation as a water quality management tool in the water security challenge: experience from the Netherlands and Australia. Water Res. 47, 7315–26. doi:10.1016/j.watres.2013.09.062

Birks, R., Hills, S., 2007. Characterisation of indicator organisms and pathogens in domestic greywater for recycling. Environ. Monit. Assess. 129, 61–9. doi:10.1007/s10661-006-9427-y

Bixio, D., Van Houtte, E., Thoeye, C., Van De Steene, B., Verbauwhede, J., Wintgens, T., Melin, T., 2008. Water Safety Plan of an Artificial Groundwater Recharge Site with Reclaimed Water for Drinking Water Production. 6th IWA WWC, 06–12 September 2008, Vienna, Austria.

BSI, 2013. Rainwater harvesting systems - Code of practice. BS 8515:2009+A1:2013. British Standards Institute, London, UK.

BSI, 2011. Greywater systems – Part 2: Domestic greywater treatment equipment – Requirements and test methods. BS 8525-2:2011. British Standards Institute, London, UK.

CAC, 2009. Food Hygiene - basic texts, 4th ed, Food and Agriculture Organization of the United Codex Alimentarius Commission. Joint FAO/WHO Food Standards Programme, Rome.

Campbell, A.C., Scott, C. a., 2011. Water reuse: policy implications of a decade of residential reclaimed water use in Tucson, Arizona. Water Int. 36, 908–923. doi:10.1080/02508060.2011.621588

Chang, E.E., Guo, H.C., Li, I.S., Chiang, P.C., Huang, C.P., 2010. Modeling the formation and assessing the risk of disinfection by-products in water distribution systems. J. Environ. Sci. Heal. - Part A Toxic/Hazardous Subst. Environ. Eng. 45, 1185–1194.

Chen, Z., Ngo, H.H., Guo, W., 2013. Risk Control in Recycled Water Schemes. Crit. Rev. Environ. Sci. Technol. 43, 2439–2510. doi:10.1080/10643389.2012.672085

Chen, Z., Ngo, H.H., Guo, W., 2012. A critical review on sustainability assessment of recycled water schemes. Sci. Total Environ. 426, 13–31. doi:10.1016/j.scitotenv.2012.03.055

Cook, A., Devine, B., Rodriguez, C., Roser, D., Khan, S., McGuinness, N., Ashbolt, N., Weinstein, P., 2009. Assessing the public health impacts of recycled water use. Interim report 1. Perth.

Cunliffe, D., Bartram, J., Briand, E., Chartier, Y., Colbourne, J., Drury, D., Lee, J., 2011. Water safety in buildings. Geneva.

Davison, A., Howard, G., Stevens, M., Callan, P., Fewtrell, L., Deere, D., Bartram, J., 2005. Water Safety Plans. World Health Organisation, Geneva.

Debroux, J., Soller, J.A., Plumlee, M.H., Kennedy, L.J., 2012. Human Health Risk Assessment of Non- Regulated Xenobiotics in Recycled Water : A Review. Hum. Ecol. Risk Assess. An Int. J. 18, 37–41. doi:10.1080/10807039.2012.672883

Derry, C., 2011. Considerations in establishing a health risk management system for effluent irrigation in modern agriculture. Isr. J. Plant Sci. 59, 125–137.

Derry, C., Attwater, R., Booth, S., 2006. Rapid health-risk assessment of effluent irrigation on an Australian university campus. Int. J. Hyg. Environ. Health 209, 159–71. doi:10.1016/j.ijheh.2005.09.004

Dewettinck, T., Van Houtte, E., Geenens, D., Van Hege, K., Verstraete, W., 2001. HACCP (Hazard Analysis and Critical Control Points) to guarantee safe water reuse and drinking water production - A case study. Water Sci. Technol. 43, 31–38.

do Céu Almeida, M., Vieira, P., Smeets, P., 2014. Extending the water safety plan concept to the urban water cycle. Water Policy 16, 298–322. doi:10.2166/wp.2013.137

do Céu Almeida, M., Vieira, P., Smeets, P., 2013. Water Cycle Safety Plan Framework. Final.

Dobbie, M.F., Brown, R.R., 2014. Transition to a water-cycle city: sociodemographic influences on Australian urban water practitioners' risk perceptions towards alternative water systems. Urban Water J. 11, 37–41. doi:10.1080/1573062X.2013.794846

Domènech, L., Saurí, D., 2010. Socio-technical transitions in water scarcity contexts: Public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. Resour. Conserv. Recycl. 55, 53–62. doi:10.1016/j.resconrec.2010.07.001

Dominguez-Chicas, A., Scrimshaw, M.D., 2010. Hazard and risk assessment for indirect potable reuse schemes: An approach for use in developing Water Safety Plans. Water Res. 44, 6115–23. doi:10.1016/j.watres.2010.07.007

Doria, M.D.F., 2010. Factors influencing public perception of drinking water quality. Water Policy 12, 1–19.

Edgar, C., Smith, J., Webster, J., Pollard, S., 2010. An international review of the challenges associated with securing " buy-in " for water safety plans within providers of drinking water supplies. J. Water Health 8, 387–398.

Escher, B.I., Allinson, M., Altenburger, R., Bain, P. a., Balaguer, P., Busch, W., Crago, J., Denslow, N.D., Dopp, E., Hilscherova, K., Humpage, A.R., Kumar, A., Grimaldi, M., Jayasinghe, B.S., Jarosova, B., Jia, A., Makarov, S., Maruya, K. a., Medvedev, A., Mehinto, A.C., Mendez, J.E., Poulsen, A., Prochazka, E., Richard, J., Schifferli, A., Schlenk, D., Scholz, S., Shiraishi, F., Snyder, S., Su, G., Tang, J.Y.M., Burg, B. Van Der, Linden, S.C. Van Der, Werner, I., Westerheide, S.D., Wong, C.K.C., Yang, M., Yeung, B.H.Y., Zhang, X., Leusch, F.D.L., 2014. Benchmarking organic micropollutants in wastewater, recycled water and drinking water with in vitro bioassays. Environ. Sci. Technol. 48, 1940–1956. doi:10.1021/es403899t

Fairbairn, I., 2006. Operation of an STP for Recycled Water Production, in: 69th Annual Water Industry Engineers and Operators' Conference. Bendigo, pp. 66–72.

Fatta-Kassinos, D., Kalavrouziotis, I.K., Koukoulakis, P.H., Vasquez, M.I., 2011. The risks associated with wastewater reuse and xenobiotics in the agroecological environment. Sci. Total Environ. 409, 3555–3563. doi:10.1016/j.scitotenv.2010.03.036

Fawell, J., Fewtrell, L., Hydes, O., Watkins, J., Wyn-Jones, P., 2005. Framework for Developing Water Reuse Criteria with Reference to Drinking Water Supplies 05/WR/29/1.

Gelting, R.J., Baloch, M. a., Zarate-Bermudez, M., Hajmeer, M.N., Yee, J.C., Brown, T., Yee, B.J., 2015. A systems analysis of irrigation water quality in an environmental assessment of an E. coli O157:H7 outbreak in the United States linked to iceberg lettuce. Agric. Water Manag. 150, 111–118. doi:10.1016/j.agwat.2014.12.002

Godfrey, S., Kumar, P., Swami, A., Wate, S.R., Dwivedi, H.B., 2005. Water Safety Plans for Rainwater and Greywater Reuse. XII International Rainwater Catchment Systems Conference.

Godfrey, S., Labhasetwar, P., Swami, A., Wate, S.R., Parihar, G., Dwivedi, H.B., 2007. Water safety plans for greywater in tribal schools, India. Waterlines 25, 8–10. doi:10.3362/0262-8104.2007.003

Godfrey, S., Singh, S., Labhasetwar, P., Dwivedi, H.B., Parihar, G., Wate, S.R., 2010. Health-based targets for greywater reuse in residential schools in Madhya Pradesh, India. Water Environ. J. 24, 215–222. doi:10.1111/j.1747-6593.2009.00180.x

Grassi, M., Rizzo, L., Farina, A., 2013. Endocrine disruptors compounds , pharmaceuticals and personal care products in urban wastewater : implications for agricultural reuse and their removal by adsorption process. Environ. Sci. Pollut. Reserach 20, 3616–3628. doi:10.1007/s11356-013-1636-7

Halliwell, D., 2014. Utilization of Hazard Analysis and Critical Control Points Approach for Evaluating Integrity of Treatment Barriers for Reuse. WRRF-09-03 PRoject Synopsis. WateReuse Research Foundation.

Hambly, a. C., Henderson, R.K., Baker, a., Stuetz, R.M., Khan, S.J., 2012. Cross-connection detection in Australian dual reticulation systems by monitoring inherent fluorescent organic matter. Environ. Technol. Rev. 1, 67–80. doi:10.1080/09593330.2012.696724

Hamilton, A.J., Boland, A.M., Stevens, D., Kelly, J., Radcliffe, J., Ziehrl, A., Dillon, P., Paulin, B., 2005. Position of the Australian horticultural industry with respect to the use of reclaimed water. Agric. Water Manag. 71, 181–209. doi:10.1016/j.agwat.2004.11.001

Hamilton, P.D., Gale, P., Pollard, S.J.T., 2006. A commentary on recent water safety initiatives in the context of water utility risk management. Environ. Int. 32, 958–66. doi:10.1016/j.envint.2006.06.001

Hass, C.N., Trussel, R.R., 1998. Framework for Assessing Reliability of Multiple Independent Barriers in Potable Water Reuse. Water Sci. Technol. 38, 1–8.

Hatt, J.W., Lamy, C., Germain, E., Tupper, M., Judd, S.J., 2013. NDMA formation in secondary wastewater effluent. Chemosphere 91, 83–7. doi:10.1016/j.chemosphere.2012.11.003

Health Canada, 2010. Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing. Ministry of Health, Ottawa.

Hills, S., 2013. Applying a Water Safety Plan Approach for Reclaimed Water Use at the 2012 Olympic Park in London, in: IWA Reuse Conference Namibia.

Hills, S., James, C., 2015. The Queen Elizabeth Olympic Park Water Recycling System, London, in: Alternative Water Supply Systems.

Hochstrat, R., Wintgens, T., Kazner, C., Jeffrey, P., Jefferson, B., Melin, T., 2010. Managed aquifer recharge with reclaimed water: approaches to a European guidance framework. Water Sci. Technol. 62, 1265–1273.

Hrudey, S.E., Conant, B., Douglas, I.P., Fawell, J., Gillespie, T., Hill, D., Leiss, W., Rose, J.B., Sinclair, M., 2011. Managing uncertainty in the provision of safe drinking water. Water Sci. Technol. Water Supply 11, 675–681. doi:10.2166/ws.2011.075

Hunter, P.R., Fewtrell, L., 2001. Acceptable risk, in: Bartram, J., Fewtrell, L. (Eds.), Water Quality: Guidelines, Standards and Health. Geneva.

Hurlimann, A., 2007. Recycled Water Risk Perception - A Comparison of Two Case Studies, in: 4th IWA Specialist Conference on Efficient Use and Management of Urban Water Supply. International Water Association and the Korean Society of Water and Wastewater, pp. 181–193. doi:10.2166/WPT.2007068

Hurlimann, A., Dolnicar, S., 2010. When public opposition defeats alternative water projects - The case of Toowoomba Australia. Water Res. 44, 287–297. doi:10.1016/j.watres.2009.09.020

Hurlimann, A., Hes, D., Othman, M., Grant, T., 2007. Charting a new course for water - is black water reuse sustainable? Water Sci. Technol. Water Supply 7, 109–118. doi:10.2166/ws.2007.107

Huxedurp, L.M., Pálsdóttir, G.Þ., Altavilla, N., 2014. Risk-based planning for water recycling in an Australian context. Water Sci. Technol. Water Supply 14, 971. doi:10.2166/ws.2014.058

Hwang, H., Lansey, K., Quintanar, D.R., 2015. Resilience-based failure mode effects and criticality analysis for regional water supply system. J. Hydroinformatics 17, 193. doi:10.2166/hydro.2014.111

ILSI, 2013. Water Recovery and Reuse: Guideline for Safe Application of Water Conservation Methods in Beverage Production and Food Processing. Washington D.C.

Institute for Sustainable Futures, 2013a. Navigating the institutional maze; Building Industry Capability to Make Recycled Water Investment Decisions.

Institute for Sustainable Futures, 2013b. Matching risk to treatment; Building Industry Capability to Make Recycled Water Investment Decisions. Prepared by the Institute for Sustainable Futures, University of Technology, Sydney for the Australian.

Janbakhsh, A., 2012. Landford Recycling Scheme - Case Study in Appendix E of US EPA 2012 Guidelines for Water Reuse, in: Guidelines for Water Reuse. pp. E114-115.

Jeffrey, P., Ryan, S., Smith, H., 2014. Establishing a Robust Case for Final Effluent Reuse. Report 14/WR/29/3.

Keremane, G.B., McKay, J., 2009. Critical Success Factors (CSFs) for private sector involvement in wastewater management: the Willunga Pipeline case study. Desalination 244, 248–260. doi:10.1016/j.desal.2008.06.006

Khan, S., 2013. Drinking Water Through Recycling - The benefits and costs of supplying direct to the distribution system. Melbourne, Australia.

Khan, S., Roser, D., 2007. Risk Assessment and Health Effects Studies of Indirect Potable Reuse. Sydney, NSW.

Kot, M., Castleden, H., Gagnon, G.A., 2014. The human dimension of water safety plans : a critical review of literature and information gaps. Environ. Rev. 23, 24–29. doi:10.1139/er-2014-0030

Law, I.B., Menge, J., Cunliffe, D., 2014. Validation of the Goreangab Reclamation Plant in Windhoek, Namibia against the 2008 Australian guidelines for water recycling. J. Water Reuse Desalin. 1–8. doi:10.2166/wrd.2014.138

Lindhe, A., Rosen, L., Norberg, T., Bergstedt, O., 2009. Fault tree analysis for integrated and probabilistic risk analysis of drinking water systems. Water Res. 43, 1641–1653. doi:10.1016/j.watres.2008.12.034

Lindhe, A., Rosen, L., Norberg, T., Røstum, J., Pettersson, T.J.R., 2013. Uncertainty modelling in multi-criteria analysis of water safety measures. Environ. Syst. Decis. 33, 195–208. doi:10.1007/s10669-013-9442-9

Listowski, A., 2009. Recycled Water at Sydney Olympic Park, in: Reuse of Various Waste Waters for HVAC&R Systems in Buildings. 17 February 2009. Australian Institute of Refrigeration, Airconditioning and Heating, Sydney, NSW.

Lockhart, G., Oswald, W.E., Hubbard, B., Medlin, E., Gelting, R.J., 2014. Development of indicators for measuring outcomes of water safety plans. J. Water, Sanit. Hyg. Dev. 4, 171. doi:10.2166/washdev.2013.159

MacGillivray, B.., Hamilton, P.., Strutt, J.., Pollard, S.J.., 2006. Risk analysis strategies in the water utility sector: An inventory of applications for better and more credible decision making. Crit. Rev. Environ. Sci. Technol. 36, 85–139.

Mainali, B., Ngo, H.H., Guo, W.S., Pham, T.T.N., Wang, X.C., Johnston, A., 2011. SWOT analysis to assist identification of the critical factors for the successful implementation of water reuse schemes. Desalin. Water Treat. 32, 297–306. doi:10.5004/dwt.2011.2714

Marks, J., Zadoroznyj, M., 2005. Managing Sustainable Urban Water Reuse: Structural Context and Cultures of Trust. Soc. Nat. Resour. An Int. J. 18, 37–41. doi:10.1080/08941920590947995

McIlwaine, S., Redwood, M., 2010. The use of greywater for irrigation of home gardens in the Middle East: Technical, social and policy issues. Waterlines 29, 90–107. doi:10.3362/1756-3488.2010.011

Meehan, K., Ormerod, K.J., Moore, S.A., 2013. Remaking Waste as Water : The Governance of Recycled Effluent for Potable Water Supply. Water Altern. 6, 67–85.

Möderl, M., Sitzenfrei, R., Lammel, J., Apperl, M., Kleidorfer, M., Rauch, W., Mo, M., 2015. Development of an urban drainage safety plan concept based on spatial risk assessment. Struct. Infrastruct. Eng. Maint. , Manag. , Life-Cycle Des. Perform. 37–41. doi:10.1080/15732479.2014.921717

Mok, H., Barker, S.F., Hamilton, A.J., 2014. A probabilistic quantitative microbial risk assessment model of norovirus disease burden from wastewater irrigation of vegetables in Shepparton Australia. Water Res. 54, 347–362. doi:10.1016/j.watres.2014.01.060

Mudaliar, M.M., 2012. Success or failure : demonstrating the effectiveness of a water safety Plan. Water Sci. Technol. Water Supply 12, 109–116. doi:10.2166/WS.2011.106

Muston, M., Halliwell, D., 2011. NatVal: Road Map Report The road map to a national validation framework for water recycling schemes. Water Quality Research Australia.

Muston, M.H., 2012. Changing of the water recycling paradigm in Australia. Water Sci. Technol. 12, 611–619.

Muston, M.H., Wille, A., 2006. Operator experience with recycling in Australia. Desalination 188, 43–50.

Nancarrow, B.E., Leviston, Z., Tucker, D.I., 2009. Measuring the predictors of communities ' behavioural decisions for potable reuse of wastewater. Water Sci. Technol. 60, 3199–3210. doi:10.2166/wst.2009.759

Nandha, M., Berry, M., Jefferson, B., Jeffrey, P., 2014. Risk assessment frameworks for MAR schemes in the UK. Environ. Earth Sci. doi:10.1007/s12665-014-3399-y

NHMRC & NRMMC, 2009. Health-Based Targets for Microbial Safety of Drinking Water Supplies – Draft Discussion Paper. Commonwealth of Australia, Canberra.

NRC, 2012. Water Reuse : Potential for Expanding the Nation â€TM s Water Supply Through Reuse of Municipal Wastewater. National Academy Press, Washington D.C.

NRMMC EPHC & AHMC, 2009. Australian Guidelines for Water Recycling Managed Aquifer Recharge. Natural Resource Ministerial Management Council, Environment Protection and Heritage Council and Australian Health Ministers.

NRMMC EPHC & AHMC, 2006. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1). Natural Resource Ministerial Management Council, Environment Protection and Heritage Council and Australian Health Ministers.

NRMMC EPHC & NHMRC, 2008. Australian guidelines for water recycling : Managing health and environmental risks (phase 2). Augmentation of Drinking Water Supplies. Canberra.

Oesterholt, F., Medema, G., van der Kooij, D., Martijnse, G., 2007. Health risk assessment of non-potable domestic water supplies in the Netherlands. J. Water Supply Res. Technol. 56, 171. doi:10.2166/aqua.2007.043

Ormerod, K.J., Scott, C.A., 2012. Drinking Wastewater : Public Trust in Potable Reuse. Sci. Technol. Human Values 1–23. doi:10.1177/0162243912444736

Page, D., Barry, K., Pavelic, P., Dillon, P., 2008. Preliminary quantitative risk assessment for the Salisbury stormwater ASTR Project.

Perrier, E., Kot, M., Castleden, H., Gagnon, G.A., 2014. Drinking water safety plans : barriers and bridges for small systems in Alberta , Canada. Water Policy 16, 1140–1154. doi:10.2166/wp.2014.207

Pickering, P., 2013. Economic viability of recycled water schemes. Australian Centre for Water Recycling Excellence, Brisbane.

Pisarenko, A.N., Marti, E., Gerrity, D., Peller, J., Dickenson, E.R. V., 2013. Formation of nitrosamines and perfluoroalkyl acids during ozonation of reclaimed waters: Implications for potable reuse, in: 2013 Water Quality Technology Conference and Exposition.

Power, K., 2010a. The adoption of the Australian Water Recycling Guidelines by regulators with specific reference to treatment validation requirements. Water Sci. Technol. 62, 1735–44.

Power, K., 2010b. Recycled water use in Australia : regulations , guidelines and validation requirements for a national approach, Waterlines. ed. National Water Commission, Canberra.

Price, J., Fielding, K.S., Leviston, Z., 2012. Supporters and Opponents of Potable Recycled Water : Culture and Cognition in the Toowoomba Referendum. Soc. Nat. Resour. 25, 980–995. doi:10.1080/08941920.2012.656185

Rapala, J., 2014. Risk Based Approach in Finland : WSP , SSP and BWSP Driving Forces for the National Risk Based Approach. Ministry of Social Affairs and Health.

Rayne, S., Forest, K., 2009. Perfluoroalkyl sulfonic and carboxylic acids: A critical review of physicochemical properties, levels and patterns in waters and wastewaters, and treatment methods. J. Environ. Sci. Heal. - Part A Toxic/Hazardous Subst. Environ. Eng. 44, 1145–1199.

Rodríguez, C., Taylor, P., Devine, B., Van Buynder, P., Weinstein, P., Cook, A., 2012. Assessing Health Risks from Pesticides in Recycled Water: A Case Study of Augmentation of Drinking Water Supplies in Perth, Western Australia. Hum. Ecol. Risk Assess. An Int. J. 18, 1216–1236. doi:10.1080/10807039.2012.725365

Rodriguez, C., Van Buynder, P., Lugg, R., Blair, P., Devine, B., Cook, A., Weinstein, P., 2009. Indirect Potable Reuse: A Sustainable Water Supply Alternative. Int. J. Environ. Res. Public Health 6, 1174–209. doi:10.3390/ijerph6031174

Rosén, L., Lindhe, a., Bergstedt, O., Norberg, T., Pettersson, T.J.R., 2010. Comparing risk-reduction measures to reach water safety targets using an integrated fault tree model. Water Sci. Technol. Water Supply 10, 428. doi:10.2166/ws.2010.089

Rosén, L.P., Hokstad, P., Lindhe, A., Sklet, S., Røstum, J., 2007. Generic Framework and Methods for Integrated Risk Management in Water Safety Plans. Techneau 2007.

Roux, A., Pirrone, M., Bowen, B., Walker, T., 2008. Water quality monitoring and risk management. Water 35, 75–78.

Russell, S., Lux, C., 2009. Getting over yuck: moving from psychological to cultural and sociotechnical analyses of responses to water recycling. Water Policy 11, 21–35.

Ryu, H., Alum, a., Mena, K.D., Abbaszadegan, M., 2007. Assessment of the risk of infection by Cryptosporidium and Giardia in non-potable reclaimed water. Water Sci. Technol. 55, 283. doi:10.2166/wst.2007.047

Salgot, M., Campos, C., Galofré, B., Tapias, J.C., 2001. Biological control tools for wastewater reclamation and reuse. A critical review. Water Sci. Technol. 43, 195–201.

Salgot, M., Huertas, E., Weber, S., Dott, W., Hollender, J., 2006. Wastewater reuse and risk: definition of key objectives. Desalination 187, 29–40. doi:10.1016/j.desal.2005.04.065

Salgot, M., Priestley, G.K., 2012. Golf Course Irrigation with Reclaimed Water in the Mediterranean: A Risk Management Matter. Water 4, 389–429. doi:10.3390/w4020389

Sanz, L.A., Gawlik, B.M., 2014. Water Reuse in Europe - Relevant guidelines , needs for and barriers to innovation (DRAFT). Joint Research Centre, Brussels.

Schäfer, A.I., Beder, S., 2006. Role of the precautionary principle in water recycling. Desalination 187, 241–252.

SEQWater, 2013. Annual Report 2012-13 For the Western Corridor Recycled Water Scheme - Recycled Water Management Plan. Brisbane.

Sinclair, M., O'Toole, J., Forbes, A., Carr, D., Leder, K., 2010. Health status of residents of an urban dual reticulation system. Int. J. Epidemiol. 39, 1667–75. doi:10.1093/ije/dyq152

Smeets, P.W.M.H., Rietveld, L.C., Dijk, J.C. Van, Medema, G.J., 2010. Practical applications of quantitative microbial risk assessment (QMRA) for water safety plans. Water Sci. Technol. 61, 1561–1568. doi:10.2166/wst.2010.839

Stenekes, N., Colebatch, H.K., Waite, D., Ashbolt, N.J., 2006. Risk and Governance in Water Recycling: Public Acceptance Revisited. Sci. Technol. Human Values 31, 107–134. doi:10.1177/0162243905283636

Storey, M. V, Deere, D., Davison, A., Tam, T., Lovell, A.J., 2007. Risk Management and Cross-Connection Detection of a Dual Reticulation System, in: S.J. Khan,R.M. Stuetz, andJ.M. Anderson, eds. (Ed.), 3rd Australian Water Association Water Reuse and Recycling Conference (REUSE07). UNSW Publishing and Printing Services, Sydney, pp. 115–123.

Summerill, C., Pollard, S.J.T., Smith, J. a, 2010a. The role of organizational culture and leadership in water safety plan implementation for improved risk management. Sci. Total Environ. 408, 4319–27. doi:10.1016/j.scitotenv.2010.06.043

Summerill, C., Smith, J., Webster, J., Pollard, S., 2010b. An international review of the challenges associated with securing " buy-in " for water safety plans within providers of drinking water supplies. J. Water Health 8, 387–398. doi:10.2166/wh.2010.047

Suter, G.W., Vermeire, T., Munns, W.R., Sekizawa, J., 2005. An integrated framework for health and ecological risk assessment. Toxicol. Appl. Pharmacol. 207, 611–6. doi:10.1016/j.taap.2005.01.051

Swartz, C.D., 2010. Windhoek, a demonstration of a multi-barrier approach to the reclamation and treatment of wastewater to produce drinking water.

Swierc, J., Page, D., Leeuwen, J. Van, 2005. Preliminary Hazard Analysis and Critical Control Points Plan (HACCP) - Salisbury Stormwater to Drinking Water Aquifer Storage Transfer and Recovery (ASTR) Project of Montana.

Tchobanoglous, G., Leverenz, H., Nellor, M.H., Crook., J., 2011. Direct Potable Reuse: A Path Forward. WateReuse Research Foundation and WateReuse, California, Alexandria, Virginia.

Thoeye, C., Van Eyck, K., Bixio, D., Weemaes, M., De Gueldre, G., 2003. Chapter 4: Methods used for health risk assessment, in: Aertgeerts, R., Angelakis, A. (Eds.), State of the Art Report Health Risks in Aquifer Recharge Using Reclaimed Water. World Health Organisation, Geneva, pp. 123–152.

Thompson, M., 2005. Port Macquarie's Urban Reclaimed Water Supply Scheme, in: IPWEA NSW Division Annual Conference 2005.

Urkiaga, A., de las Fuentes, L., Bis, B., Chiru, E., Balasz, B., Hernández, F., 2008. Development of analysis tools for social, economic and ecological effects of water reuse. Desalination 218, 81–91. doi:10.1016/j.desal.2006.08.023

USEPA, 2013. Energy Efficiency in Water and Wastewater Facilities. United States Environmental Protection Agency.

USEPA, 2012. Guidelines for Water Reuse. United States Environmental Protection Agency.

van Asselt, M., Renn, O., 2011. Risk Governance. J. Risk Res. 14, 431–449. doi:10.1080/13669877.2011.553730

Van den Akker, B., Trinh, T., Coleman, H.M., Stuetz, R.M., Le-Clech, P., Khan, S.J., 2014. Validation of a full-scale membrane bioreactor and the impact of membrane cleaning on the removal of microbial indicators. Bioresour. Technol. 155, 437.

van der Hoek, J.P., Bertelkamp, C., Verliefde, a. R.D., Singhal, N., 2014. Drinking water treatment technologies in Europe: state of the art – challenges – research needs. J. Water Supply Res. Technol. 63, 124. doi:10.2166/aqua.2013.007

Viljoen, F.C., 2010. The World Health Organization's water safety plan is much more than just an integrated drinking water quality management plan. Water Sci. Technol. 61, 173–9. doi:10.2166/wst.2010.792

Weber, S., Khan, S., Hollender, J., 2006. Human risk assessment of organic contaminants in reclaimed wastewater used for irrigation. Desalination 187, 53–64. doi:10.1016/j.desal.2005.04.067

WECF, 2014. Developing a Water & Sanitation Safety Plan in a Rural Community. How to accomplish a water and sanitation safety plan? Munich.

Weemaes, M., 2011. Indirect potable reuse in Europe : R & D initiatives needed for a safe operation & maintenance ., in: IWA Reuse Conference Barcelona 2011.

WHO, 2015. Sanitation Safety Plan Manual. World Health Organisation, Geneva.

WHO, 2011. Guidelines for drinking-water quality, WHO chronicle. World Health Organisation, Geneva.

WHO, 2006. Guidelines for the Safe Use of Wastewater, Excreta and Greywater. World Health Organisation, Geneva.

Wintgens, T., Hochstrat, R., 2006. Integrated Concepts for Reuse of Upgraded Wastewater. WP3 D19.

Woo, D.M., Vicente, K.J., 2003. Sociotechnical systems , risk management , and public health : comparing the North Battleford and Walkerton outbreaks. Reliab. Eng. Syst. Saf. 80, 253–269. doi:10.1016/S0951-8320(03)00052-8

Wu, Z., McKay, J., Keremane, G., 2012. Issues Affecting Community Attitudes and Intended Behaviours in Stormwater Reuse: A Case Study of Salisbury, South Australia. Water 4, 835–847. doi:10.3390/w4040835

Ying, G.-G., Kookana, R., Waite, T.., 2004. Endocrine Disrupting Chemicals (EDCs) and Pharmaceuticals and Personal Care Products (PPCPs) in Reclaimed Water in Australia, Water. Adelaide.

Chapter 3. Collaboration on risk management: the governance of a non-potable water scheme in London

D. Goodwin[1], M. Raffin[2], P. Jeffrey[1], H. M. Smith[1]

[1]Cranfield Water Science Institute, Cranfield University, Bedfordshire, UK, MK43 0AL

[2]Thames Water Utilities Ltd, Innovation, Reading STW, Island Road, Reading, UK RG2 0RP

Abstract

Ageing water infrastructure and population growth, issues that are characteristic of megacities, are likely to exacerbate water supply deficits in London. To address this threat, wastewater reclamation and non-potable reuse can potentially close the supply-demand gap without impacting on environmental water bodies. There is a need to understand the types of challenges that diverse stakeholders face in relation to the governance of NPR schemes, and how those challenges might be addressed in a megacity context. A case study is used to explore these challenges for an operational sewer mining scheme in London, where reclaimed non-potable water is used for irrigation and toilet flushing at the site of the London 2012 Olympic Park. The results highlight that collaboration and learning opportunities are perceived as necessary to improve scheme governance. The findings indicate that formal and informal engagement activities centred on risk management can support the development of common understandings, build important inter-stakeholder relationships and help maintain trust. Non-potable reuse can contribute to the resilience of megacities through infrastructure diversification, but its feasibility will depend on the willingness of stakeholders to participate and continually negotiate new risk management practices.

Keywords: Non-potable reuse, water reuse, risk, governance, collaboration

3.1 Introduction

Megacities magnify and concentrate risks related to water infrastructure failure, water stress and water quality (IRGC, 2010; Li et al., 2015). These qualities have an acknowledged impact on water supply and this has helped to elevate the viability of water reuse as a water management option (Van Leeuwen and Sjerps, 2015). Examples of water reuse scheme contributions in megacities include aquifer recharge in Mexico City (Sosa-Rodriguez, 2011) and on-site reclamation and reuse in individual buildings in Tokyo (Kimura et al., 2013). Approaches to water reuse encompass larger-scale schemes that use highly treated effluent to augment public drinking water supplies (e.g. Orange County, California or Big Spring, Texas), as well as smaller-scale schemes providing non-potable water for specified uses (e.g. urban irrigation, toilet flushing, or street cleaning). Such non-potable reuse (NPR) water supply options can be economical (depending on the characteristics of the design and the economic assessment of benefits - Bieker et al., 2010) and adaptable to existing water infrastructure constraints (e.g. where there are potable water network or sewer capacity issues). This can make them particularly suited to high growth areas of megacities (Tjandraatmadja et al., 2005).

Risk management is essential for providing safe non-potable water supplies (Hochstrat et al., 2008; Toze, 2006). However, it is also acknowledged that contemporary risk management processes for water supplies (e.g. the Water Reuse Safety Plan) may not adequately capture broader risks associated with different water reuse schemes (Huxedurp et al., 2014) nor an appropriate range of stakeholder perspectives (Campbell and Scott, 2011). Furthermore, efforts to minimise risks to public health and the environment from non-potable water supplies can require adherence with a wide range of (often fragmented or overlapping) guidelines, regulations and policies (Hanjra et al., 2012). Meeting these challenges may be further hampered as the many stakeholders involved may have an inadequate understanding of the different roles and responsibilities which may lead to conflicts, for example, if contractual arrangements have not worked (Turner et al., 2016). While previous studies have examined governance approaches for NPR (e.g. Dillon et al., 2010; Domènech and Saurí, 2010; Hanjra et al., 2012), there remains a general need for evidence to inform the development of clearer and more effective processes for managing such schemes.

Megacities present a particularly challenging context for the governance of NPR schemes, due to the scale of water supply issues and the number and diversity of potential stakeholders (Varis et al., 2006). These issues can lead to fragmentation of technological and management solutions (Li et al., 2015) and of stakeholder responsibilities and decision making (Varis et al., 2006). Such fragmentation can exacerbate existing water management problems (Li et al., 2015) whilst also increasing the potential for misunderstandings and conflict between stakeholders (Brown, 2008). Many solutions to these challenges centre on developing more inclusive stakeholder engagement processes (Lebel et al., 2015). However, there is a need for a better understanding of how the inclusion of multiple stakeholders can improve the governance of NPR schemes (Ferguson et al., 2013), with particular reference to regulatory oversight (Hanjra et al., 2012) and risk management activities (Dunn et al., 2015).

The recognised lack of critically reported practical experience describing how NPR might be incorporated into more strategic water management practice (Ferguson et al., 2013) highlights the benefits of learning from case specific evaluations (Moglia et al., 2011). Specifically, this study contributes to the aforementioned gaps through a case study of a community-scale water recycling scheme in the urban growth area of East London. The queries guiding this study are: (1) what are the main challenges that stakeholders see in relation to managing the risks associated with the NPR scheme; (2) how do they think those challenges might be overcome in order to promote more effective NPR scheme governance; and (3) how might case specific learnings inform practical aspects of future NPR schemes in London and other megacities? The following sections outline the research methods (including a description of the case study) and present the results. The discussion then considers the practical implications of the research findings, particularly in light of current understandings around the inclusion of stakeholders in NPR scheme governance, with reference to the megacity context.

3.2 Methods

This study employed a single case study approach (Yin, 2011) and collected and analysed data from semi-structured interviews and documents. Similar approaches have been used by a number of related studies to draw practical insights into aspects of water reuse (e.g. Marks and Zadoroznyj, 2005; Marks, 2006), urban water management (e.g. Ferguson et al., 2013), water safety planning (e.g. Perrier et al., 2014) and risk governance (e.g. Dunn et al., 2015; Mauelshagen et al., 2014). This section will first describe the case study and then describe the methods of data collection and analysis.

3.2.1 Case study description

The selected case was the Old Ford Water Recycling Plant (OFWRP) which constitutes the largest community-scale NPR scheme in the United Kingdom. The scheme was implemented for the London 2012 Olympic and Paralympic Games and formed part of the event's sustainable water strategy (Knight et al., 2012). The scheme (Figure 3-1) involves abstracting wastewater from a combined sewer (the Northern Outfall Sewer), treating it with a membrane bioreactor followed by granular activated carbon and disinfection with sodium hypochlorite, and distributing it through dual pipe reticulation to customers located at the nearby Queen Elizabeth Olympic Park (QEOP). The average flow in the combined sewer is 116,000 m^3/day, whilst the OFWRP is designed to provide 574 m^3/day of non-potable water (Hills and James, 2015). The non-potable water supply is used both directly and indirectly (through topping up rainwater and stormwater harvesting systems) for irrigation and toilet flushing. A unique regulatory position and unique water quality standards were required for the scheme as it was the first of its kind in the country. A Water Reuse Safety Plan (WRSP) approach was developed for risk assessment and management (based on the format used in drinking water regulation).

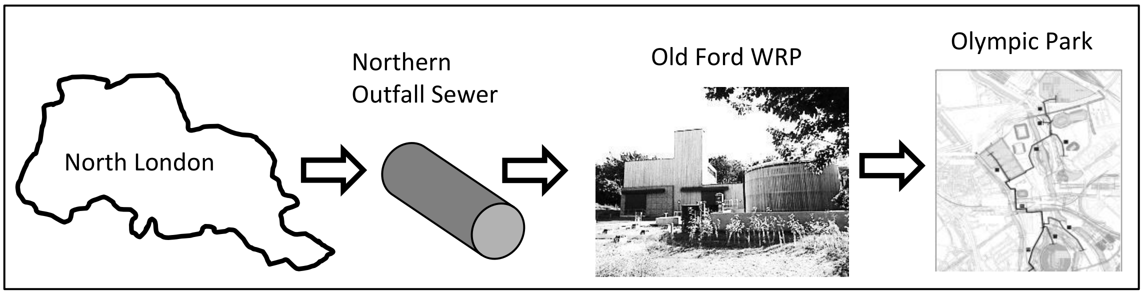


Figure 3-1 The physical catchment to tap boundary of the scheme

The stakeholders involved in the OFWRP scheme have a wide range of roles and responsibilities. Thames Water Ltd is responsible for the OFWRP, the combined sewer and the dual pipe distribution network. In terms of the Olympic Park planning and management, the Olympic Delivery Authority (ODA) was the public body responsible for delivering the London 2012 Olympic and Paralympic Games and implemented the scheme in partnership with Thames Water (Knight et al., 2012). Following the Olympics, the ODA handed responsibilities for planning and development in the Park to the London Legacy Development Corporation (LLDC). The LLDC are also customers of the OFWRP, overseeing the use of the non-potable water in a number of venues and across the parklands for irrigation. Other venues and areas of the park are the responsibility of the Lee Valley Regional Park Authority and, adjacent the park, East Village is indirectly connected to the non-potable water network. Finally, the venues and parkland within the Olympic Park play host to a range of local and international events and are frequented by both the general public as well as members of sporting and community organisations.

The Old Ford scheme also helps address the broader water supply challenge for London, wherein current water balance models predict an emerging public potable water supply deficit of up to 414 mega-litres per day by 2040 (Thames Water, 2014). The population of Greater London (the third largest of the three UN defined European megacities after Moscow and Paris) is predicted to grow to 11.5 million by 2030 (United Nations, 2015) - particularly in over forty designated development opportunity and intensification areas (Greater London Authority, 2015a). This growth is projected to be highest in the east of the city, with an extra 600,000 people living in areas including and surrounding the case study location by 2040 (Greater London Authority, 2015b). Planned development includes residential housing growth along with new office space, retail space, schools, university campuses, a museum, a technology hub and potentially other industries such as concrete manufacturing (LLDC, 2015). Planning documents have articulated some general ambitions for promoting non-potable water supplies to support new housing and growth areas in London (e.g. The London Plan, Greater London Authority, 2015), and specifically in the Olympic Park planning area (e.g. Local Plan, LLDC, 2015). However, there is a lack of clear policy drivers for such schemes. In addition, regulations to govern activities such as sewer mining and NPR in the UK are yet to be comprehensively developed.

3.2.2 Data collection and analysis

Qualitative data was purposively collected across the organisations involved with the case study to represent the diversity of stakeholders. The organisations represented by the data included national and regional (Greater London) government and regulatory organisations; Olympic Park management and planning organisations; the water company (Thames Water); and various non-potable water customers, end users and operation and maintenance contractors. Data consisted of semi-structured interviews (N=30) and documents (N=36), which were collected to represent these four generalised stakeholder groups (Figure 3-2)[1]. Semi-structured interviews took place over a three year period (2012 to 2015). They lasted between 30 and 60 minutes and were recorded with permission before being transcribed. Interviews elicited views on: (1) the overall objectives for the project; (2) hazards and risks involved with implementing and operating the NPR scheme; (3) perceptions of water quality and quantity; (4) the capabilities and the limitations of risk assessment and risk management activities; (5) the establishment of water quality criteria and a regulatory position; and (6)

[1] Refer to Appendix A Table A-1 for more details.

organisational roles, responsibilities and interactions. Interviewees were given the opportunity to comment on the draft interview transcripts and thus confirm the authenticity of the data.

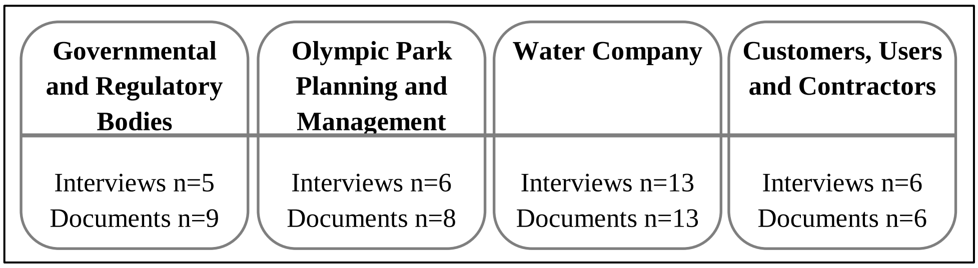


Figure 3-2 Generalised stakeholder groups showing the distribution of collected data

Documents included in the dataset were published between 2009 and 2015 and were used to supplement and triangulate the interview data. Collated documents included meeting minutes, conference presentations, commercial and public reports, policy statements and online web content (news articles and summary reports). The documents related to descriptions of the scheme and contained records of planning, design, scheme governance, risk management and regulatory discussions and decisions from the perspective of the different stakeholders involved. Figure 3-3 illustrates the timing of data collection relative to a selection of notable events in the scheme's development. The QSR NVivo 11 data management program was used to store interview transcripts and documents and to facilitate the qualitative analysis.

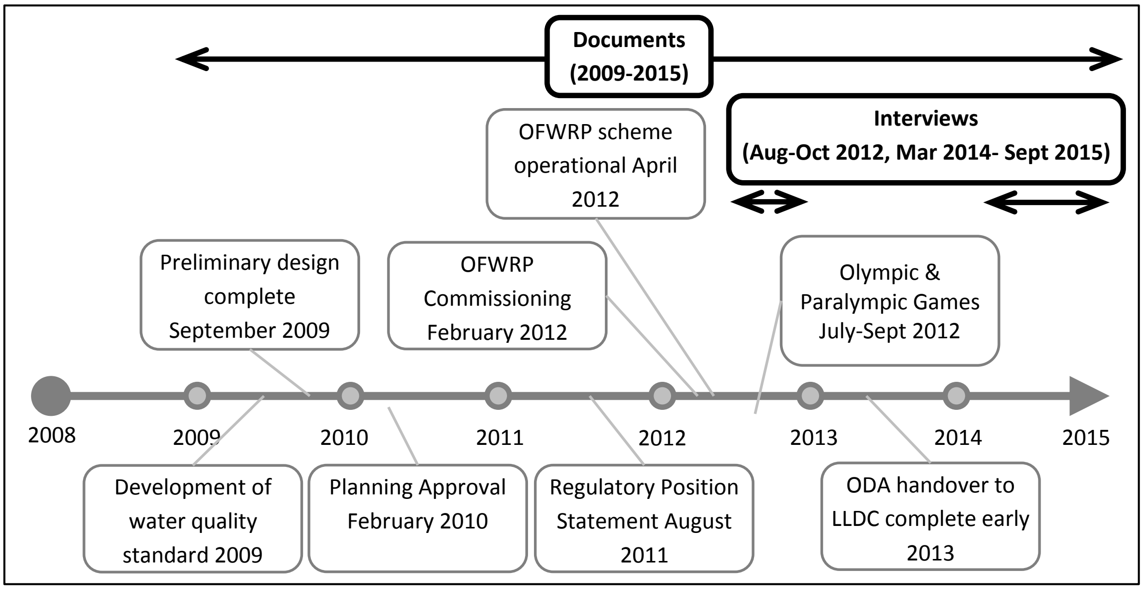


Figure 3-3 Time slice of selected project events and data collection

Table 3-1 Thematic summary of the perceived challenges and solutions for governing scheme risks

Themes – Challenges	Sub-themes	Example extract to illustrate the challenge
1. The challenge is to develop mutual understandings of diverse needs and expectations	1.1. Understand water quality requirements	*"So they didn't know because no one asked that question; how do you want your water? Out of the tap's fine. But when you actually start analysing it and going oh, we don't want any whatever it is, we don't want this, we don't want that, it's just ridiculous."* (Int.PPM.05)
	1.2. Understand risk perceptions	*"We are disappointed to hear that this water will not be used to water the artificial hockey pitches due to perceived health risks."* (D.GRB.10)
	1.3. Maintain trust	*"Our commercial users are aware that they are using a different network, but they trust for it to be maintained in the same way that the potable water network is."* (Int.PPM.06)
2. To challenge is to define clear roles and responsibilities (including on the oversight of a range of procedures, rules and regulations)	2.1. Gain clear commitment	*"No, I think that people – not in a bad way, people not really understanding what they're saying and what they're committed to."* (Int.PPM.05)
	2.2. Link procedures	*"Links are not always clear between the reclaimed water safety plan spreadsheet and associated procedures and there is an opportunity to enhance inter-connectedness of elements associated with the safety plan."* (Int.WC.01)
	2.3. Streamline rules and regulations	*"In the UK, dual reticulation schemes of this type are rare and the guidance available is not very specific. The current UK guidance on a whole range of related topics, such as pipework labelling, could benefit from being streamlined and consolidated.* (D.WC.54)
3. The challenge is to improve awareness, knowledge and capabilities (particularly industry experience and decision making)	3.1 Improve awareness	*"I don't think many people know about it. Just do a survey on people exiting the park when they leave were they even aware?"* (Int.CEUC.05)
	3.2. Improve technical knowledge and understanding	*"There needs to be a better understanding of what happens with loss of treatment integrity, particularly with the membrane which provides an important barrier".* (Int.WC.03)
	3.3. Improve industry skills and experience	*"There were some issues with the non-potable system at the start of the project, including incorrect specifications"* (Int.WC.04)
	3.4. Improve decision-making	*"During the initial operational period, the uncertainty over what demands were actually going to materialise was not helpful but were inevitable due to the nature of the project."* (D.WC.43)
Themes - Solutions	**Sub-themes**	**Example extract to illustrate the solution**
4. The solution is to use inclusive, collaborative and learning processes to build knowledge and mutual understandings	4.1 informally generate knowledge through risk taking, experimentation and learning by doing	*"Sometimes you have to take risks initially to gain knowledge and once you've got that knowledge then you can manage those risks."*(Int.WC.14)†
	4.2 Formally use different types and levels of engagement to encourage learning	*"I think a bit more training on it would be handy, without a doubt. Just to flag it up to people that have been on the park as long as I have or whatever… Refresh every year or something like that."(Int.CEUC.03)*

†Data reference system: Int = Interviewee. D=Document. 01 = Interviewee/Document identification number for group. Stakeholder group codes: CEUC = Customers, End Users and Contractors; WC = Water Company, PPM = Park Planning and Management, GRB = Governmental and Regulatory Bodies.

The study used semantic thematic analysis (Braun & Clarke, 2006) to generate a structured view of the data that was predominantly inductive but also guided by concepts derived from literature. Themes and sub-themes were developed through iteration and using thematic network maps (Attride-Stirling, 2001) to aid the analytical process. Themes were continually reviewed and refined until they were considered to have largely distinctive meanings. Triangulation between sources of data (both interviews and documents) was used to explore patterns and firm up confidence in the collected views. Themes were thus the units of analysis that captured important aspects of the data and facilitated interpretive analysis to make sense of the data and describe what it meant with respect to the research questions (Braun and Clarke, 2006). Sub-themes gave structure and detail to the themes.

3.3 Results

The sections below present the four overall themes, and their associated sub-themes, which emerged from the analysis. The first three themes describe the main challenges that stakeholders perceived in relation to managing the risks associated with the implementation and operation of the NPR scheme. The final theme describes how the stakeholders thought that these challenges might best be tackled in order to improve scheme governance (Table 3-1). Example extracts from the data are provided in the tables as a means of illustrating the types of perspectives that contributed to the development of the themes and sub-themes.

3.3.1 The challenge of developing mutual understandings of diverse expectations

The challenge perceived by the stakeholder groups of developing mutual understandings of needs and expectations was a dominant theme. Expectations were identified as differing particularly over aspects of non-potable water quality and the associated perceptions of risks relating to the possibility of certain contaminants in the water. Also, closely related to both of these sub-themes, maintaining trust was identified across the stakeholder groups as an important challenge to confront when attempting to develop mutual understandings.

The first sub-theme related to understanding the non-potable water quality needs of the customers and end users and also the expectations of the other stakeholder groups. The non-potable water was originally conceived to be used for toilet flushing, parkland irrigation, cooling tower water (energy centre) and hockey field irrigation, and, as such, there were a number of differences over which quality characteristics were considered important. Microbial parameters were clearly of interest (given the imperative of protecting public health), however, water quality preferences also related to technology risks (i.e. the water's potential impact on irrigation equipment or cooling tower operations) and aesthetic characteristics (e.g. colour and odour). On reflection, a number of interviewees from the customer, park management and water company stakeholder groups thought that the quality standards were stricter than they necessarily needed to be and there was some indication of a desire for some quality parameters to be adjusted. However, it was unclear how such an adjustment could be accomplished. On the other hand, it was thought that changing the water quality might deter new customers from connecting in the future and thus the water company was reluctant to do this.

The challenge of understanding the risk perceptions of different stakeholders constituted the second sub-theme. Different views on risk were identified in the data – for example, regulators, the water company and park management were concerned about the risks to irrigation workers from their exposure to the non-potable water, but the workers themselves indicated they had few concerns. An example of these different perspectives related to the extent of personal protection equipment needed for irrigation contractors, with workers perceiving some occupational health and safety requirements as overly conservative. Furthermore, perceptions of significant risks were seen as underpinning the failure to connect both the hockey fields and the energy centre cooling towers to the non-potable water network. For the energy centre, that data suggests a failure by the water company and the park management to fully comprehend the risk management expectations of the centre's operators. Whilst health and safety (legionella risks) and operational risks were suggested as unresolved issues, the data also suggested complications to contractual arrangements as well. On the other hand, the decision not to irrigate the hockey fields (with non-potable water) was attributed to health risk concerns of the Olympic organisers (who at the time were also the customers). For the water company interviewees, there were some health risk concerns with irrigating hockey fields as well. However, on reflection, it was largely agreed that the failure to connect these two uses had introduced cost risks for the scheme that impacted on its longer-term viability.

The last sub-theme encompassed the challenge of maintaining trust between the stakeholder groups. The analysis found a nervousness, particularly from the water company and regulators, around the potential for misuse or unintended use of the non-potable water supply, resulting in negative health consequences (thus increasing perceptions of risk). In other words, the water company and regulators showed a slight degree of mistrust in the end users of the non-potable water, and/or those who might come into contact with the distribution network. Conversely, other stakeholders' trust in the water company to consistently supply safe water was repeatedly described by interviewees. This was supported by the view that the water company is a responsible organisation and would not compromise on public health. In summary, whilst levels of trust described by all stakeholder groups were interpreted as being sufficient, the analysis also identified that adverse events – e.g. the (potentially unintended) misuse of the non-potable supply – could significantly impact on this.

3.3.2 The challenge of clarifying roles and responsibilities

Analysis of the interview and document data illuminated the challenge of clarifying roles and responsibilities for individuals, within organisations and between organisations. This theme further encapsulated the challenge of unifying the various procedures, rules and regulations that were overseen by the different organisations. The results showed that the apparent duplication of responsibilities and/or poor definition of responsibilities had the potential to increase risk.

The first sub-theme described the challenge of gaining commitment from stakeholders to support and implement the scheme. The implication was that a lack of commitment intensified the challenge of clarifying roles and responsibilities and potentially led to fragmented decisions. The Olympics and Paralympic games were described as an important catalyst for gaining initial commitment to the scheme, but many felt that commitment has waned after the games. Moreover, the short-term nature of the OFWRP's contract (2012-2019) was described as introducing uncertainty and hindering commitment from potential new non-potable water customers – and thus impacting on the longer-term viability of the scheme. On the other hand, contractual arrangements were seen as helpful in that they established clear commitment to certain responsibilities, such as water quality compliance reporting. Finally, some interviewees highlighted a lack of commitment from regulators, outside of those closely involved with the scheme. For example, occupational health and safety and drinking water regulation were considered by some to contradict the promotion of non-potable water use.

In a similar vein, the challenge of improving links between a range of managerial procedures, as well as consolidating these where there was duplication, was the second sub-theme. The data described examples of overlapping requirements, such as the Water Reuse Safety Plan approach overlapping unnecessarily with aspects of health and safety assessment. Other interviewees, however, identified strengths derived from unifying existing procedures, such as transferring the catchment to tap risk assessment format from drinking water to reuse. Notably, there was some confusion highlighted as to who was responsible for overseeing certain procedures (e.g. for undertaking certain risk management activities such as installing signage). This particularly related to demarcating areas inside and outside of buildings thus introducing zones where responsibilities for managing risks were not clear.

The final sub-theme described challenges arising from fragmented or overlapping rules and regulations. For example, whilst the use of the United States Environmental Protection Agency non-potable water quality standards was described by some as beneficial, there were also problems attributed to interpreting conflicts with UK standards and regulation (including drinking water quality regulation). The lack of UK guidance and standards for non-potable water quality and distribution network construction was often described as a significant challenge for scheme governance. For the guidance that did exist, there was confusion expressed around some conflicting recommendations and terminology. For example, British standards for rainwater harvesting differ from those for greywater recycling on some water quality parameters, even though the two technologies are often combined. The multiple layers of overlapping planning responsibilities for London was also thought to introduce confusion. For example, planning requirements for non-potable water supplies in new developments differed in the guidance produced at national, regional and local levels. Finally, whilst the bespoke regulatory position developed for the site was described as enabling the scheme to progress (in a previously unregulated area), it was also suggested that future schemes in London (or other cities) would not necessarily benefit from this as the activity remained unregulated.

3.3.3 The challenge of improving awareness, knowledge and capabilities

All stakeholder groups highlighted the challenge of improving awareness, knowledge and capabilities around the risks associated with NPR. Whilst the four stakeholder groups differed in some respects on the types of risks they were concerned about, there was also concordance. Common points of focus included public health risks and particularly the potential for cross-connections with the drinking water supply being introduced through, for example, a lack of awareness of the scheme. The analysis found that, while many stakeholders felt that aspects of awareness, technical knowledge and capabilities had improved over time, new dimensions to these challenges had also been introduced.

The challenge of improving awareness of the scheme and its associated risks (e.g. awareness of the health risks associated with using non-potable water) was a sub-theme. Perceptions of a lack of awareness focused on the contractors responsible for constructing the non-potable water distribution network, both initially and with new network extensions. Additionally, interviewees highlighted that the number of contractors working on the Park for different landscape and construction projects exacerbated the need for raising awareness. The lack of general awareness was thought to arise principally from the scheme being the first of its kind in the UK. There was some evidence of an increased awareness of the scheme occurring through some contractors being on the site over a number of years. Other broader concerns related to public awareness of the water resource issues in London, awareness of NPR as a potential solution for those issues, and awareness of the NPR scheme at the Olympic Park.

The next related sub-theme described the challenge of improving technical knowledge and understanding of various aspects of the scheme, including scheme planning, design, installation and operation. Once again, much of this related to the scheme being the first of its kind in the UK. The stakeholder groups described a range of aspects to this sub-theme and focused on: compliance with water regulations, public health, environmental impacts and the cost-benefit balance. For example, there were concerns that the scheme might not be cost effective, but knowledge to support such an assessment was limited. It was clear that many stakeholders thought knowledge and understanding had increased over time. However, whilst technical knowledge of the scheme was thought to have improved in many areas, it was also suggested that this was unevenly distributed across stakeholders. For example, there were concerns that changes in key staff meant that valuable knowledge could be easily lost. The data also highlighted a desire to improve knowledge and understanding of the contribution NPR could make to water resource management in London, as a means of encouraging similar schemes across the city.

The challenge of improving capabilities (skills and experience) within the industry – particularly related to specification, procurement and construction – was another sub-theme. This sub-theme is closely associated with those above, but it specifically highlights the role of industry experience. Many of the challenges highlighted in the data related to the installation of the pipework for the non-potable distribution system and a lack of compliance with regulations, which were attributed to a lack of skill and experience in the industry. The main concerns raised were thus water regulation compliance (e.g. pipe fittings) and the risk of cross-contamination both inside buildings and in landscaped areas. More than promoting awareness, the challenge was to develop skills and expertise in design, construction and maintenance of the NPR scheme and its separate distribution network.

Finally, the challenge of making decisions under uncertain conditions was highlighted in the data. This data summarised perspectives relating to early design decisions that had (unintentionally) introduced other scheme risks. Such introduced risks included the nature of the non-potable distribution network design (being dendritic rather than a ring main, which creates the potential for stagnation), inaccuracies in the original demand estimates (leading to some operational and cost-benefit risks), and design specifications for some equipment associated with water treatment (leading to higher than necessary energy and chemical use). Notably, the colourless nature of the non-potable water (which was a specific treatment requirement early on) was considered by one interviewee as potentially introducing risks as it was visually indistinguishable from the drinking water supply (making cross-contamination difficult to detect).

3.3.4 Solutions to these challenges – collaboration and learning

A single theme summarised how the stakeholders perceived that inclusive opportunities for collaboration and learning were necessary parts of processes to improve scheme governance. Joint working towards common goals was repeatedly raised as a preferred practice, as illustrated by the following interviewee: *"Different projects require different inputs by different organisations and working together in a collaborative way. We've worked all the way through like that. Something that's really helped facilitate that understanding [of needs and expectations] and relationship building from our perspective is that we've always had individuals co-located with the contractors . . . with the design engineers and contractors, the delivery bodies"* (Int.GRB.05: Governmental and Regulatory stakeholder group). The theme was also supported by data that highlighted where a lack of inclusion, collaboration or learning had meant that some challenges had not been addressed. For example, some data described frustrating attempts to arrange meetings intended to discuss water quality criteria and scheme design, concluding that some *"meetings were generally not well attended and little was learnt"* (D.WC.43: Water Company stakeholder group). Many of the specific examples of collaboration in practice focused on risk management (using a Water Reuse Safety Plan approach) and the negotiation of water quality standards and the regulatory position for the scheme.

The first sub-theme identified a number of more informal processes that supported inclusiveness, collaborative working and learning. Knowledge generation, particularly in co-working situations, was described as important for improving capabilities in risk management activities and operational and design decision making. Informal discussions often took place during scheduled risk management activities, particularly between the water company and customers, end users, contractors and members of the public. For example, such discussions were described as occurring during testing for cross-connections, flushing of the non-potable water network, water quality sampling and water regulation inspections. One interviewee discussed an informal communication network that irrigation workers had established to negotiate non-potable water network risks (e.g. loss of pressures and lack of supply) during periods of high demand for non-potable water. The data highlighted a link between creating the right environment for risk taking and achieving desirable outcomes – described by one interviewee as the need to learn through taking risks in order to generate important knowledge to improve risk management. This conceptual thread extended to the role of experimentation for generating learning opportunities and new knowledge. When discussing the management of water quality risks during winter, one interviewee suggested an untried solution and that it was worth *"probably just taking a risk and see what happens"* (Int.CEUC.05: Customer and End User stakeholder group).

The scheme itself was seen as a beneficial experiment for generating knowledge, and for engaging a range of stakeholder (including the general public), in order to pave the way for similar schemes elsewhere in London. Being involved with the scheme was considered as a learning opportunity that was described by one interviewee as improving knowledge and capabilities, *"because I had to immerse myself in it and understand it, I'm very comfortable talking about it, telling people how they can use it. But across the industry, that's not the case."* (Int.PPM.05: Park Planning and Management stakeholder group). Finally, it was recognised that the innovative nature of this scheme meant that some mistakes were inevitable (as with any innovative technology), but these could provide many opportunities for leaning-by-doing, as one interviewee described: *"Because we've actually picked up loads of little things that you do when you're going round and checking everything; if you make a mistake, then basically this happens"* (R.WC.14: Water Company stakeholder group).

The second sub-theme summarised formal processes for knowledge sharing and learning, including training, educational briefings, site tours and information sharing (communication). Whilst many engagement activities often had specific agendas, it was felt that some also allowed for broader discussions of scheme governance, water resource management and risk. It was suggested that educational briefings and site tours encouraged those involved to ask questions and raise discussions which contributed to improving their awareness (particularly as many individuals were only involved with certain aspects of the scheme). Furthermore, examples in the data described the site tours as a platform to engage customers and stakeholders in debate on London's water resource management. It was suggested that engagement framed around the Water Reuse Safety Plan has led to the relaxation of a number of water quality monitoring requirements, thus indicating how formal knowledge transfer had helped develop mutual understandings of acceptable water quality risks. There were a number of useful learnings on engagement documented for the scheme, one interviewee described how early discussions and negotiations helped develop a service level agreement to clarify organisational responsibilities. Another interviewee described their efforts in talking about the scheme with the different venues as helping to understand different risks and also raise awareness.

Although different types and levels of engagement were seen as necessary for sharing knowledge, learning and relationship building, a number of constraints were also described. Some felt improvements could be made in the exchange of information (a communication deficit). For example, one interviewee described how a lack of suitably timed communication meant that some contractors were not initially aware of design and installation standards. Other examples included requests for more communication of operational incidents (e.g. an expected change in water pressure) and more education on risks and precautions to improve awareness, particularly for end users. Another interviewee thought a lack of involvement from a number of different departments in the water company had led to fragmentation in scheme decisions and its ongoing management and that more focus on early engagement might have helped. The analysis flagged a number of obstacles to engagement, including the time required, problems with organisation structures, the number and variety of organisations involved and demands being put on individuals. One interviewee from the customer group identified how they were sometimes not included in stakeholder meetings and therefore didn't have direct access to information they wanted. Another interviewee summarised some difficulties carrying out successful engagement, *"it's a big investment, you need to have a knowledgeable technical type person that can do customer engagement"* (Int.PPM.05: Park Planning and Management stakeholder group). Thus, although engagement was often desired as a means of facing governance challenges, this was not always matched in practice.

3.4 Discussion

3.4.1 Collaboration and learning to address governance challenges

The results highlighted how stakeholders perceive collaboration and joint working processes as helpful to promote learning and to forge mutual understandings, and thereby contribute to more effective scheme governance. This study thus provides some empirical support to previous findings advocating collaborative approaches to meet diverse challenges for the governance of water quality (Dunn et al., 2015) and scheme risks (Perrier et al., 2014). This finding also leads to consideration of broader collaborative (or social) learning theory, which suggests less hierarchical modes of water governance (Pahl-Wostl et al., 2008a). Whilst this is relevant for alternative water systems like community-scale NPR, the potential for adverse events (like technical failures) to have a detrimental effect on collaborative learning processes should also be recognised (Domènech and Saurí, 2010). Furthermore, evidence from this study also shows that although collaborative processes were desired, this was not necessarily matched in practice. This mismatch supports previous findings in water governance, for example where guidelines may contain aspirations for collaborative processes that are not implemented (Dore et al., 2012). So whilst it is recognised that collaboration and learning can help to clarify misunderstandings, there will be procedural and behavioural challenges to this – even when stakeholders are willing.

This study highlighted some practical hurdles in resolving stakeholder differences, including the time necessary for negotiations or difficulties communicating with individuals or organisations. With respect to addressing these and other scheme governance challenges, this study found evidence of the benefits of stakeholder deliberation during practice-based activities and particularly those associated with risk management. A notable finding was that informal collaboration occurred during practical risk management tasks. It was thought that these informal working relationships helped to promote learning and to mitigate risks. This finding firstly supports previous studies that suggested collaborative learning occurs when stakeholders engage in common tasks based on inter-dependent relationships (Moglia et al., 2011). Furthermore, this finding supports the relevance of informal communications in environmental risk governance (Mauelshagen et al., 2014) and particular when stakeholders might not see good reason for formal engagement (Bos et al., 2013). What this contribution specifically adds is that there can be benefits to informal collaboration during risk management activities for non-potable water reuse. Such opportunities are likely to arise around non-potable network management where the different stakeholder groups most frequently meet. This finding has implications for the content of risk-based management frameworks currently promoted for water reuse. In particular, future guidance might focus attention on recommendations for approaching informal engagement and for establishing inclusive risk management teams (that include a range of stakeholders and representatives from the communities of practice) - previously suggested for NPR (Attwater and Derry, 2005).

Findings of this study provide support for the use of a range of different types of engagement tailored to the needs of different stakeholders as well as to their available resources (OECD, 2015). Whilst it is not surprising that formally planned engagement activities may need to change over time in response to stakeholders needs (Turner et al., 2016), this study also suggests that a level of experimentation is necessary to discover which techniques work best . The results from this study also corroborate previous findings around the benefits of using information exchange to support collaboration instead of only seeking to provide expert advice (Pahl-Wostl et al., 2008b). However, whilst this study supports the idea that involving more stakeholders in collaborative processes may help legitimise risk-based decisions (Hermans et al., 2012), previous studies have highlighted numerous difficulties in conceiving and implementing formal collaborative initiatives. For instance, such arrangements may be weakened by vague definitions of roles and responsibilities (Hahn, 2011), which is of particular relevance to NPR schemes as the importance of defining roles and responsibilities has been identified as critical to their success (Farrelly and Brown, 2011). Thus, ill-conceived formal collaborative processes could potentially exacerbate the fragmentation of different procedures and rules (Hanjra et al., 2012) and increase the potential for conflict (Turner et al., 2016). Moreover, these processes will also face challenges from time constraints, intra-organisational fragmentation and unrealistic demands put on individuals. This contribution has highlighted the benefits of incorporating more informal collaborative opportunities that can help address some of these issues and bolster formal collaboration efforts.

3.4.2 Implications for future NPR schemes in megacities

The findings of this study suggest there are benefits to understanding case-specific experiences to develop practical knowledge on how to negotiate NPR scheme implementation and operational risks. For stakeholder inclusion in future NPR scheme governance, this case study has highlighted that both formal and informal engagement mechanisms should be applied, as they are suited to different stakeholder groups. The findings support the view that formalised engagement activities such as site tours (Marks, 2006) or community forums (Russell et al., 2008) can provide a platform for raising questions and discussing concerns. Secondly, more informal collaboration can be stimulated by specific actions (Domènech and Saurí, 2010) and this study puts forward the benefit of focusing on inclusive opportunities in day to day risk management activities. Time poor contractors and local managers may prefer more informal, activity based collaboration. On the other hand, the Water Reuse Safety Plan format provides a formal vehicle for discussing risks with regulators or water resource managers. Many world regions have made considerable progress in developing risk management and scheme governance guidance for NPR (e.g. NRMMC EPHC & AHMC, 2006; USEPA, 2012), but this tends to focus predominantly on formal mechanisms for stakeholder engagement. Therefore, a broader suite of informal, practice-based opportunities for collaboration could suit a wider range of stakeholders and help improve future schemes.

Technological solutions like NPR could address emerging water supply challenges in megacities (Tjandraatmadja et al., 2005) and help diversify their water supply infrastructure in order to build resilience (Marlow et al., 2013). As previously mentioned, the number and diversity of stakeholders in megacities can lead to fragmentation of water management solutions (Li et al., 2015) and of stakeholder responsibilities (Varis et al., 2006). However, megacities can also provide fertile ground for local-scale experimentation with new solutions, because they provide opportunities to include 'outsiders' or fringe stakeholders in engagement processes, thus diffusing knowledge and experiences more broadly and across a range of governance scales, from local to national (Farrelly and Brown, 2011). This can allow a broader range of perspectives to infiltrate the engagement processes, and can also help local solutions to be 'scaled up' more quickly. The case study presented here has illustrated how a localised NPR scheme can present a focal point for such experimentation in a megacity context. Stakeholders demonstrated a willingness to 'learn by doing' and experiment, not just with technology, but with different risk managements approaches and different mechanisms for collaboration. Lessons from these activities could potentially be scaled up as urban intensification increases, and particularly as NPR becomes seen as a more viable solution for cities like London and the wider region (e.g. European Commission, 2016).

3.5 Conclusion

Using data from semi-structured interviews and documents, this study identified three main challenges associated with the governance of an NPR scheme in London: 1) the need to develop mutual understandings of diverse expectations; 2) the need to clarify roles and responsibilities; and 3) the need to improve awareness, knowledge and capabilities. Findings also showed that collaboration and learning processes, especially those focused on risk and risk management activities, can help address these challenges. In particular, our findings highlighted that risk management activities around the non-potable water network provided opportunities for more informal modes of collaboration. Furthermore, this study has shown that a broader spectrum of engagement approaches (both formal and informal) can facilitate dialogue around divergent objectives and help build relationships and maintain trust. Such collaborative processes can help make governance mechanisms more responsive to the risk and stakeholder dynamics characteristic of megacities like London. These case specific findings can inform practices for future NPR schemes in megacities.

Non-potable reuse is a viable tool to help address the water resource challenges of megacities. In turn, megacities provide challenging but fruitful contexts in which to develop more effective governance approaches for NPR schemes, in part by facilitating experimentation with, and scale-up of niche solutions. The synthesis of learnings and experiences from similar case studies will help to build better understandings of common solutions to governance challenges for NPR schemes. However, more evidence is needed to illustrate how NPR can contribute to more integrated water resource management approaches, as well as related public health, environmental and economic challenges for megacities. Future research could also explore the relationship between stakeholder intentions and actual behaviours, for example, where knowledge sharing is envisioned but not necessarily practised. This may be extended to examine stakeholders' willingness to actively participate in NPR risk management, such as through catchment management or behaviour based risk barriers. Finally, there are opportunities to evaluate practice-based mechanisms for collaboration and deliberation, which can help to legitimise water management proposals. Collating this evidence can contribute to finding better water management solutions for growing urban agglomerations like London and other megacities.

3.6 Acknowledgements

The views expressed here are those of the authors and do not necessarily represent the individuals or organisations involved in the research. However, the authors are grateful to all those who gave up their time to participate in this study, and we offer thanks to them and the organisations they represent. The authors would also like to acknowledge Nikki Dudley for her help with transcribing interviews. This research was co-funded by the UK's Engineering and Physical Science Research Council (EPSRC) grant number EP/G037094/1 and Thames Water through the STREAM Industrial Doctorate Centre.

3.7 References

Attride-Stirling, J., 2001. Thematic Networks: an analytic tool for qualitative research. Qual. Res. 1, 385–405.

Baggett, S., Jeffrey, P., Jefferson, B., 2006. Risk perception in participatory planning for water reuse. Desalination 187, 149–158. doi:10.1016/j.desal.2005.04.075

Bieker, S., Cornel, P., Wagner, M., 2010. Semicentralised supply and treatment systems: Integrated infrastructure solutions for fast growing urban areas. Water Sci. Technol. 61, 2905–2913. doi:10.2166/wst.2010.189

Borgomeo, E., Mortazavi-Naeini, M., Hall, J.W., O'Sullivan, M.J., Watson, T., 2016. Trading-off tolerable risk with climate change adaptation costs in water supply systems. Water Resour. Res. 52, 622–643. doi:10.1002/ 2015WR018164

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3, 77–101. doi:10.1191/1478088706qp063oa

Brown, R.R., 2008. Local Institutional Development and Organizational Change for Advancing Sustainable Urban Water Futures. Environ. Manage. 41, 221 –233. doi:10.1007/s00267-007-9046-6

Campbell, A.C., Scott, C. a., 2011. Water reuse: policy implications of a decade of residential reclaimed water use in Tucson, Arizona. Water Int. 36, 908–923. doi:10.1080/02508060.2011.621588

Castro, J.E., Kaika, M., Swyngedouw, E., 2016. London : Structural Continuities and Institutional Change in Water Management London : Structural Continuities and Institutional Change in Water Management 4313. doi:10.1080/09654310303635

Dillon, P., Toze, S., Page, D., Vanderzalm, J., Bekele, E., Sidhu, J., Page, D., Vanderzalm, J., 2010. Managed aquifer recharge: rediscovering nature as a leading edge technology. Water Sci. Technol. 62, 2338–2345. doi:10.2166/wst.2010.444

Domènech, L., Saurí, D., 2010. Socio-technical transitions in water scarcity contexts: Public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. Resour. Conserv. Recycl. 55, 53–62. doi:10.1016/j.resconrec.2010.07.001

Dore, J., Lebel, L., Molle, F., 2012. A framework for analysing transboundary water governance complexes , illustrated in the Mekong Region. J. Hydrol. 466-467, 23–36. doi:10.1016/j.jhydrol.2012.07.023

Dunn, G., Harris, L., Bakker, K., 2015. Microbial risk governance: challenges and opportunities in fresh water management in Canada. Can. Water Resour. J. 40, 237–249. doi:10.1080/07011784.2015.1043648

Environment Agency, 2015. Water supply and resilience and infrastructure: Environment Agency advice to Defra. Bristol.

European Commission, 2016. Guidelines on Integrating Water Reuse into Water Planning and Management in the context of the WFD. Brussels.

Farrelly, M., Brown, R., 2011. Rethinking urban water management: Experimentation as a way forward? Glob. Environ. Chang. 21, 721–732. doi:10.1016/j.gloenvcha.2011.01.007

Ferguson, B.C., Brown, R.R., Frantzeskaki, N., de Haan, F.J., Deletic, A., 2013. The enabling institutional context for integrated water management: lessons from Melbourne. Water Res. 47, 7300–14. doi:10.1016/j.watres.2013.09.045

Greater London Authority, 2015a. City in the East. London.

Greater London Authority, 2015b. GLA 2014 round of trend-based population projections - Results. Update 03-2015. London.

Greater London Authority, 2015c. The London Plan. London.

Hahn, T., 2011. Self-Organized Governance Networks for Ecosystem Management : Who Is Accountable? Ecol. Soc. 16, 18.

Hanjra, M.A., Blackwell, J., Carr, G., Zhang, F., Jackson, T.M., 2012. Wastewater irrigation: Implications for water governance and public policy. Int. J. Hyg. Environ. Health 215, 255–269. doi:10.1016/j.ijheh.2011.10.003

Hermans, M.A., Fox, T., van Asselt, M., 2012. Risk Governance, in: Roeser, S., Hillerbrand, R., Sandin, P., Peterson, M. (Eds.), Handbook of Risk Theory. Springer Science, Berlin, pp. 1094–1112. doi:10.1007/978-94-007-1433-5

Hills, S., James, C., 2015. The Queen Elizabeth Olympic Park Water Recycling System, London, in: Alternative Water Supply Systems.

Hochstrat, R., Wintgens, T., Melin, T., 2008. Development of integrated water reuse strategies. Desalination 218, 208–217. doi:10.1016/j.desal.2006.08.029

Huxedurp, L.M., Pálsdóttir, G.Þ., Altavilla, N., 2014. Risk-based planning for water recycling in an Australian context. Water Sci. Technol. Water Supply 14, 971. doi:10.2166/ws.2014.058

IRGC, 2010. Emerging risks in Megacities. Geneva, Switzerland.

Kimura, K., Funamizu, N., Oi, Y., 2013. On-site water reclamation and reuse in individual buildings in Japan, in: Lazarova, V., Asano, T., Bahri, A., Anderson, J. (Eds.), Milestones in Water Reuse. IWA Publishing, London, pp. 169–174.

Knight, H., Maybank, R., Hannan, P., King, D., Rigley, R., 2012. Lessons learned from the London 2012 Games Construction Project – The Old Ford Water Recycling Plant and Non-Potable Water Distribution Network. London, UK.

Lebel, L., Sinh, B.T., Nikitina, E., 2015. Adaptive governance of risks: climate, water and disasters, in: Shaw, R., Pulhin, J.M., Pereira, J.J. (Eds.), Climate Change Adaptation and Disaster Risk Reduction : Issues and Challenges. Emerald Group Publishing Limited, Bingley, pp. 115–142.

Li, E., Endter-Wada, J., Li, S., 2015. Characterizing and Contextualizing the Water Challenges of Megacities. J. Am. Water Resour. Assoc. 51, 589–613. doi:10.1111/1752-1688.12310

LLDC, 2015. Local Plan 2015 to 2031. London Legacy Development Coorporation. London.

Marks, J., 2006. Taking the Public Seriously : The Case of Potable and Non Potable Reuse. Desalination Volume 187, 137–147.

Marks, J., Zadoroznyj, M., 2005. Managing Sustainable Urban Water Reuse: Structural Context and Cultures of Trust. Soc. Nat. Resour. An Int. J. 18, 37–41. doi:10.1080/08941920590947995

Marlow, D.R., Moglia, M., Cook, S., Beale, D.J., 2013. Towards sustainable urban water management: A critical reassessment. Water Res. 47, 7150–7161. doi:10.1016/j.watres.2013.07.046

Mauelshagen, C., Smith, M., Schiller, F., Denyer, D., Rocks, S., Pollard, S., 2014. Effective risk governance for environmental policy making : A knowledge management perspective. Environ. Sci. Policy 41, 23–32. doi:10.1016/j.envsci.2014.04.014

Mayor of London, 2014. London Infrastructure Plan 2050 Update. Mayor of London. London.

Moglia, M., Alexander, K.S., Sharma, A., 2011. Discussion of the enabling environments for decentralised water systems M. Moglia, K. S. Alexander and A. Sharma. Water Sci. Technol. 63, 2331–2340. doi:10.2166/wst.2011.443

NRMMC EPHC & AHMC, 2006. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1). Natural Resource Ministerial Management Council, Environment Protection and Heritage Council and Australian Health Ministers.

OECD, 2015. Stakeholder Engagement for Inclusive Water Governance, OECD Studies on Water. Paris. doi:http://dx.doi.org/10.1787/9789264231122-en

Pahl-Wostl, C., Mostert, E., Tàbara, D., 2008a. The Growing Importance of Social Learning in Water Resources Management and Sustainability Science. Ecol. Econ. 13, 24.

Pahl-Wostl, C., Tàbara, D., Bouwen, R., Craps, M., Dewulf, A., Mostert, E., Ridder, D., Taillieu, T., 2008b. The importance of social learning and culture for sustainable water management. Ecol. Econ. 64, 484–495. doi:10.1016/j.ecolecon.2007.08.007

Perrier, E., Kot, M., Castleden, H., Gagnon, G.A., 2014. Drinking water safety plans : barriers and bridges for small systems in Alberta , Canada. Water Policy 16, 1140–1154. doi:10.2166/wp.2014.207

Sosa-Rodriguez, F.S., 2011. Exploring the risks of ineffective water supply and sewage disposal: A case study of Mexico City. Environ. Hazards 9, 135–146. doi:10.3763/ehaz.2010.0016

Stovin, V.R., Moore, S.L., Wall, M., Ashley, R.M., 2013. The potential to retrofit sustainable drainage systems to address combined sewer overflow discharges in the Thames Tideway catchment. Water Environ. J. 27, 216–228. doi:10.1111/j.1747-6593.2012.00353.x

Thames Water, 2014. Revised Draft Water Resources Management Plan (2015-2040) - Section 6: Baseline Supply Demand Position. Thames Water Ltd. Reading, UK.

Tjandraatmadja, G., Burn, S., Mclaughlin, M., Biswas, T., 2005. Rethinking urban water systems – revisiting concepts in urban wastewater collection and treatment to ensure infrastructure sustainability. Water Sci. Technol. Water Supply 5, 145–154.

Toze, S., 2006. Water reuse and health risks — real vs. perceived. Desalination 187, 41–51. doi:10.1016/j.desal.2005.04.066

Turner, A., Mukheibir, P., Mitchell, C., Chong, J., Retamal, M., Murta, J., Carrard, N., Delaney, C., 2016. Recycled water – Lessons from Australia on dealing with risk and uncertainty. Water Pract. Technol. 11, 127–138. doi:10.2166/wpt.2016.015

United Nations, 2015. World Urbanisation Prospects: 2014 Revision. New York.

USEPA, 2012. Guidelines for Water Reuse. United States Environmental Protection Agency.

Van Leeuwen, K., Sjerps, R., 2015. Istanbul: the challenges of integrated water resources management in Europa's megacity. Environ. Dev. Sustain. doi:10.1007/s10668-015-9636

Varis, O., Biswas, A.K., Tortajada, C., Lundqvist, J., 2006. Megacities and Water Management. Int. J. Water Resour. Dev. 22, 377–394. doi:10.1080/07900620600684550

Whitehead, P.G., Crossman, J., Balana, B.B., Futter, M.N., Comber, S., Jin, L., Skuras, D., Wade, a J., Bowes, M.J., Read, D.S., 2013. A cost-effectiveness analysis of water security and water quality: impacts of climate and land-use change on the River Thames system. Philos. Trans. R. Soc. A Math. \t\t\t\tPhysical Eng. Sci. 371. doi:10.1098/rsta.2012.0413

Yin, R.K., 2012. Applications of Case Study Research: Third Edition. SAGE Publications Ltd.

Chapter 4. Evaluating media framing and public reactions in the context of a water reuse proposal

D. Goodwin[1], M. Raffin[2], P. Jeffrey[1], H. M. Smith[1]

[1]Cranfield Water Science Institute, Cranfield University, Bedfordshire, UK, MK43 0AL

[2]Thames Water Utilities Ltd, Innovation, Reading STW, Island Road, Reading, UK RG2 0RP

Abstract

The public is increasingly engaging with information about water reuse proposals through the Internet. Though there are benefits to engaging the public online, there may also be challenges associated with media bias or online advocacy. This study qualitatively examines the public response (online comments, n = 1323) to online news reporting an indirect potable reuse proposal for London. The study found no evidence of the media's framing of the event strongly shaping the unsolicited online public reactions. Findings suggest that, though communications may struggle to counter longer-term news agendas, there may be benefits to experimenting with framing water safety measures and shorter-term gains.

Keywords: media framing, online communication, public engagement, social media, reuse

4.1 Introduction

Globally, as climate change and population expansion challenge existing water supply regimes, the number of water reuse schemes and proposals is growing. Public support is crucial for new schemes and water resource planners and managers are conscious of potential opposition (Hurlimann & Dolnicar, 2010). Thus, there is an ongoing challenge for water service providers to constructively engage with diverse societal concerns and to build support for both the principle of water reuse and individual projects. The news media can play an important role in conveying information (Hurlimann & Dolnicar, 2012; Lee & Tan, 2016) and shaping perceptions of water management issues (Mistry & Driedger, 2012). In the context of water reuse, there are particular interests in understanding the potential challenges arising from negative media campaigns (Hurlimann & Dolnicar, 2010) such as 'toilet to tap' framings (Rozin, Haddad, Nemeroff, & Slovic, 2015) or antagonistic media relations (Hartley, 2006). However, there are also many potential benefits of proactively engaging with the media (Harris-Lovett, Binz, Sedlak, Kiparsky, & Truffer, 2015) and building positive relationships (Simpson & Stratton, 2011).

Public acceptance of water reuse schemes, particularly those designed to supplement drinking water supplies, is shaped by specific contextual factors. Examples include public perceptions of economic bias in San Diego's unsuccessful water reuse scheme proposal during the 1990s (Hartley, 2006) and, in the case of Toowoomba in Australia, concerns about the town's image and health risks (Hurlimann & Dolnicar, 2010). Despite a body of international research spanning back to the 1970s (e.g. Bruvold, 1972), there remain limitations to current understanding of how specific communities might respond to particular water reuse proposals (Hurlimann & Dolnicar, 2016; Ross, Fielding, & Louis, 2014). This may be due to the breadth of public responses which can be influenced by consumers' expectations (Marks & Zadoroznyj, 2005), worldviews (Price, Fielding, & Leviston, 2012) or personal experiences (Leong, 2016).

Public attitudes and behaviours are known to be influenced by the media, which can alter public perceptions of risk (Kasperson et al., 1988) and trust in different sources of information (Mase, Cho, & Prokopy, 2015). Social norms, pre-existing attitudes (Pan & Kosicki, 1993) and other social conditions can also contribute to shaping public reactions to media and risk events (Kasperson et al., 1988; Leiserowitz, Maibach, Roser-Renouf, Smith, & Dawson, 2013). The media's interaction with the public is also dynamic, and though news outlets can be responsive to changing public opinions, they can also selectively provide information to set agendas and help shape public opinion (Carvalho & Burgess, 2005). Thus, media outlets can employ 'frames' in their reporting practices, which are used to promote a particular problem definition (Entman, 1993). A 'framing effect' occurs if the characteristics of media coverage affect the public's interpretations (Scheufele, 1999).

Media framing may contribute to polarising community attitudes towards water management (Wei, Wei, Western, Skinner, & Lyle, 2015). Research has focused on content analysis of media reporting of water management (Hurlimann & Dolnicar, 2012; Xiong, Wei, Zhang, & Wei, 2016), and specifically water reuse (Leong, 2010; van Vuuren, 2009), to identify framing perspectives. Though past research has revealed bias and framing in media reporting around water reuse – including an emphasis on uncertainty (Hurlimann & Dolnicar, 2012) and 'toilet to tap' framings (Marks, 2006) – less is known about how the public might respond to such framing practices. This is relevant to water reuse, as it has been suggested that media framing (including speculation over health risks) has reduced public confidence in specific scheme proposals (e.g. the Western Corridor, Australia - Ross et al., 2014). Conversely, ongoing public engagement and proactive media outreach may also increase public support, as is suggested for schemes in Orange County (Harris-Lovett et al., 2015) and Singapore (Leong, 2010; Mainali et al., 2011).

Both the news media and the public are increasingly turning to the Internet to disseminate information, and debate the pros and cons of different issues (Westerman, Spence, & van der Heide, 2014). For example, Regan et al. (2014) thematically explored dietary heath risk perceptions through online comments on two online media articles. Correspondingly, there is increased interest in studying online interactions across a range of water resource management domains, including through online participation tools (Bojovic, Bonzanigo, Giupponi, & Maziotis, 2015; White, Kingston, & Barker, 2010), social media (Tang, Zhang, & Xu, 2015) and online comments (Russell-Verma, Smith, & Jeffrey, 2015). A recent exploration of online comments on an aquifer recharge proposal (river water) in Finland concluded that debate on the subject was prone to polarisation and lacked attention to benefits and risks (Lyytimaki & Assmuth, 2014). Unsolicited online commentary therefore presents an opportunity for insight into public responses to real-world reuse scenarios. Though public responses to individual fictional news articles have been studied (Kemp, Randle, Hurlimann, & Dolnicar, 2012), the influence of actual media reporting on public responses to a real water reuse proposal has not yet been examined.

This study responds to calls for more in-depth considerations of the influence of media reporting on public responses to water reuse (Leong, 2010; Lyytimaki & Assmuth, 2014) and the potential benefits of media monitoring for developing responses to public concerns or to negative reporting (Hurlimann & Dolnicar, 2012). This research examines a recent proposal to implement indirect potable reuse (IPR) in London (UK) and uses this context to explore how the news media reported on the proposed scheme, as well as public reactions to those reports captured through unsolicited online commentary. The principal questions that this contribution seeks to address are: (1) How did different news organisations in the UK frame the proposed reuse scheme in online articles? (2) How did the public respond to the articles, and how did those responses articulate perceived justifications for the scheme (e.g. water shortages) and perceived impacts of the scheme (e.g. risks, benefits)? And, (3) To what extent did a framing effect occur (i.e. did the media's framing of the scheme seemingly influence the public's online responses)? The following sections present the context for the IPR scheme in London, outline the methods and present the results. The discussion then considers the implications of the research findings, particularly in light of current understandings around the use of: (1) online commentary as a mechanism to gauge public reactions and (2) proactive media outreach for engaging the public on water reuse scheme proposals.

4.1.1 IPR for London

A projected water supply deficit was highlighted in Thames Water's (2014) most recent Water Resource Management Plan for London. This deficit is thought to be driven by a combination of climate change impacts, reductions in the licensed abstraction volumes and population growth (Huskova, Matrosov, Harou, Kasprzyk, & Lambert, 2016). To help address it, the water company has proposed a number of water supply augmentation options, one being an IPR scheme. The IPR option includes advanced treatment of wastewater from a sewage treatment works that is then returned to a river upstream of an abstraction point of a drinking water treatment plant. The suggested reuse option is for a 150 ML per day scheme, programmed for 2027, which will follow a substantial demand management programme and smaller groundwater and water transfer schemes (Thames Water, 2015). The IPR option contrasts with existing instances of unplanned (or de facto) IPR, in which, due to historical developments along waterways, some sewage treatment works already discharge into rivers upstream of abstraction points. Treated wastewater is known to contribute to base flow in the River Thames (and its tributaries) and this proportion can be significant in dry weather conditions (Crook, Mosher, & Casteline, 2005). This is relevant to an IPR proposal as there is already a level of public awareness and acceptance of this state of affairs (Hills et al., 2009).

Previous public perception research has indicated the public is receptive to an IPR scheme proposal for London, with 60% of respondents indicating that they were supportive (Aitken, Bell, Hills, & Rees, 2014). However, the same study also identified that public support may be contingent on trust in the authorities that manage planned reuse and that this trust may be influenced by evaluations of other aspects of water supply and management (such as water leakage and cost). Moreover, in contrast with other international cities, past media coverage of water management issues in London has been shown to be critical of the privatised nature of the water industry (Bell, 2009). It is also worth noting that Thames Water's announcement of its IPR proposal, and its subsequent coverage in the news media, occurred following a series of notable meteorological events. In the spring of 2012, after two successive dry winters, Thames Water (along with other water companies) implemented water use restrictions in anticipation of severe drought over the summer (Thames Water, 2013). This was followed, in the summer of 2012, by a period of record rainfall and flooding in the south of England (Met Office, 2016), which caused many to question water companies' motivations in retaining water use restrictions (Russell-Verma et al., 2015). With respect to this study, such antecedent events may have had an influence on public expectations and discussions of water use and supply in London.

4.2 Methods

4.2.1 Data collection and selection

News articles and associated online comments were collected using online search engines, social media searches and Factiva (an online, subscription-based, news and information management resource) combining the following search terms with Boolean expressions: London, drinking, wastewater, sewage, recycling and water reuse. The search was purposive and focused on identifying Internet sources with news and comments relating to a statement released by Thames Water in May 2013 describing their IPR water resource option. Searches returned 35 websites that included 21 individual news articles and 1,708 online comments. The complete data-set collected is summarised in Appendix B, Table B-1. Comments included those posted on news media websites and those on social media (e.g. Facebook). They ranged in length from one word to some longer pieces of over 500 words but were typically one or two sentences. Many of the articles reported on or reproduced news content that originated in six prominent UK media organisations. Thus, the articles, secondary sources and comments were organised into cases corresponding to these six articles. In addition, there were some other UK and other international news sites that did not relate to these six articles.

The six media organisations that produced the central articles were prominent in the sense that they included the BBC (public service broadcaster) – the most used online news source in the UK (Newman, Fletcher, Levy, & Nielsen, 2016) – and five of the ten most widely read online daily newspapers, both in Greater London and nationally (National Readership Survey, 2016). The UK has a diverse news market, with some notable differences between major news outlets in terms of their content and editorial stances. On this basis, the six articles were purposively selected as they represented the breadth of the UK broadsheet and tabloid news with London representation (Table 4-1). For further discussion on the history, political stance and readership of the selected news sources, interested readers can consult a number of publications including Dunleavy & Taylor (2017) for a broad overview, Boykoff (2008) for a focus on UK tabloids and Carvalho & Burgess (2005) for a focus on UK broadsheets.

Table 4-1 A summary of the news articles and comments selected for analysis

Case	Description of news source*	National readership rank†	Article references and date published	Title of article	Online sources for article and comments	Online Comments	Social Media Posts	Total	Total Coded	% Coded
BBC	National public broadcaster. No print version. Politically neutral	**	BBC, (10 May 2013)	London 'could drink treated sewage' - Thames Water	BBC website and Facebook pages, Reddit, Twitter	0	105	105	39	37%
Daily Mail	Tabloid, popularist, politically right wing, conservative	1	McDermott, (10 May 2013)	Would you drink sewage? What millions will be asked as suppliers desperately try to beat water shortages	Daily Mail website and Facebook page, Twitter	685	128	813	254	31%
Evening Standard	Regional – London. Free paper. Politically centre-right, conservative	8	Cecil, (9 May 2013)	Drinking treated sewage could be the answer to the capital's water shortage, says Thames Water	Evening Standard website, Twitter	28	32	60	39	65%
Express	Tabloid, popularist, politically right wing conservative, Eurosceptic	10	La Borde, (10 May 2013)	So, would you like to drink recycled sewage? - Weird – News	Express website and Facebook page	9	42	51	34	67%
Guardian	Broadsheet. Politically centre-left, liberal, social-democrat	6	Saner, (10 May 2013)	Poll: are you happy to drink recycled sewage water?	Guardian website, Twitter	98	66	164	82	50%
Telegraph	Broadsheet, politically centre-right, conservative	4	Dixon, (9 May 2013)	Householders asked if they would drink treated sewage water	Telegraph website, Twitter	107	23	130	89	68%
					Total	927	386	1,323	537	41%

*See: Anderson, Allan, Petersen, & Wilkinson, (2005); Boykoff, (2008); Carvalho & Burgess, (2005); Dunleavy & Taylor (2017)
** the BBC is the most read online source (Newman et al., 2016) but is not ranked with the news brands
†Total online and print for combined daily and weekend editions in 2015 (National Readership Survey, 2016)

Other articles and their associated comments were excluded from the analysis (Appendix, Table A1). Some of the excluded articles were produced by regional UK news sites with limited reach and readership. Two of the excluded articles were produced by news outlets based in India and received no comments. The secondary articles that reported on the six principal articles were also excluded (see Suran, Holton, & Coleman, 2014, for similar exclusion criteria). These consisted of UK and international websites mainly containing environmentally focused news and discussion forums. These articles were excluded as they either reproduced the content of the six principal articles or were located on specialist websites with specific agendas and limited reach (some had no comments).

There are notable differences between the readerships of different news sites based on their demographic profiles, political orientations and their perceptions of certain socially charged issues, such as immigration (Duffy & Rowden, 2005). On this basis, it was concluded that the online comments responding to these six UK news articles could represent a diversity of opinions with knowledge of London's water resource management context. Comments were included in the analysis where they directly responded to one of the six articles. Comments were excluded if they did not respond directly to one of the six articles, or there was insufficient text to enable the semantic meaning to be labelled and categorised. Though it was not possible to determine the geographic location of many commenters, it was clear that many had experiences of London. Moreover, overall, the responses to the six selected articles demonstrated knowledge of the water resource management context of London and south-east England, existing water supply arrangements as well more exogenous social and political factors. The data selected for analysis originated from 13 different online sources (including news websites and social media sites) and encompassed the six articles and 1,323 comments.

4.2.2 Analytical approach

The six cases were used to organise and analyse the data using a framework-based approach (Ritchie & Lewis, 2003).This study used an inductive, data-driven thematic analysis and followed methods outlined by Braun & Clarke (2006). Coding was used to sort the news article content and comment data into categories, and tables were then used to organise the data by themes and cases. Comments were not coded if they clearly did not reflect on the London (or south-east England) water resource context. Coding was also halted for a particular set of comments if it was judged that saturation had been reached – i.e. no new concepts were emerging from reviewing successive data. This occurred within the comments responding to the *Daily Mail* article (C2.S8.A2). In this instance, the relatively large volume of comments (685) contained much repetition. Therefore, though *Daily Mail* comments dominated the sample, they did not dominate the analysis. Coding was undertaken using QSR International's NVivo software (version 10 and 11) and Microsoft Excel 2010 was used to organise themes into tables for comparison.

Coding was largely semantic, but due to the abbreviated nature of some comment data, some interpretation of latent meaning is acknowledged. A codebook was used to define codes and outline assumptions or interpretations made when coding. Data were coded that described perceptions of: (1) the water resource context for London; (2) the causes of the water supply deficit; (3) potential consequences of the scheme (e.g. risks or benefits); and (4) scheme barriers and preferences for management initiatives. The data were also categorised based on the sentiment expressed towards the proposal using labels for neutral, positive, negative or mixed sentiment (Feinberg et al., 2015). The unit of analysis for coding related to a text segment that conveyed a single idea and therefore could be the entire comment or a single word (Braun & Clarke, 2006; Ledford & Anderson, 2013; Price et al., 2012; Russell-Verma et al., 2015; Suran et al., 2014). For example, some of the coded text for 'yuck as a perceived scheme barrier' consisted of few words, such as *'Eww!'* (C1.S5). On the other hand, many single ideas were conveyed using more descriptive text. NVivo ('query' and 'explore') and Excel functions were used to aid the interrogation of the data and codes – this included quantification of the number of sources and text segments coded for each of the cases.

Themes were developed and refined by first sorting the codes then through iteration with the aid of thematic network maps to understand how themes related to each other. A random sample of 10% of the comment data was double coded by a second researcher and the level of inter-coder agreement was high (>95%). The percentage agreement of above 80% indicated the coding was reliable (Hurlimann & Dolnicar, 2012) and though there are limitations to this method, it is appropriate for qualitative analysis (Campbell, Quincy, Osserman, & Pedersen, 2013; Carey, Morgan, & Oxtoby, 1996).

The analysis of the news articles themselves also drew on media framing analysis concepts (Pan & Kosicki, 1993; Scheufele, 1999). The analysis, therefore, sought to identify the salient themes of the articles and whether certain problem definitions were being promoted. Media framing concepts helped focus the analysis on identifying features of the articles for both their structure, such as the arrangement of words or phrases, and their functional elements, such as images, terminology, language and tone (Entman, Matthes, & Pellicano, 2009). The analysis also considered the use of frame typologies describing generic or issue-specific themes (Entman et al., 2009) along with losses, e.g. costs, or gains, e.g. benefits (Holton, Lee, & Coleman, 2014). However, it was not within the scope of this study to evaluate the nature of external factors that may have influenced the selection of media frames. The articles were published over a short period of time (9 - 10 May 2013) and thus the analysis was concerned with framing around a single issue or event, rather than longer-term agenda setting.

To explore the potential influence of the article frames on the responses (i.e. the online comments), again, framing analysis concepts were employed using the definition that *'a framing effect occurs when audiences pay substantial attention to news messages'* (Scheufele & Tewksbury, 2007). This stage of analysis sought to qualitatively examine whether there was evidence that the media frames, considered as an independent variable, could be said to resonate with popular knowledge (Escobar & Demeritt, 2014) and, more specifically, to influence the responses (Scheufele, 1999). Drawing on pattern matching techniques (Yin, 2011), the proposition was that a framing effect would be indicated if similar patterns of themes and relative strength of sentiment (as coded) were observed between the articles and comments, across the cases. This was achieved by comparing the salient article framing characteristics with the audience's interpretations of the information presented, as reflected in the comments. Though this was qualitatively determined, quantitative outputs (e.g. proportion of comments per theme) were also reviewed to aid the interpretation. Given the wide range of compounding factors shaping the online comments, the findings from this analysis are indicative (rather than conclusive), but can nonetheless offer insight into the potential relationship between media framing and public responses.

This study was subject to review and approval by the university's research ethics committee, and it followed associated advice for conducting online research. Guided by this advice and previous related studies (Regan et al., 2014), paraphrased quotes were used where possible to reduce the traceability of individual comments through online searches and to keep quotations anonymous.

4.2.3 Limitations

There are recognised shortcomings to using online comments as data, including inability to gauge the representativeness of a given sample (due to lack of information about commenters), the exclusion of individuals without Internet access, and a prevalence of inaccurate information in comments (Anstead & Loughlin, 2014; Jaspal, Nerlich, & Koteyko, 2012). Therefore, it is widely acknowledged that people commenting online are not wholly representative of the views of the broader population (Regan et al., 2014). Moreover, a number of studies show that people commenting online are likely to voice strong opinions or exaggerate and their comments are more likely to be negative or disagree with the subject matter (Beninger et al., 2014; Regan et al., 2014). Therefore, online comments are more likely to represent the extremes of public opinion rather than the average. However, though online comments cannot be interpreted as generalizable (Regan et al., 2014) and there are other limitations, these online spaces do give individuals the opportunity to engage in extended conversations and present unsolicited reactions to both the articles and other commenters (Suran et al., 2014). The views offered therefore accurately reflect how some people react to issues presented in the news media and can provide insight into opinions that are not affected by researcher bias in survey questions (Regan et al., 2014; Russell, Lux, & Hampton, 2008).

4.3 Results

The findings reported below help address the principal research questions. The following sub-sections outline: (1) the identified characteristics of how the media framed the water reuse proposal; (2) the characteristics of public responses identified in the online comments; and (3) an interpretation of article framing effects.

4.3.1 Media framing of the news event

All of the articles alluded to a sense of disgust using 'toilet to tap' as a dominant frame and particularly through introducing some version of the somewhat misleading concept of 'drinking sewage' in the headlines. Regarding the use of imagery, with the exception of the Express (who used an image of a urinal) the articles used fairly generic and neutral water related pictures such as taps with flowing water. The *Evening Standard* and *Daily Mail* articles differed in their choices and included pictures of water treatment works. In terms of sources of information, all of the articles referred to the Thames Water spokesperson as their main source. Only two articles directly quoted other sources. The *Guardian* provided the perspective of a microbiologist and the BBC provided three quotes from the public in the article (all negative towards the proposal). The *Evening Standard* made reference to members of Parliament who *'are encouraging local people to respond'* (C3.S11.A4) (Cecil, 2013) and to Southern Water (a water company that covers areas to the south of London and is also considering similar proposals). No other organisations were mentioned in any of the articles.

There was evidence of the selective presentation of information being used as a framing technique in the articles. For instance, only one article (*Evening Standard*) indicated the inclusion of additional water treatment technology to ensure safety: *'It involves putting treated effluent from a sewage works through a further process which allows the effluent to be returned to a river at a higher than usual quality'* (C3.S11.A4) (Cecil, 2013). Another example of the selective presentation of information was found in the *Guardian* article, which was the only one to introduce possible beneficial impacts, or gains, from the scheme. These environmental benefits of more flow in the river were also weighed against potential environmental impacts (river pollution including higher levels of pharmaceuticals) and the potential for trade-offs between water treatment costs and risk management. Three articles (*Express*, *Evening Standard* and *Daily Mail*) mentioned the water would be treated to drinking water standards, for which the *Daily Mail* provided additional detail of the drinking water treatment processes (including the removal of pesticides and organic compounds and disinfection). The importance of public perception was put forward in three of the articles with the *Guardian* focusing on its relevance to the proposed IPR scheme for London while the *Evening Standard* and the *Telegraph* highlighted public opposition to other unsuccessful international schemes. All six articles highlighted that water reuse already occurs in London and how predicted population growth could exacerbate possible water shortages.

With the exception of the BBC, the articles: (1) mentioned that IPR was being considered as one of a number of options; (2) gave a brief definition of IPR; and (3) discussed variations of popular perception that the existing water supply has passed through 'seven sets of kidneys' before it reaches taps in London. Thus, in terms of framing out certain information, it was notable that the BBC was the only case not to introduce these three aforementioned matters in either the article or associated sources (i.e. Facebook page introductions to the story). Also of note was the comparative brevity of the BBC article (the shortest article with 267 words), particularly given that it is the most used online news source in the UK. Other noted exclusions included the *Guardian* as the only article not to mention reuse being practised internationally. Thus, the presence or absence of certain information provided evidence of framing. It was not within the scope of this study, however, to evaluate the reasoning behind these choices except to note that different editorial and journalistic preferences (along with time pressures, for example) and antecedent events are likely to have played a part.

The *Guardian* article introduced potential uncertainty of health risks (*'the pharmaceuticals in sewage are quite resistant to breaking down'*) and environmental impacts (*'If there is no further treatment of the sewage before they inject it into the rivers, that could have implications for things that live in the river'*) along with the possible costs associated with managing these risks (*'It's a problem that can be solved by throwing money at it.'*), adding that, *'the water is going to be from sewage effluent and that's more of an unknown'* (C5.S18.A8) (Saner, 2013). These extracts were collectively classified during the analysis as potentially being used to introduce uncertainty and doubts to readers about the potential impacts of the water reuse scheme proposal (hedging). In contrast, themes relating to water safety management (e.g. the existence of a research programme, the capabilities of water treatment technology and the presence of drinking water standards) and to the nature of the water cycle were categorised as being presented with more certainty and optimism (and reassurance) towards the prospects of the proposal.

The analysis identified the use of both generic and issue-specific themes in the media frames. The more generic theme of water shortages being caused by population growth was identified across all of the articles. In all instances, this theme was used in defining the problem and a potential for loss, for example: *'could lead to usage bans and eventually see some homes without enough water'* (C6.S28.A16) (Dixon, 2013). In some cases this theme encompassed descriptions of more sensational consequences, for example, *'drastic measures will be needed'* (C5.S18.A8) (Saner, 2013). Some articles also emphasised specific elements of the proposed scheme design, thus encouraging the reader to consider the possibility of problems. For example, two articles (*Express* and *Telegraph*) emphasised that the recycled water from the proposed scheme would be returned closer to drinking water treatment works than instances of de-facto reuse,: *'Waste water . . . is currently treated and returned to the environment miles from treatment works which process drinking water. But the new process being investigated would mean toilet water which has been treated will be <u>put straight back</u> in a river upstream of a water treatment plant'* (C4.S16.A6 – emphasis added) (La Borde, 2013).

Overall, the BBC (albeit briefly), *Daily Mail* and *Evening Standard* were identified as more balanced in terms of the use of positive and negative sentiments towards the proposal (e.g. through tone, emphasis and selection of information). On the other hand, the *Telegraph*, *Express* and *Guardian* were evaluated as somewhat more negatively biased in their overall sentiment towards the proposed reuse scheme. Despite these observations however, it is worth noting that much of the articles' representations of the scheme was also categorised as having a neutral sentiment.

4.3.2 Public responses

Five thematic categories emerged from the qualitative analysis of the online comments describing characteristics of the public's response to the proposed IPR scheme. These were: (1) perceptions of water quality and risks, (2) trust in organisations to manage water resources, (3) perceptions of underlying problems and their root causes (e.g. population growth as a root cause for impending water shortages), (4) environmental conservation values and (5) perceptions and knowledge of the climate and the water-cycle. Together, these characteristics appear to shape commenters' reactions towards the proposed reuse scheme and their broader preferences for supply-side or demand-side solutions.

Perceptions of water quality and risks identified in the comment data were associated with both health-related matters and also other water quality characteristics such as taste or hardness. This theme was evident across all of the cases and generally referred to perceived negative impacts, or losses, associated with the proposed reuse scheme. Health risk perceptions were expressed relating to a range of contaminants, including pathogens and pharmaceuticals, which were seen by some as being able to pass through the treatment system and enter the drinking water supply, for example, *'Varying amounts of pathogens, pharmaceutical chemicals . . . and other trace chemicals are able to pass through the treatment and filtering process, potentially causing danger to humans'* (C3.S11.A4). On the other hand, there were those who thought the process would be safe, particular if the water met drinking water standards. In the data, there were examples of risk and quality perceptions of water reuse being judged based on perceptions of the existing water supply or other everyday activities (particularly the consumption of food and beverage products). These responses were often anchored to anecdotes or personal experiences and negative perceptions of the existing quality of water supply (such as water hardness or taste). A repeated example was that the water already tasted bad and therefore the reuse scheme would not make this worse (some speculated that recycled water might taste better).

Trust in London's water resource management was identified in the analysis as influencing responses to the proposal across all six cases. For instance, a lack of trust was directed towards a range of organisations including the water company (and particularly its privatised nature), the British government and the European Union. The lack of trust was often associated with the failure of such organisations to meet consumer expectations - including failure (particularly on the part of the water company) to repair water leaks. Other reasons for this lack of trust included scepticism towards the motivation of the water company (which was described as being out to make a profit or increase prices) and a lack of perceived control (or influence) over the outcomes of water resource management decisions. In terms of ways to improve trust, the role of communication was identified. A number of comments highlighted perceived communication problems that were then linked with a lack of trust, for example, *'The biggest concern is what they don't take out, drugs, hormones antibiotics etc. That's the stuff that really does damage to us. <u>But it's never talked about is it?</u>'* (C4.S16.A6 – emphasis added).

Though the theme of trust in water resource management consisted of predominantly negative sentiments towards the reuse scheme, some positive sentiments were identified. These were particularly associated with regulations to control drinking water safety and referred to both UK drinking water standards and European water quality regulations. Some comments also expressed a high degree of trust in regulators, suggesting that they wouldn't allow water companies to supply unsafe water. Moreover, while many comments expressed a lack of trust regarding the water company's financial motivations (e.g. they might increase water bills), some instead speculated on the potential for gains if recycled water were less expensive.

The comments articulated various perspectives on a number of underlying problems contributing to the water management challenges described in the articles. These perceptions of root causes were used to support preferences for management options, particularly relating to population growth and water infrastructure preferences. These types of perceptions were particularly evident in comments with a negative sentiment towards the proposed reuse scheme. Population growth was perceived as driving the water supply deficit and many expressed strong views that population growth (particularly immigration) should be limited, and that other infrastructure (e.g. housing, transport, water) was already inadequate. A number of commenters voiced preferences for other supply-side solutions such as new reservoirs, water transfers or desalination.

Perceptions, and particularly personal experiences, of the climate meant that some comments argued that London (or the UK more generally) has sufficient rainfall and therefore additional water resources were not necessary (if they were managed effectively). The counter-claim to this was also evident in comments which argued that the IPR scheme was a good idea because the region was becoming drier. Some comments suggested that climate change was not occurring and that more energy intensive seawater desalination should therefore be the preferred solution. This theme describing perceived root causes of water management problems was dominant across the cases with the exception of the Guardian where there was relatively less interest in this type of argument.

Environmental conservation values were also identified and often in comments with negative sentiments towards the IPR scheme. These values influenced preferences for water resource conservation that prioritised reducing network leakage and behaviour change over the need for a new source of water. Environmental values were identified that exhibited preferences for other supply-side solutions as well, such as rainwater harvesting and community non-potable reuse instead of the IPR scheme.

Across the comment data, and all cases, a frequent response was that all water is already naturally recycled and that, therefore, the principle of IPR was not surprising or contentious. Similar comments referenced popular knowledge or the belief that the practice already happens in London (i.e. *de-facto* IPR), for example, *'I thought we had been drinking recycled water for years'* (C1.S2). Similar responses often cited the belief (also introduced in the articles) that drinking water in London has already passed through several sets of kidneys before it reaches the tap. Finally, knowledge of water reuse (and technology such as reverse osmosis to manage health risks) being used in other international settings (e.g. Singapore) was drawn on in some comments to lend support to the principle of IPR.

Table 4-2 Comparison of the article themes with the responses including the relative strength of the sentiment expressed towards the proposal

	Description of context			Perceived driving factors			Perceived scheme barriers		Perceived impacts				Risk management initiatives		
Case	Reuse already occurs	There are other options	IPR process	Pop. Growth	Climate	Mgmt of water resources	Yuck	Public perception	Cost	Health risk	Env. impact	Future proofing	Existing research	Water treatment technology	Quality standards (drinking water)
1.	A+, C+	C-	×	A, C-	×	C-	A-, C-	×	C-	C-	×	A+	A	C+	×
2.	A+, C+	A+, C-	A	A, C-	A-, C-	C-	A-, C-	×	C-	C-	×	A+	A	A, C+	A+, C+
3.	A+, C+	A+, C-	A	A, C-	A-, C+	C-	A-, C	A-	C-	C	×	A+	A	A+	A+
4.	A-, C+	A+, C-	A-	A-, C-	A-	C-	A-, C	×	C+	C-	×	A+	×	C+	A
5.	A, C+	A+, C-	A	A, C-	A-, C+	C-	A-, C-	A-, C-	A-, C+	A-, C-	A, C	A+. C+	×	C+	C+
6.	A-, C+	A+, C-	A	A-, C-	A-	C-	A-, C-	A-	C-	C-	×	A+	×	C	×

1 = BBC, 2= Daily Mail, 3 = Evening Standard, 4 = Express, 5 = Guardian, 6 = Telegraph
A = Present in article, C = Present in comments, +/- = indicates a dominance of a positive or negative sentiment towards the proposal
× = not identified in either the article or comments

4.3.3 Framing effects

Though there were some identifiable differences in the types of framing employed by the news articles, the analysis did not highlight any apparent related differences in the themes or in the relative strength of sentiment expressed in the comments. Therefore the analysis did not find evidence that the media frames used in the news articles had any influence on the patterns of responses that the articles elicited (Table 4-2). For example, despite the issue-specific 'toilet to tap' framing employed in the articles, the origin of the water was described as unimportant by some (particularly those who expressed the view that 'all water is recycled'). Instead, what the analysis highlighted was that some reactions were largely consistent across the six cases regardless of what information was present in the article and how it was presented. Examples of consistent reactions included negative sentiments towards the reuse proposal that were related to perceptions of root causes like population growth (a subject for which the views in the comments were generally much stronger and far more diverse than in the articles) and preferences for alternative solutions (particularly fixing existing water network leaks).

Health risk concerns from chemicals (e.g. hormones, pharmaceuticals) were expressed in the comments across all cases. However, only the *Guardian* article had included this aspect in its problem frame. Conversely, another characteristic of the comments that was consistent across all cases was the absence of responses describing the longer-term benefits of water resource planning, a subject which was mentioned by all the articles. Only one case (the Guardian) included comments that articulated a perceived benefit from longer-term planning. Thus, these findings provided more evidence that the media frames being used in the articles were not significantly influencing the responses.

The analysis showed that descriptions of the water cycle, *de-facto* IPR and of other international water reuse schemes were being used positively in the comments, in support of the IPR scheme, irrespective of an article's framing. Moreover, knowledge of water treatment technology (such as reverse osmosis) and water quality regulation were raised across the comments of multiple cases as valid ways of managing safety, even when such topics were not raised in the articles themselves. Therefore, though the news event could be interpreted as having resonated with popular knowledge, the articles' frames could not be interpreted as having a framing effect on online responses. In summary, existing attitudes (including attitudes to certain socially charged and political issues) and popular knowledge appeared to have more influence on the responses than the news articles themselves. These observations, to some extent, probably reflect established differences between the readerships of the different publications (as mentioned previously), people gaining knowledge from different sources and the longer-term agendas these different media organisations promote.

4.4 Discussion

This study adds support to previously highlighted benefits of using online comments to capture snapshots of public reactions to water-related events and proposals (Russell-Verma et al., 2015), also noting that some time is necessary to collate and analyse these types of data. Though there are recognised limitations (discussed previously) associated with such data, they can offer a near-real-time view of public responses as they emerge. In this study, the analysis of online comments highlighted the diverse ways in which the public responded to the IPR proposal for London as described by six prominent UK news organisations. Moreover, the data showed a familiarity with the water resource management context (as well as related social and political factors). Thus, in spite of the sample not being representative of London's general public, it was evident that it did represent how some people (with knowledge of the context) reacted, providing useful insight into the potential breadth of public opinions. As there is a desire to extend public engagement and participation around water reuse proposals (Hartley, 2006), online platforms may potentially offer innovative ways to experiment with different messages and techniques.

Analysis of online comments and social media data is likely to become more common – both in general and in the context of water management. The findings of this study draw attention to the need to consider more reflexive, mixed method approaches (e.g. see Doria et al., 2009) that can incorporate social media data analyses, particularly in the context of evaluating the potential breadth of public responses to water reuse scheme proposals. Complementary methods could include questionnaires, focus groups and analysis of documents produced by policy forums or campaign organisations. The incorporation of interpretive approaches may help improve attempts to understand public acceptance of water reuse (Fielding & Roiko, 2014) which can struggle to account for how different people interpret meaning (Marks, Martin, & Zadoroznyj, 2008). This insight also corroborates conclusion from a related UK study

(Russell-Verma et al., 2015), providing additional, independent evidence of the benefits of exploring the qualitative richness of online comment data.

Water reuse has a low profile in the UK so it is not surprising that comments displayed favourable attitudes towards other supply side solutions (e.g water transfers) - other studies have also indicated these preferences are well established (Russell-Verma et al., 2015). The present findings indicate a tendency for the comments to draw on more generic perceptions of the underlying problems contributing to the water resource management challenge, such as population growth. Conversely, issue-specific frames such as 'toilet to tap', which were prominent in the news articles, did not strongly feature in the comments. This study, therefore, provides some support to other IPR studies showing that people's underlying attitudes or values might underpin their perceptions of water supply problems and their associated reactions to water reuse schemes (Price et al., 2012). The present findings indicate that, in this case and in similar contexts, people's perceptions of certain underlying root causes of water management problems may strongly influence their initial reactions to water reuse scheme proposals. Thus, public outreach that does not sufficiently engage with these concerns may mean some negative perceptions continue to undermine single communication efforts.

This study was the first known attempt to explore how the framing of an actual news event (the announcement of a real IPR proposal for London) may have influenced unsolicited public responses to water reuse through the use of 'naturally occurring' online data. Moreover, despite the small sample of news articles, these did demonstrate how the breadth of prominent UK news media could vary the framing of the IPR scheme under question. The lack of evidence of the influence of media framing, in this case, is likely to be due in part to the short timescale considered. This supports a previous study suggesting limited short-term influence of news media reporting on a water reuse proposal (van Vuuren, 2009).Though it has been suggested that media framing contributes to polarising attitudes towards water management proposals (Wei et al., 2015), this may be set by longer-term agendas (Carvalho & Burgess, 2005; Leong, 2010). Longer-term media agendas may, therefore, challenge single media communication events of IPR scheme proposals and supersede more issues-specific frames if they shape people's perceptions of more general issues such as population growth.

However, this research also suggests that single media events may allow water resource planners, public relations experts and academics to experiment with communicating issues-specific themes such as referring to popular knowledge of the existing water supply and health risk contexts, and emphasising new water safety initiatives, specific research activities and short-term IPR scheme benefits. These claims are supported by previously suggested benefits of promoting public deliberations around the water-cycle (Lyytimaki & Assmuth, 2014) and water safety (Russell et al., 2008). Building these narratives may help counter longer-term agendas being set by the media or other stakeholders and contribute to the continuous communication needed to build public understanding (Kemp et al., 2012).

This study did not find evidence that media speculation on the health risks associated with reuse affected the public response in comments, as has been suggested for other scheme proposals (Ross et al., 2014). This finding is consistent with related research, suggesting other influences, such as trusted opinion leaders (van Vuuren, 2009). In contrast to other findings (Lyytimaki & Assmuth, 2014), lack of attention to relevant risks was not observed in the comments. However, the findings did show a lack of attention to scheme benefits (or gains), in both the articles and the comments. There was limited attention to short-term benefits across all data and the comments did not reflect the articles' framings of longer-term benefits of water resource management planning. This could relate to people tending to concentrate on more immediate concerns, such as health risk, instead of longer-term benefits, such as water security for future generations (Kemp et al., 2012).The implication of the findings of this study is that promotion of IPR schemes in the media may be aided by the better articulation of more immediate or tangible benefits to help improve public perceptions.

4.5 Conclusion

The analysis found no evidence that the media's framing of a single news event describing a water reuse scheme proposal for London had a strong influence on online responses. Instead, people's perceptions of more general causes of water management problems, environmental values and prior knowledge of the water-cycle, were plausibly more influential. Though constrained by limitations on the generalisability of the findings, this study suggests online comments can help highlight themes describing positive sentiments towards the principle of water reuse and to the specific reuse proposal. Moreover, individual media events can offer useful opportunities for water resource planners, public relations experts and academics to explore the impact of different issue-specific framings, such as, popular knowledge of the water-cycle and areas of confidence in water safety initiatives to manage perceived risks.

There is a need for further exploration of how message themes around water safety initiatives and short-term benefits might affect public support for water reuse schemes. There is also a need to build understanding of how public engagement methods can be developed that sufficiently engage with diverse concerns, particular regarding broader concerns linked to perceptions of water resource management. Finally, this study also raised a number of other avenues for future research, particularly related to theoretical, methodological and practical aspects of using online platforms and social media to support public engagement research.

4.6 Acknowledgements

This research was co-funded by the UK's Engineering and Physical Science Research Council (EPSRC) grant number EP/G037094/1 and Thames Water through the STREAM Industrial Doctorate Centre. Thanks to the research assistance provided by Harpreet Mann.

4.7 References

Aitken, V., Bell, S., Hills, S., & Rees, L. (2014). Public acceptability of indirect potable water reuse in the south-east of England. Water Science & Technology: Water Supply, 1–11. http://doi.org/10.2166/ws.2014.051

Anderson, A., Allan, S., Petersen, A., & Wilkinson, C. (2005). The Framing of Nanotechnologies in the British Newspaper Press. Science Communication, 27(2), 200–220. http://doi.org/10.1177/1075547005281472

Anstead, N., & Loughlin, B. O. (2014). Social Media Analysis and Public Opinion : The 2010 UK General Election. Journal of Computer-Mediated Communication, 1–17. http://doi.org/10.1111/jcc4.12102

BBC. (2013). London â€TM could drink treated sewage â€TM - Thames Water. Retrieved June 1, 2015, from www.bbc.co.uk/news/uk-england-london-22479216

Bell, S. (2009). The driest continent and the greediest water company : newspaper reporting of drought in Sydney and London. International Journal of Environmental Studies, 66(5), 581–589. http://doi.org/10.1080/00207230903239220

Beninger, A. K., Fry, A., Jago, N., Lepps, H., Nass, L., Silvester, H., … Silvester, H. (2014). Research using social media; users' views. NatCen Social Research. London.

Bojovic, D., Bonzanigo, L., Giupponi, C., & Maziotis, A. (2015). Online participation in climate change adaptation : A case study of agricultural adaptation measures in Northern Italy. Journal of Environmental Management, 157, 8–19. http://doi.org/10.1016/j.jenvman.2015.04.001

Boykoff, M. T. (2008). The cultural politics of climate change discourse in UK tabloids. Political Geography, 27(5), 549–569. http://doi.org/10.1016/j.polgeo.2008.05.002

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. http://doi.org/10.1191/1478088706qp063oa

Bruvold, W. (1972). Public Attitudes Towards Reuse of Reclaimed Water, Contribution No.137. School of Public Health, University of California, Berkeley.

Campbell, J. L., Quincy, C., Osserman, J., & Pedersen, O. K. (2013). Coding In-depth Semistructured Interviews: Problems of Unitization and Intercoder Reliability and Agreement. Sociological Methods & Research, 42(3), 294–320. http://doi.org/10.1177/0049124113500475

Carey, J., Morgan, M., & Oxtoby, M. J. (1996). Intercoder Agreement in Analysis of Responses to Open-Ended Interview Questions: Examples from Tuberculosis Research. Cultural Anthropology Methods, 8(3), 1–5.

Carvalho, A., & Burgess, J. (2005). Cultural circuits of climate change in U.K. broadsheet newspapers, 1985-2003. Risk Analysis, 25(6), 1457–1469. http://doi.org/10.1111/j.1539-6924.2005.00692.x

Cecil, N. (2013). Drinking treated sewage could be the answer to the capital's water shortage, says Thames Water. Retrieved June 1, 2015, from www.standard.co.uk/news/london/drinking-treated-sewage-could-be-the-answer-to-the-capitals-water-shortage-says-thames-water-8608672.html

Crook, J., Mosher, J. J., & Casteline, J. M. (2005). Status and Role of Water Reuse: An international Review. London.

Dunleavy, P., Taylor, R. (2017) The 2017 Audit of UK Democracy. October 2017. Core-funded by the Joseph Rowntree Charitable Trust with the assistance of the London School of Economics and Political Science, from www.democraticaudit.com/wp-content/uploads/2017/11/2017AuditofUKDemocracy.pdf

Dixon, H. (2013). Householders asked if they would drink treated sewage water. Retrieved June 1, 2015, from www.telegraph.co.uk/news/earth/earthnews/10047555/Householders-asked-if-they-would-drink-treated-sewage-water.html

Doria, M. D. F., Pidgeon, N., & Hunter, P. R. (2009). Perceptions of drinking water quality and risk and its effect on behaviour: a cross-national study. Science of the Total Environment, 407(21), 5455–64. http://doi.org/10.1016/j.scitotenv.2009.06.031

Duffy, B., & Rowden, L. (2005). You Are What You Read? How newspaper readership is related to views. London.

Entman, R. M. (1993). Framing: Toward Clarification of a Fractured Paradigm. Journal of Communication, 43(4), 51–58. http://doi.org/10.1111/j.1460-2466.1993.tb01304.x

Entman, R. M., Matthes, J., & Pellicano, L. (2009). Nature, Sources, and Effects of News Framing. In K. Wahl-Jorgensen & T. Hanitzsch (Eds.), The Handbook of Journalism Studies. Abingdon, Oxon: Taylor & Francis.

Escobar, M. P., & Demeritt, D. (2014). Flooding and the framing of risk in British broadsheets, 1985-2010. Public Understanding of Science (Bristol, England), 23(2000), 454–71.

http://doi.org/10.1177/0963662512457613

Feinberg, Y., Pereira, J. A., Quach, S., Kwong, J. C., Crowcroft, N. S., Wilson, S. E., … Deeks, S. L. (2015). Understanding Public Perceptions of the HPV Vaccination Based on Online Comments to Canadian News Articles. PLoS ONE, 10(6), 1–13.

Fielding, K. S., & Roiko, A. H. (2014). Providing information promotes greater public support for potable recycled water. Water Research, 61, 86–96. http://doi.org/10.1016/j.watres.2014.05.002

Harris-Lovett, S., Binz, C., Sedlak, D. L., Kiparsky, M., & Truffer, B. (2015). Beyond User Acceptance: A Legitimacy Framework for Potable Water Reuse in California. Environmental Science & Technology, 49, 7552–7561. http://doi.org/10.1021/acs.est.5b00504

Hartley, T. W. (2006). Public perception and participation in water reuse. Desalination, 187, 115–126. http://doi.org/10.1016/j.desal.2005.04.072

Hills, S., Germain, E., Birks, R., Wyber, A., Tormenta, S., Risdale, H., & Raffin, M. (2009). A holistic approach to explore the potential of planned Indirect Potable Reuse for London. In IWA Reuse Conference, Brisbane, September 2009 (pp. 1–3). Brisbane: IWA Publishing.

Holton, A., Lee, N., & Coleman, R. (2014). Commenting on health: a framing analysis of user comments in response to health articles online. Journal of Health Communication, 19(7), 825–37. http://doi.org/10.1080/10810730.2013.837554

Hurlimann, A., & Dolnicar, S. (2010). When public opposition defeats alternative water projects - The case of Toowoomba Australia. Water Research, 44(1), 287–297. http://doi.org/10.1016/j.watres.2009.09.020

Hurlimann, A., & Dolnicar, S. (2012). Newspaper coverage of water issues in Australia. Water Research, 46(19), 6497–6507. http://doi.org/10.1016/j.watres.2012.09.028

Hurlimann, A., & Dolnicar, S. (2016). Public acceptance and perceptions of alternative water sources : a comparative study in nine locations. International Journal of Water Resources Development, 32(4), 650–673. http://doi.org/10.1080/07900627.2016.1143350

Huskova, I., Matrosov, E. S., Harou, J. J., Kasprzyk, J. R., & Lambert, C. (2016). Screening robust water infrastructure investments and their trade-offs under global change : A London example. Global Environmental Change, 41, 216–227. http://doi.org/10.1016/j.gloenvcha.2016.10.007

Jaspal, R., Nerlich, B., & Koteyko, N. (2012). Contesting Science by Appealing to Its Norms : Readers Discuss Climate Science in the Daily Mail. Science Communication, 35(3), 383–420. http://doi.org/10.1177/1075547012459274

Kasperson, R. E., Renn, O., Slovic, P., Brown, H. S., Emel, J., Goble, R., … Ratick, S. (1988). The Social Amplification of Risk: A Conceptual Framework. Risk Analysis, 8(2), 177–187. http://doi.org/10.1111/j.1539-6924.1988.tb01168.x

Kemp, B., Randle, M. J., Hurlimann, A., & Dolnicar, S. (2012). Community acceptance of recycled water - can we inoculate the public against scare campaigns? Journal of Public Affairs, 12, 337–346.

La Borde, L. (2013). So, would you like to drink recycled sewage? Retrieved May 1, 2015, from www.express.co.uk/news/weird/398502/So-would-you-like-to-drink-recycled-sewage

Ledford, C. J. W., & Anderson, L. N. (2013). Online social networking in discussions of risk: applying the CAUSE model in a content analysis of Facebook. Health, Risk & Society, 15(February), 251–264. http://doi.org/10.1080/13698575.2013.776016

Lee, H., & Tan, T. P. (2016). Singapore's experience with reclaimed water: NEWater. International Journal of Water Resources Development, 32(4), 611–621. http://doi.org/10.1080/07900627.2015.1120188

Leiserowitz, A. A., Maibach, E. W., Roser-Renouf, C., Smith, N., & Dawson, E. (2013). Climategate, Public Opinion, and the Loss of Trust. American Behavioral Scientist, 57(6), 818–837. http://doi.org/10.1177/0002764212458272

Leong, C. (2010). Eliminating " Yuck ": A Simple Exposition of Media and Social Change in Water Reuse Policies. International Journal of Water Resources Development, 26(1), 111–124. http://doi.org/10.1080/07900620903392174

Leong, C. (2016). A lived-experience investigation of narratives : recycled drinking water. International Journal of Water Resources Development, 32(4), 637–649. http://doi.org/10.1080/07900627.2015.1126235

Lyytimaki, J., & Assmuth, T. (2014). Down with the flow: public debates shaping the risk framing of artificial groundwater recharge. GeoJournal, 80, 113–127. http://doi.org/10.1007/s10708-014-9540-3

Mainali, B., Ngo, H. H., Guo, W. S., Pham, T. T. N., Wang, X. C., & Johnston, A. (2011). SWOT analysis to assist identification of the critical factors for the successful implementation of water reuse schemes. Desalination and Water Treatment, 32(1–3), 297–306. http://doi.org/10.5004/dwt.2011.2714

Marks, J. (2006). Taking the Public Seriously: The Case of Potable and Non Potable Reuse. Desalination, 187(1–3), 137–147. http://doi.org/10.1016/j.desal.2005.04.074

Marks, J., Martin, B., & Zadoroznyj, M. (2008). How Australians order acceptance of recycled water National baseline data. Journal of Sociology, 44(1), 83–99. http://doi.org/10.1177/1440783307085844

Marks, J., & Zadoroznyj, M. (2005). Managing Sustainable Urban Water Reuse: Structural Context and Cultures of Trust. Society & Natural Resources : An International Journal, 18(6), 37–41. http://doi.org/10.1080/08941920590947995

Mase, A. S., Cho, H., & Prokopy, L. S. (2015). Enhancing the Social Amplification of Risk Framework (SARF) by exploring trust, the availability heuristic, and agricultural advisors â€TM belief in climate change. Journal of Environmental Psychology, 41, 166–176. http://doi.org/10.1016/j.jenvp.2014.12.004

McDermott, N. (2013). Would you drink sewage? What millions will be asked as suppliers desperately try to beat water shortages. Retrieved June 1, 2015, from www.dailymail.co.uk/news/article-2322249/Would-drink-sewage-What-millions-asked-suppliers-desperately-try-beat-water-shortages.html

Met Office. (2016). Past weather events. Retrieved June 3, 2016, from www.metoffice.gov.uk/climate/uk/interesting#y2012

Mistry, B., & Driedger, S. M. (2012). Do the leads tell the whole story? An analysis of story leads of the Walkerton, Ontario E.coli contamination of drinking water supplies. Health, Risk & Socity, 14(6), 583–603.

National Readership Survey. (2016). Results: Newsbrands Print/PC. Retrieved June 29, 2016, from www.nrs.co.uk/latest-results/nrs-padd-results/newspapers-nrspaddresults/

Newman, N., Fletcher, R., Levy, D., & Nielsen, R. K. (2016). Reuters Institute Digital News Report 2016. Oxford, UK.

Pan, Z., & Kosicki, G. (1993). Framing analysis: An approach to news discourse. Political Communication, 10, 55–75. http://doi.org/10.1080/10584609.1993.9962963

Price, J., Fielding, K. S., & Leviston, Z. (2012). Supporters and Opponents of Potable Recycled Water : Culture and Cognition in the Toowoomba Referendum. Society and Natural Resources, 25, 980–995. http://doi.org/10.1080/08941920.2012.656185

Regan, Á., Shan, L., Mcconnon, Á., Marcu, A., Raats, M., Wall, P., & Barnett, J. (2014). Strategies for dismissing dietary risks : insights from user-generated comments online. Health, Risk & Socity, 16(4), 308–322. http://doi.org/10.1080/13698575.2014.919993

Ritchie, J., & Lewis, J. (2003). Qualitative research practice: A guide for social science students and researchers. London, UK: SAGE Publications Ltd. http://doi.org/10.4135/9781452230108

Ross, V. L., Fielding, K. S., & Louis, W. R. (2014). Social trust, risk perceptions and public acceptance of recycled water: Testing a social-psychological model. Journal of Environmental Management, 137, 61–68. http://doi.org/10.1016/j.jenvman.2014.01.039

Rozin, P., Haddad, B., Nemeroff, C., & Slovic, P. (2015). Psychological aspects of the rejection of recycled water: Contamination, purification and disgust. Judgement and Decision Making, 10(1), 50–63.

Russell-Verma, S., Smith, H. M., & Jeffrey, P. (2015). Public views on drought mitigation : Evidence from the comments sections of on-line news sources. Urban Water Journal, 1–9. http://doi.org/10.1080/1573062X.2014.993998

Russell, S., Lux, C., & Hampton, G. (2008). Beyond "Information": Integrating Consultation and Education for Water Recycling Initiatives. Society & Natural Resources, 22(November 2014), 56–65. http://doi.org/10.1080/08941920801910666

Saner, E. (2013). Poll: are you happy to drink recycled sewage water? Retrieved June 1, 2015, from www.theguardian.com/environment/shortcuts/poll/2013/may/10/water-health

Scheufele, D. A. (1999). Framing as a theory of media effects. Journal of Communication, 49, 103–122. http://doi.org/10.1111/j.1460-2466.1999.tb02784.x

Scheufele, D. A., & Tewksbury, D. (2007). Framing, agenda setting, and priming: The evolution of three media effects models. Journal of Communication, 57, 9–20. http://doi.org/10.1111/j.1460-2466.2006.00326.x

Simpson, J., & Stratton, H. (2011). Talking about water : words and images that enhance understanding. National Water Commission, Canberra.

Suran, M., Holton, A. E., & Coleman, R. (2014). Topical Punch : Health Topics as Drivers of Idiosyncratic Reader Responses to Online News. http://doi.org/10.1177/1077699014550093

Tang, Z., Zhang, L., & Xu, F. (2015). Examining the role of social media in California's drought risk management in 2014. Natural Hazards, 79(1), 171–193. http://doi.org/10.1007/s11069-015-1835-2

Thames Water. (2013). Annual performance report 2012/2013. Reading, UK.

Thames Water. (2014). Revised Draft Water Resources Management Plan (2015-2040) - Section 6: Baseline Supply Demand Position. Reading, UK.

Thames Water. (2015). Thames Water Water Resources Management Plan 2015 - 2040 - Executive Summary. Reading, UK.

van Vuuren, K. (2009). Press bias and local power in the Toowoomba water referendum. Communication, Politics & Culture, 42(1), 55–73.

Wei, J., Wei, Y., Western, A., Skinner, D., & Lyle, C. (2015). Evolution of newspaper coverage of water issues in Australia during 1843 – 2011. AMBIO, 44, 319–331. http://doi.org/10.1007/s13280-014-0571-2

Westerman, D., Spence, P. R., & van der Heide, B. (2014). Social media as information source: Recency of updates and credibility of information. Journal of Computer-Mediated Communication, 19(2), 171–183. http://doi.org/doi:10.1111/jcc4.12041

White, I., Kingston, R., & Barker, A. (2010). Participatory geographic information systems and public engagement within flood risk management. Journal of Flood Risk Management, (3), 337–346. http://doi.org/10.1111/j.1753-318X.2010.01083.x

Xiong, Y., Wei, Y., Zhang, Z., & Wei, J. (2016). Evolution of China's water issues as framed in Chinese mainstream newspaper. Ambio, 45(2), 241–253. http://doi.org/10.1007/s13280-015-0716-y

Yin, R. K. (2011). Applications of Case Study Research: Third Edition. SAGE Publications Ltd.

Chapter 5. Informing public attitudes to non-potable water reuse – the significance of message framing

D. Goodwin[1], M. Raffin[2], P. Jeffrey[1], H. M. Smith[1]

[1]Cranfield Water Science Institute, Cranfield University, Bedfordshire, UK, MK43 0AL

[2]Thames Water Utilities Ltd, Innovation, Reading STW, Island Road, Reading, UK RG2 0RP

Abstract

While water reuse is of increasing relevance for many water-stressed regions, it is often considered a contentious water resource option. Previous research has shown that providing the public with information about reuse options can have positive impacts on levels of acceptability, although such impacts can be confined to specific groups. In this context, there is growing interest in understanding the impact of different forms and mechanisms of communication with the public around reuse. Where previous studies in this vein focused on water reuse for potable applications, this contribution has investigated the use of video animations to communicate the safety of non-potable recycled water schemes. The aim of this study was to evaluate how different ways of framing messages about the safety of recycled water might impact on public attitudes. Participants were recruited in London (n=753), UK, and randomly allocated to test and control groups, with the former being exposed to one of four video animations that used different frames to convey messages about recycled water safety. Surveys collected pre- and post-video message responses for dependent variables including acceptance of non-potable recycled water, risk perceptions and trust. Our findings complement existing knowledge on the impacts of different types of messaging on public attitudes to reuse schemes with important evidence for the positive influence of water safety communications which are framed in terms of compliance with water quality requirements. The results also indicate that this kind of communication can improve trust in the authorities responsible for managing recycled water safety. The results are of value to water resource planners looking to develop communication resources for engaging with the public and improving perceptions of water reuse. Importantly, the findings help isolate the effects of specific message frames, and inform the debate on whether an increased understanding of risk positively or negatively influences willingness to support water reuse schemes.

Keywords: Non-potable water, recycled water, communication, message framing, public attitudes

5.1 Introduction

It is often claimed that the acceptability and ultimate success of water reuse schemes are enhanced by early public engagement in planning and design (Frijns et al., 2016; Hurlimann and Dolnicar, 2016; Lee and Tan, 2016). In place of 'decide-announce-defend', the importance of pursuing more inclusive approaches is clearly articulated in water reuse regulations and guidelines (European Commission, 2016; NRMMC EPHC & AHMC, 2006; USEPA, 2012). This imperative for timely public engagement has also been informed by the experiences of both successful (Harris-Lovett et al., 2015) and unsuccessful (Hurlimann and Dolnicar, 2010) schemes involving both potable and non-potable recycled water uses. The accumulating evidence links inadequate public engagement efforts with low levels of public support for, or increased levels of resistance to, reuse projects (Russell et al., 2008). In response to this challenge, enhanced levels of transparency and inclusive dialogue about risks and benefits have been suggested as mechanisms by which attitudes and opinions can be better understood and wider public trust built (Khan and Gerrard, 2006).

The repurposing of wastewater for non-potable uses is consistently evaluated by the public to be less contentious than its reuse for drinking water (Hurlimann and Dolnicar, 2016). However, there are well-recognised nuances within this general principle that relate acceptability to the degree of contact with, or exposure to, the water (Bruvold, 1988; Dolnicar and Schäfer, 2009; Friedler et al., 2006; Marks, 2006). For example, use of the water for purposes involving higher exposure, such as in swimming pools, is consistently less acceptable than its use for flushing toilets (Dolnicar and Schäfer, 2009). Explanations for these differences draw from the psychology of contamination and disgust (Rozin et al., 2015; Wester et al., 2015), and from cultural risk evaluations, suggesting preferences for more 'pure' uses (Marks et al., 2008). Whilst these differences are well documented, it has also been shown that they can vary considerably depending on context. For example, there are cases of 'overwhelming' public acceptance for schemes involving potable reuse (e.g. NeWater, Singapore - Mainali et al., 2011) and of underwhelming acceptance for lower exposure uses such as toilet flushing (Buyukkamaci and Alkan, 2013). Health risk fears often lie behind expressed public concerns with specific evidence emerging from cases involving irrigated crops (Wu et al., 2015) and cross-contamination in household drinking water supplies (Hambly et al., 2012). There is now a sizeable legacy of research that has engaged with the challenge of understanding the factors underpinning public acceptance (Bruvold, 1988; Dolnicar et al., 2011; Nancarrow et al., 2008; Ross et al., 2014). However, contemporary developments in the field have seen increasing interest in understanding and explaining how and why public attitudes evolve (Fielding and Roiko, 2014).

Initial negative reactions towards water reuse can be moderated through effective communication and engagement (Leong, 2016, 2010; Russell and Lux, 2009). For example, individuals have exhibited a willingness to re-evaluate their attitudes when provided with details about water treatment processes and contaminants (Dolnicar et al., 2010; Russell et al., 2008; Wester et al., 2016). Such information provision has also been shown to improve public trust in the institution or organisation that is planning a particular water reuse scheme (Price et al., 2015). However, there are also challenges to gauging, and subsequently interpreting, the impact of information provision. Shifts in attitudes and behaviours can depend on the initial strength of an attitude (Erber et al., 1995) or on factors which underpin the overall stability of an individual's evaluation of a given phenomenon (object, issue or situation) and their susceptibility to the influence of information (Krosnick et al., 1989; Krosnick and Petty, 1995). Attitude change resulting from information about water reuse has been shown to be correlated with the strength of more general attitudes to new technology (de Koster and Achterberg, 2015) and the strength of initial attitudes to water reuse (Price et al., 2015). To date, however, there is no compelling evidence to suggest that demographic parameters play a strong role in shaping how people modify their attitudes to water reuse (Dolnicar et al., 2010; Fielding and Roiko, 2014).

How people react to information about water reuse is thought to depend to a greater extent on the information processing experience (Dolnicar et al., 2010; Russell et al., 2008). As such, there is keen interest in developing understandings of communicative processes – in particular, understanding how framing (e.g. the careful selection or emphasis of certain pieces of information) might influence how people interpret and make sense of water management information (Dewulf et al., 2009, 2005; Mankad, 2012). This agenda has brought into sharp focus the content of messaging for water reuse schemes. Studies have shown positive impacts from providing information that adopts particular terminology (Menegaki et al., 2009; Simpson and Stratton, 2011), includes descriptions of water treatment processes (Dolnicar et al., 2010), or clearly identifies the risks and benefits of recycled water (Price et al., 2015). Contrastingly, other work has shown no effect from providing additional information about levels of pollutants (Fielding and Roiko, 2014). Despite these advances in knowledge, there remain limitations to our understanding of how specific communities might respond to different messages and which modes of communication are more effective (Fielding and Roiko, 2014; Rozin et al., 2015; Russell et al., 2008).

Recent years have seen a notable increase in the deployment of graphical materials (Dolnicar et al., 2010), and animations and videos in particular (Russell et al., 2008; Wintgens and Hochstrat, 2006), to present information about water reuse. The associated benefits of using such media include improvements in accessibility and understanding (Ishii and Boyer, 2016; Islam et al., 2015; Tang et al., 2015). Videos can help viewers grasp more complex resource management concepts (Krantz and Monroe, 2016). As such, they are an increasingly familiar information source, and can enhance levels of interest and motivation (Arvai and Louie, 2014). Such demonstrated benefits have led to the development of video animation resources discussing water management (e.g. Sydney Water's 'tap™' video - Motion and Kearnes, 2014) and, specifically for water reuse, videos describing *de facto* indirect potable reuse ('Downstream' - Harris-Lovett et al., 2015), direct potable reuse ('The Ways of Water' - WateReuse, 2014) and sewer mining (DESSIN, 2017). Despite the growing use of video messaging, scientific evaluations of video interventions are sparse (Arvai and Louie, 2014).

This paper aims to examine the impact of message framing on public attitudes towards non-potable water reuse through the use of video messages that selectively communicate information regarding the safety of non-potable recycled water use in London. As previously mentioned, framing involves the purposeful selection and emphasis of certain pieces of information in messages (Entman, 1993). Correspondingly, the content of the different video messages used in this study included different focal characteristics, depending on the frame being employed (Hallahan, 1999; Levin et al., 1998). This study responds directly to calls for more effort to unpack and investigate whether specific characteristics of messages about recycled water have different degrees of impact on public perceptions (Dolnicar et al., 2014; Harris-Lovett et al., 2015; Mankad, 2012; Price et al., 2015, 2012; Rozin et al., 2015). We consider how different demographic sub-groups react to the messages (Dolnicar et al., 2010) and, through a longitudinal design, take into account a frequently identified need to build understandings of the longevity of the impact of information on attitudes (Dolnicar et al., 2014). Drawing on existing understandings and areas of ambiguity reviewed above, this study design is guided by the following questions: (1) Can initial attitudes towards non-potable recycled water be influenced by messages conveyed through video animations? (2) To what extent does message framing (variation in the focal characteristics of a message according to the frame being employed) affect responses, and do certain frames have more of an impact on initial attitudes? (3) To what extent is the impact of message framing associated with the potential degree of exposure to the recycled water or initial levels of support? (4) How might messages about recycled water be improved to help meet the public's expectations, and how might video animations be used more effectively for engaging the public when developing recycled water schemes?

5.2 Methodology

5.2.1 Participants and materials

5.2.1.1 Participant recruitment

Study participants were recruited for a two-stage, pre and post video message survey by drawing candidates from a database of over forty thousand London residents (over 18 years of age). The survey panel aggregator (Qualtrics) worked with a number of partners with relevant databases of participants to then randomly select participants to take part (although there were some exclusions, for example, participants who have recently taken surveys). The survey company had accesses to niche panels that could access harder to reach demographic categories. Based on the experience of similar studies using online panel-based surveys (e.g. Dolnicar et al., 2014), the response rate was likely to be in the order of 15-20%, however this was not specifically documented for this study. Participants received a compensation payment at standard rates used by the online survey panel aggregator. For the initial survey at Time 1 (T_1), 783 surveys were started and 753 successfully completed. Using a minimum time completion filter to improve data quality (set at the 10th percentile completion time), 689 valid survey responses were received. For the second stage of the survey at Time 2 (T_2), 565 responses were started with 6% not completed. Using the minimum time filter, 479 valid responses were received. After matching the valid responses from T_1 and T_2, the final sample of valid matched pairs was N = 441. For the completed surveys at T_1 and T_2, the attrition rate was 30%. Accounting for the completion quality features, 41% of completed responses at T_1 were not included in the final T_2 sample.

Demographic data was collected for gender, age, ethnicity, highest level of education and annual household income. Demographic characteristics of the valid T_1 responses included a mean age of 42.42 (SD = 16.31, range 18 – 90), with 354 females (51.4%) and 335 males (48.6%). For ethnicity, 73.1% identified as White (British, Irish or Other), 9.6% as Black or Black British, 8.1% as Asian or British Asian, 4.6% as mixed ethic background and 4.5% as any other backgrounds. The demographic proportions completing these surveys accorded well with the general London population over 18 years of age for age (mean = 43.39) and gender (48.8% male, 51.2% female). The sample, however, was over representative for those identifying as white ethnicities (60% in London) and for those with university degrees (38% in London compared with 51% in the sample).

Characteristics of the final sample validly completing both stages included a mean age of 47.40 years (SD=15.65, range = 18 – 90), with 247 females (56%) and 194 males (44%). Attrition rates varied for different sub-groups and, for example, were higher for males, those under 35 and those from mixed and Asian or British Asian ethnic backgrounds. Using cross-tabulation (Pearson Chi-Square), the proportions for gender (χ^2 = 2.816, *df* = 1, *p* = 0.093), ethnicity (χ^2 = 3.973, *df* = 5, *p* = 0.553), annual income (χ^2 = 0.506, *df* = 5, *p* = 0.992) and level of education (χ^2 = 6.446, *df* = 10, *p* = 0.776) were not significantly different between the two sample points. However, due to high attrition in the younger age groups, the change in the distribution of participants between the age categories was statistically significantly (χ^2 = 31.041, *df* = 5, *p* = 0.001) and the implications of this were explored in the analysis.

Taking into account any necessary adjustments to the sample based on the representativeness of demographic sub-groups, the final sample of respondents drawn from a database of London residents was of sufficient size to consider the possible representativeness with respect to the general London population aged over 18 of 6.4 million (GLAIntelligence, 2016) (for claims made about proportions the confidence level was 95% +/- 5% error). However, given the known challenges associated with sampling biases in internet surveys and panel based recruitment (Van Selm and Jankowski, 2006), potential methodological biases (e.g. acquiescence and social desirability bias) along with the biases identified in the demographic proportions of the data, any such generalisation were drawn with caveats.

5.2.1.2 Materials - survey and video design

The independent variables were message frames, which determined the selection of content information for four different video messages. The video messages were developed using animation software and embedded in a Qualtrics online survey. The videos were designed using Sparkol's VideoScribe animation software with each one lasting approximately one and a half minutes. The selection of frames, and the resulting design of message content (including terminology), was informed by the water reuse communication literature (specifically Macpherson, 2014, 2011; Menegaki et al., 2009; Motion and Kearnes, 2014; Po et al., 2005; Simpson and Stratton, 2011; WRRF, 2010).

Before undertaking the full experiment the survey instrument and videos were piloted to address design problems and to check interpretations of the words and phrases used (de Vaus, 2002). The survey questions and video materials were pre-tested through consultation with a number of water resource specialists and academics. The surveys and materials were updated based on these consultations and then piloted over the two-stages with a small sample of the public (T_1, N = 56; T_2, N = 33). Following this pilot, further refinements were made to the question items and their wording based on results from Cronbach's alpha scores, qualitative feedback and comprehension check questions. These responses were not included in the reported data set.

5.2.2 Study procedure

Following confirmation of informed consent, all participants completed the introductory stages of the survey which included basic demographic questions and initial dependent variable measurements (Figure 5-1). Subsequent to completing the initial part of the survey at T_1, participants were randomly assigned to one of five message groups to either watch a video animation or not (control group with no message). Immediately following the videos, a number of statements were used to gauge: (1) how easy the video messages were to understand, and (2) whether participants recognised the focal characteristics of the message to which they'd been assigned (the inclusion of comprehension checks follows recommendations from Hull, 2014; Islam et al., 2015). These categorical data were then used to interpret the participants' ability to comprehend and recall the specificities of the information contained in the messages by comparing the four message groups using Pearson's Chi-squared test (p = 0.05, df = 3, χ^2 = 7.815).

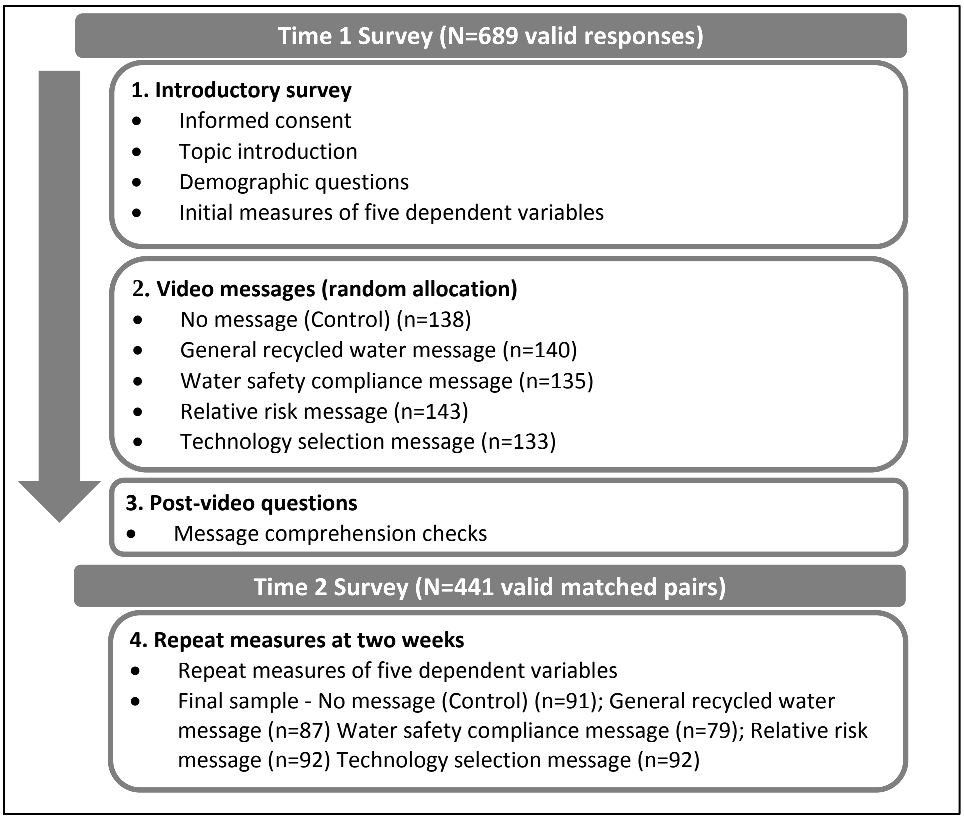


Figure 5-1 Two-stage pre and post video message study procedure

Repeat measures were taken two weeks after participants initially viewed the video messages (T_2). A two-week interval was selected based on related studies (Dolnicar et al., 2010; Price et al., 2015) and followed a similar study design to Roseth (2008). Drawing from attitude change theory, our approach assumes that: (1) attitudes should remain stable in the absence of 'shock' events (Krosnick and Petty, 1995) and (2) messages can initiate long-term attitude changes if participants are motivated (the message is relevant) and able to process them (Dainton, 2004). Comparable procedural designs with post-information repeat measures taken after a lapsed time period can be seen in related studies (Burns and Slovic, 2012; Evans et al., 2014; Howell, 2011; Islam et al., 2015; Keramitsoglou and Tsagarakis, 2011). The study design acknowledged that attitudes could be affected by exposure to other issues that come into public attention after viewing the messages (Russell et al., 2008) – although there is evidence that these effects are likely to be small (Dolnicar et al., 2014). There was also the potential for attitudes to be influenced simply through reflecting on the topic after completing the first survey (Roseth, 2008). Therefore, the no message (control) group was used to help monitor for such effects. Furthermore, both the news media and weather were monitored during the data collection period of April 2016. During this time, river flooding was reported in west London in early April (Al-Othman, 2016). However, overall, climatic records showed that the month was at or below seasonal averages for temperature and rainfall and described as 'unexceptional' (Met Office, 2016).

5.2.2.1 Experimental video messages

Four video messages, based on four different message frames, were developed to communicate information regarding the safety of non-potable recycled water in a London water management context (Appendix C). The selection of frames drew from the broader framing literature, spanning psychology (Levin et al., 1998), public relations (Hallahan, 1999) sociology (Nisbet, 2009) and meta-paradigmatic perspectives (Dewulf et al., 2009). The message framing literature around water reuse (Goodwin et al., 2017; Mankad, 2012; Menegaki et al., 2009; Rozin et al., 2015; Wester et al., 2016) was also used to help develop message frames that were suited to the specific water resource context and characteristics of water safety. This overall literature base was used to develop a conceptual message framing typology (Table 5-1) that links contextual frames, attribute frames and valance frames (positive and negative aspects). The typology provides an overarching framework for constructing messages around water reuse schemes.

Table 5-1 Conceptual message framing typology for communication around water reuse

			Context frames	Attribute Frames	Valence frames
Overview			Providing context to frame situations and objects (Hallahan, 1999; Pan and Kosicki, 1993) Framing for bridging cognition and culture within social contexts (Van Gorp, 2007).	Focal attributes, characteristics of objects and situations specific to a context (Hallahan, 1999; Levin et al., 1998; Mankad, 2012).	Framing based on valance (i.e. positive or negative aspects): losses and gains, risky choice (probability you might win or lose) and goals (what you might lose or gain) (Levin et al., 1998; Mankad, 2012).
Frame typology for communicating water reuse safety management (with examples)					
Water resource management			**Context for water resource management challenges** E.g. Temporal and spatial scales (Tang et al., 2015), geography, causes (e.g. climate change, population growth), consequences, people affected and alternative management options (Lyytimaki and Assmuth, 2014)	**Attributes of water resource management** E.g. Investment in flood defences, risk-based management approaches (Escobar and Demeritt, 2014) or the chemical quality of raw water (Lyytimaki and Assmuth, 2014).	**Positive or negative aspects of water resource management** E.g. Potential losses such as water shortages or gains from economic opportunities (Lyytimaki and Assmuth, 2014). Media framing flood events as losses (costs, damage, loss of life) (Escobar and Demeritt, 2014)
	Water Reuse (as a management intervention)		**Context of water reuse** E.g. Context of the recycled water's history (Rozin et al., 2015) or contrasting international reuse examples (Price et al., 2015)	**Attributes of water reuse** E.g. Energy used to process the recycled water (Price et al., 2015) or specific uses for the water (e.g. drinking, toilet flushing) (Dolnicar et al., 2010).	**Positive or negative aspects of water reuse** E.g. Reuse as a secure water supply or negative health risks (Price et al., 2015) Framing planned potable reuse as an improvement over existing water supplies (gains) (Harris-Lovett et al., 2015)
		Water Safety	**Context of water (reuse) safety** Health risk relative to other public health issues (Price et al., 2015)	**Attributes of water safety management** E.g. Details of the water treatment processes (Dolnicar et al., 2010) or about levels of specific pollutants (Fielding and Roiko, 2014).	**Positive or negative aspects of water safety management** Use of cognitive or affective images (e.g. a picture of a pregnant woman drinking water) (Wester et al., 2016)

Based on this message framing typology, a general message frame was developed which emphasises the water supply challenge for London and the potential role of non-potable water reuse in addressing that challenge (Figure 5-2). This frame was informed by literature related to the London water supply context (e.g. Aitken et al., 2014; Bell and Aitken, 2008; Clark et al., 2000; Goodwin et al., 2015; Hills et al., 2009, 2001; Jeffrey, 2002; Jeffrey and Jefferson, 2003; Smith et al., 2014). The associated general message described the context of the existing water supply regime, the influence of climate change and population growth, the potential for a future water supply deficit and, finally, the potential benefit of non-potable water reuse interventions, whilst acknowledging potential risks from contaminants, as follows:

Water reuse for non-drinking water - a future water supply option for London? London's rivers flow through urban and agricultural areas; Water from these rivers is treated to provide drinking water; However, climate change and population growth mean that extra water may be required in the future; Water reuse removes contaminants from wastewater to purify the water; This recycled water can then be safely used for many non-drinking water purposes like irrigation of parks and gardens or for toilet flushing; Water reuse can provide extra non-drinking water that is safe for human use and safe for the environment.

Figure 5-2 The general (contextual) video message (thumbnail shows the opening animation slide of the video messages)

Following the typology, three alternative frames were developed, which added additional focal characteristics to the general message. These three alternative frames were developed by thematically reviewing water recycling studies focusing on public communications (e.g. Fielding and Roiko, 2014; Goodwin et al., 2017; Harris-Lovett et al., 2015; Price et al., 2015; Roseth, 2008; Ross et al., 2014; Rozin et al., 2015; Wester et al., 2016). The frames (see **Figure 5-1**), and their associated message content, are: (1) 'water quality compliance' – wherein the message emphasises that management practices ensure compliance with water quality standards (like monitoring, sampling, testing and reporting) to protect human and environmental health from contaminants; (2) 'relative risk' – wherein the message emphasises that contaminants may be detected in recycled water but that exposure is relative to other every-day exposures to similar contaminants, such as those in personal care products, food and drinks, air and medicines; and (3) 'technology selection' – wherein the message emphasises that the selection of water treatment technology (including biological treatment, carbon filtration, membrane filtration, chemical oxidation and disinfection) targets the removal of specific contaminants to protect human and environmental health. In each video message, specific terms that echoed the overarching frame (e.g. 'compliance', 'relative exposure', 'technology') were repeated throughout the message (Corvello and Milligan, 2010).

5.2.2.2 Dependent variables

The survey vehicle used Likert-type questions to quantify measurements for five dependent variables relating to attitudes to non-potable water reuse, these were: (1) acceptance; (2) support; (3) behavioural intentions (willingness to use the water); (4) risk perceptions; and (5) trust (Table 5-2). The questions used in the survey built on elicitation methods previously shown to be consistent and reliable measures of these dependent variables (Aitken et al., 2014; Costa-Font and Gil, 2009; Doria et al., 2009; Fielding and Roiko, 2014; Miller and Buys, 2008; Nancarrow et al., 2009; Po et al., 2005; Price et al., 2015; Ross et al., 2014), taking into account contextual specificities and issues identified during piloting. Acceptance was defined as a combination of support (attitude) and behavioural intentions. This methodological modification attempted to provide a clearer distinction between these terms which are often combined in single question groupings (Nancarrow et al., 2009; Price et al., 2015). Responses were recorded using a 6 point scale (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4= agree, 5 = strongly agree and 6 = don't know). To improve response validity, some questions used reverse wording (which were re-coded for analysis). The results for individual question items were added (Corbetta, 2003) to form the five dependent variables for analysis. The internal consistency for all of the variables was evaluated with Cronbach alpha to be satisfactory (Table 5-2).

Table 5-2 Question items used for measuring dependent variables

Dependent variable	Question Items	Reliability (α)
Acceptance (9 items)	Acceptance combines all Support & Behavioural Intention questions (see question items summarised below)	0.885 (n=689†)
Support (5 items)	1. I support using recycled water for watering gardens and flushing toilets 2. I support using recycled water for industrial processes (e.g. electricity generation) 3. I support using recycled water for recreational swimming (e.g. in swimming pools) 4. I support using recycled water to irrigate edible food crops 5. I support using recycled water for washing clothes	0.789 (n=711†)
Behavioural intentions (4 items)	6. I would be willing to use recycled water for watering gardens and flushing toilets 7. I would be willing to buy a home that uses recycled water for watering gardens and flushing toilets 8. I would be willing to consume food irrigated with recycled water 9. I would be willing to swim in water containing some recycled water	0.780 (n=713†)
Risk Perceptions (6 items)	10. Using recycled water for watering gardens or flushing toilets would cause a public health risk (reversed) 11. The risks from using recycled water for watering gardens or flushing toilets are small compared to other everyday risks 12. Water treatment technology can control the risks to public health 13. I would accept lower quality recycled water for watering gardens or for flushing toilets if this meant avoiding a hosepipe ban 14. Compliance with water quality standards can control the risks to public health 15. Consuming food irrigated with recycled water would NOT cause a public health risk	0.735 (n=654†)
Trust (7 items)	16. I think that the water company has good intentions in managing London's water supply 17. I can trust the water company to provide a good quality supply for watering gardens or flushing toilets 18. I trust regulators (e.g. Drinking Water Inspectorate and the Environment Agency) to set safe water quality standards 19. I trust regulators (e.g. Drinking Water Inspectorate, the Environment Agency) to check recycled water complies with quality standards set down in law 20. I do NOT trust the technology involved in water reuse (reversed) 21. I do NOT trust science and technology to produce safe recycled water (reversed) 22. I trust the government to manage the balance of a range of public health concerns in our society	0.862 (n=705†)
Acceptance of medium-high exposure uses (4 items)	Support questions 3 and 4. Behavioural intention questions 8 and 9.	0.832 (n=707†)
Acceptance of low exposure uses (4 items)	Support questions 1 and 2. Behavioural intention questions 6 and 7.	0.781 (n=731†)

†Number of valid responses at T_1, excluding 'don't know' for this calculation.

Table 5-3 Classification of the relative degree of exposure used for this study*

Degree of exposure	Type of exposure	Log10 Exposure (pppy†)	Exposure (mL pppy)	Events (per year)	Exposure (mL per event)	References
Medium-High	Swimming	3.42	2,600	52	50	16-37mL (Dufour et al., 2006); 31-51mL (Schets et al., 2011).
	Consuming irrigated fruit and vegetables	2.69	490	140	3.5	1mL (non-lettuce, raw produce) 140 times per year, lettuce 5mL, 70 times per year (NRMMC EPHC & AHMC, 2006)
Low	Irrigating garden at home	1.95	90	90	1.0	NRMMC EPHC & AHMC, (2006)
	Toilet flushing at home	1.26	18.3	1,825	0.01	NRMMC EPHC & AHMC, (2006)
	Washing clothes at home	0.42	2.6	260	0.01	Exposure of one person in average household NRMMC EPHC & AHMC, (2006)
	Industrial processes (e.g. electricity generation)	0.38	2.5	48	0.05	Hamilton & Haas, (2016) 0.5 µL (high-pressure hose). Storey et al., (2004) 0.06 mL (showering).

†per person per year
*Note that the categories are relative and studies considering different exposures should evaluate the groupings

The types of non-potable reuse represented a range of exposure levels. Due to previous classification categories being ambiguous, a new relative classification method was devised based on estimations of annual per-person exposure (Table 5-3). For example, previous studies have classified both domestic clothes washing and recreational swimming as 'high contact' and private garden irrigation and domestic toilet flushing as 'medium contact' (Friedler et al., 2006; Matos et al., 2014), whilst others have classified the latter as 'low contact' (Bruvold, 1988). Industrial processes have been classified as 'low' (electronics - Bruvold, 1988), 'medium' (cotton processing) and 'high' (food processing) contact (Friedler et al., 2006). Two additional dependent variables, acceptance of low exposure uses (4 items) and acceptance of medium-high exposure uses (4 items), were considered in this study, both with satisfactory internal consistency (Table 5-2). Support for washing clothes was excluded from the low exposure category. This was due to previous irregularities between the degree of exposure and the level of support. As such, washing clothes was considered individually as a case for special scrutiny and support for this use was analysed as a single question item.

5.2.2.3 Demographic variables

Age and gender were adopted as basic demographic descriptors, as variations in both have been shown to be associated with differences in attitudes to science. For example, women have been shown to feel less confident in engaging with science, while younger adults (aged 16-24) have been shown to be less likely to evaluate the benefits of science as outweighing potential harms (Castell et al., 2014). The latter age-based difference has been observed in attitudes to water reuse in London, with lower support for non-potable reuse shown in younger age groups (aged 18-24) (Smith et al., 2014). Attitudes have been shown to be more impressionable at younger ages (typically up to 25 years old) (Krosnick et al., 1989). As age-based sample sizes within message groups were small, age was separated into two cohorts: (1) younger (45 years and under) and (2) older (over 45 years of age).

5.2.2.4 Statistical analysis

All data were analysed using IBM SPSS Statistics version 22.0. Non-parametric statistical tests were used to test significance levels between and within groups as: (1) the data distribution for the five dependent attitude variables was non-normal (Shapiro-Wilk $p < 0.05$, *skewness -0.9 to - 0.6, kurtosis 0.8 to 1.7*); (2) some questions were tested as single items (considered as ordinal scales), and (3) the demographic data (using gender and age categories) was of a categorical nature. Whilst the non-normal data distributions violated the assumptions of parametric tests (ANOVA and paired t-test), these analyses were still carried out to help understand any sensitivities with the non-parametric tests. The parametric tests produced the same pattern of results as those reported in the paper, however, mostly with smaller *p*-values (thus the more conservative non-parametric results are reported). It is further noted that non-parametric tests may have an increased chance of a Type II error in normal distributions (Field, 2009), although, results from parametric and non-parametric tests are often similar (Winter and Dodou, 2012). The possible influences of differences in the demographic composition of the five message groups were examined through weighting. This was achieved using SPSS *weight cases* function to adjust the composition of the groups (based on the frequency of demographic data for age, gender and ethnicity) to b reflective of (1) the proportions in the overall sample, and (2) the proportions in the London population. This weighting of the sample was also found not to alter the pattern of results reported (that is the analysis returned the same significant results as those reported in the paper - although the significance of the *p-values* differed slightly). Although non-parametric statistics were used, mean values (M) were also reported as normalised (per question item) for comparative purposes only.

The Kruskal–Wallis H-test with post hoc tests was used to analyse the variance between the five message groups (independent samples) to establish whether there were any significant differences ($p = 0.05$, $df = 4$, $\chi^2 = 9.488$) at either T_1 and T_2. The hypotheses tested were that: (H1) there would be no significant differences between the responses for participant assigned to the five message groups (T_1), however, (H2) after the video messages (T_2) there would be differences between the five message groups. The Wilcoxon signed-rank test was used for repeat measures (matched samples) to determine if the dependent variables changed significantly over time within the message groups ($p < 0.05; z > 1.96, z < -1.96$). Effect sizes were calculated following (Field, 2009) as the *z-score* divided by the square-root of total observations ($T_1 + T_2$) and are reported with respect to Cohen's categories for small (r= 0.1), medium (r =0.3) and large (r =0.5) effects. For the no message (control) group, it was hypothesised that: (H3) there would be no changes in responses over time. For the message groups, it was hypothesised that: (H4) the messages would change responses over time. No firm hypotheses were made regarding the relationship between the two demographic factors (age and gender) and the impact of the messages.

Two further hypotheses were developed based on the initial levels of support for the different recycled water options. Firstly, that: (H5) the impact of message framing would depend on the participants' initial support for the proposed use involving the highest exposure – recreational swimming. Secondly, that: (H6) acceptance of uses involving a low degree of exposure (4 items) would be more stable over time than acceptance of uses involving a medium-high degree of exposure (4 items). Finally, it was hypothesised that: (H7) perceptions of risk associated with low-exposure uses, namely flushing toilets and irrigating gardens (single item, Question 10), would be more stable over time than perceptions of risk associated with medium-high-exposure uses, such as irrigating food crops (single item, Question 15).

5.3 Results

5.3.1 Overview

The results for initial support and behavioural intentions are summarised in Figure 5-3 which shows the patterns of responses with respect to recycled water uses with different classifications of the degree of contact. The highest support was for the use involving a low degree of exposure – industrial uses (95% agree), toilet flushing and garden watering (92% agree). The lowest initial support was for the use involving the highest degree of exposure – use in recreation swimming areas (51% agree). As with previous studies, support for the use of recycled water to wash clothes (70% agree) was lower than would be expected given the relatively low degree of exposure associated with the use. Indeed, individual exposure to recycled water as a result of clothes washing is feasibly lower than exposure from toilet flushing or garden watering – two recycled water uses which saw higher levels of support. This suggests some ambiguity around how exposure is perceived (or has previously been estimated) in clothes washing applications.

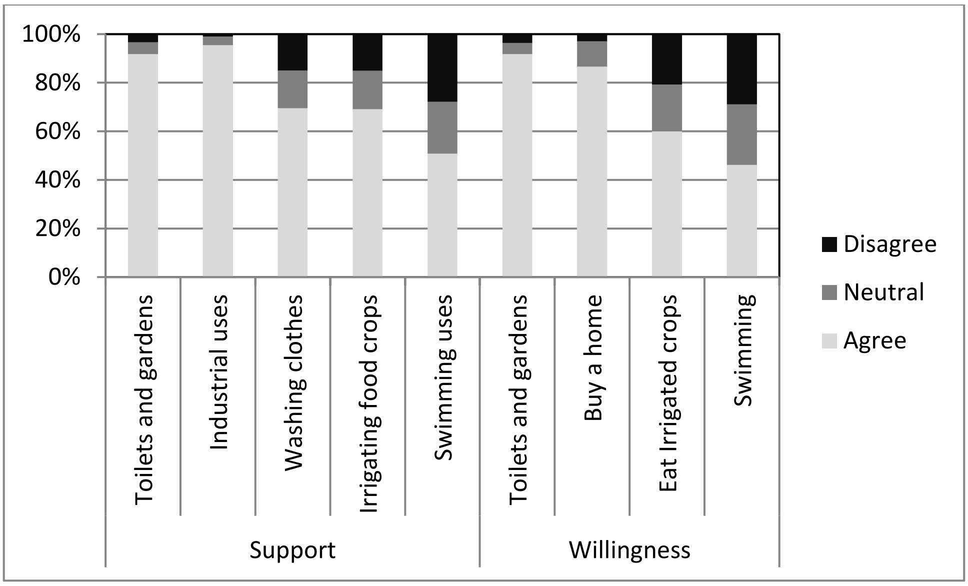


Figure 5-3 Proportion of participants agreeing to statements asking for their support and behavioural intentions (willingness) towards the use of recycled water for a range of purposes (T_1)

Analysis using the Kruskal-Wallis H-test showed there was no significant differences in the attitudinal responses to the five dependent variables for the participants' who went on to be randomly assigned to the five message groups. This indicated that at T1 attitudes were consistent across the sample and that no group displayed any initial attitudinal differences compared with other groups before viewing a video message. Whilst, participant may have had different starting points in terms of knowledge or experience of the water uses discussed in this study (for example, active swimmers or gardeners), the random assignment of participants facilitated heterogeneity of initial attitudes in the experimental groups. The dependent variable with the most variance at T_1 was behavioural intentions ($\chi^2 = 1.056, p = 0.901$), whilst the variable with the least variance was trust ($\chi^2 = 0.287, p = 0.991$). Although the level of variance increased at T_2, these were not statistically significant (thus refuting hypothesis H2). Variance was most pronounced for the 'trust' variable ($\chi^2 = 5.040, p = 0.283$). The increase in variance between T_1 and T_2 indicated a possible impact from the messages but it could not be established whether this related to any particular message group.

Considering the entire sample of valid matched pairs (N = 441) and the variable of time (with repeat measures using the Wilcoxon signed-rank test), there were not any significant changes in any dependent variables. The most noticeable change was for the trust variable (M_{T1} = 3.70, M_{T2} = 3.73; z = -1.202, p = 0.229, r = 0.04). Similarly, for the four video messages considered as a single information condition (n = 350, that is, excluding the no message control group), there were no overall significant changes in the measurements over time. Once again, the most noticeable change was for the trust variable (M_{T1} = 3.71, M_{T2} = 3.76; z = -1.765, p = 0.078, r = 0.06). There were also no significant changes over time for the two degrees of exposure variables (acceptance of medium-high and low exposure uses).

There were, however, differences between demographic groupings in the four video message groups considered as a single information conditions (n = 350). Using the Mann-Whitney U-test, women were shown to have significantly higher overall levels of acceptance than men at T_1 (M_{male} = 3.89, M_{female} = 4.07; z=-2.817, p=0.005, r = 0.14) and T_2 (M_{male} = 3.92, M_{female} = 4.10; z=-2.273, p=0.023, r = 0.11). Overall measurements of risk perceptions and trust were not significantly different between men and women at T_1 or T_2. When comparing the younger and the older age groups, the two age groups significantly differed at T_1 for acceptance ($M_{younger}$ = 3.88, M_{older} = 4.10; z=-3.014, p=0.003, r = 0.15), risk perceptions ($M_{younger}$ = 3.67, M_{older} = 4.01; z=-5.397, p=0.001, r = 0.27), acceptance of low exposure uses ($M_{younger}$ = 4.40, M_{older} = 4.59; z=-3.364, p=0.001, r = 0.17) and acceptance of medium-high exposure uses ($M_{younger}$ = 3.39, M_{older} = 3.67; z=-2.314, p=0.021, r = 0.12) categories. At T_2 there were significant age differences for acceptance ($M_{younger}$ = 3.89, M_{older} = 4.16; z=-3.460, p=0.001, r = 0.17), risk perceptions ($M_{younger}$ = 3.69, M_{older} = 4.02; z=-5.395, p=0.001, r = 0.27), low exposure uses ($M_{younger}$ = 4.32, M_{older} = 4.67; z=-5.022, p=0.001, r = 0.25), and medium-high exposure uses ($M_{younger}$ = 3.48, M_{older} = 3.69; z=-1.969, p=0.049, r = 0.10). Looking at the paired samples over time, trust improved for men in these video information conditions (M_{T1} = 3.72, M_{T2} = 3.80; z = -2.173, p = 0.030, r = 0.17). None of the other dependent variables changed significantly over time, based on gender. Neither age group changed significantly over time for the five dependent variables or for the degree of exposure categories. There were a number of statistically significant changes in the dependent variables over time within the individual message groups. The following sub-sections report these results and describe the salient findings including commentary on how the dependent variables changed over time, analysis of the message comprehension checks and qualitative feedback from the surveys.

5.3.2 No message (control) group

The dependent variable measurements for T_1 and T_2 were compared to investigate whether they had changed over time. The absence of information was associated with a drop in acceptance, particularly in the older age group for low-exposure uses and for those initially supportive. Plausible explanations for these changes include participants reflecting on the topic after completing the first survey, the influence of other external events, and respondent fatigue. The results showed a significant decrease in levels of acceptance (M_{T1} = 4.00, M_{T2} = 3.88; *p=0.018, z=-2.370,* r = *0.17*) and behavioural intentions (M_{T1} = 3.92, M_{T2} = 3.78; *p=0.023, z=-2.275, r = 0.16*) although both with a small effect size. These results allow us to reject the hypothesis (H3) that there would not be any changes in the no message group. Further inspection of this result showed that the changes were largely due to the participants moving from 'strongly agree' to 'agree'. As such, although overall levels of acceptance were unchanged, the strength of attitudes decreased. This is evidenced by the significant decrease in acceptance of the low exposure uses (4 items; M_{T1} = 4.56, M_{T2} = 4.42; *p = 0.004, z = -2.847, r = 0.20*) but not for washing clothes or medium-high exposure uses. The analysis also showed a significant decrease in overall acceptance for those initially supportive of water reuse for the highest exposure use (M_{T1} = 4.52, M_{T2} = 4.30; *p = 0.002, z = -3.088, r = 0.30*). Finally, a decline in both acceptance (M_{T1} = 4.04, M_{T2} = 3.86; *p = 0.023, z = -2.281, r = 0.16*) and support (M_{T1} = 4.10, M_{T2} = 3.92; *p = 0.042, z = -2.035, r = 0.14)* was noted for the older age group. In the qualitative feedback, some responds requested more details on water reuse, for example, *"More information on the technology and alternatives would be useful."* The need to build trust was evident as a theme as one respondent stated, *"I do not trust the water companies or government to protect the general public"*, whilst another commented that *"I don't think anybody has anything to worry about . . . I'm sure they're not going to poison us on purpose"*.

5.3.3 General non-potable recycled water (context) message group

This message was well understood by the participants (as evidenced by the high proportion of responses agreeing with the statement "the message was easy to understand") and there were a number of statistically significant positive changes in the dependent variables over time. The results for this general message (which discussed the role of water recycling in the water resource management context of London) showed a significant positive change in the score for trust over time (M_{T1} = 3.70, M_{T2} = 3.81; *p = 0.032, z = -2.143, r = 0.15*). This, therefore, gave some support to the hypothesis (H4) that the messages would improve participants' responses. Based on initial support, a significant positive change in acceptance was observed only for those categorised as initially opposed to the highest exposure use (9 items; M_{T1} = 3.23, M_{T2} = 3.43; *p = 0.024, z = -2.264, r = 0.32*). There were no other significant differences between any of the variables, including for degree of exposure categories, between T_1 and T_2. Of the four video messages, this general message had the highest proportion of responses agreeing that the video was easy to understand (97%). Whilst there was no target comprehension category for the general video, this message group had the highest proportion of respondents agreeing with the statement, "the message helped me understand about recycled water" (78%). This, however, was not significantly different to the other message groups (*$p = 0.30, \chi^2 = 3.63$*).

5.3.4 Water quality compliance message group

This message was well understood by participants and there were a number of significant positive changes in attitude measurements over time. The results indicated that this message was effective in changing attitudes amongst those initially opposed and for positively changing risk perceptions and trust. The results for this message group showed significant positive changes for risk perceptions ($M_{T1} = 3.79$, $M_{T2} = 3.95$; *$p = 0.005, z = -2.828, r = 0.20$*) and trust ($M_{T1} = 3.69$, $M_{T2} = 3.82$; *$p = 0.041, z = -2.042, r = 0.14$*). In terms of acceptance, an improvement with medium effect size was observed for those initially opposed to recycled water for the highest exposure use (9 items; $M_{T1} = 3.24$, $M_{T2} = 3.71$; *$p = 0.001, z = -3.244, r = 0.44$*). Furthermore, there were significant positive changes for both risk perceptions (6 items; $M_{T1} = 3.34$, $M_{T2} = 3.64$; *$p = 0.015, z = -2.443, r = 0.33$*) and trust (7 items; $M_{T1} = 3.40$, $M_{T2} = 3.70$; *$p = 0.009, z = -2.611, r = 0.36$*) for those same participants. The results from this message group supported the hypothesis (H5) that the impact of message framing would depend on participants' initial level of support.

With respect to the degree of exposure with recycled water, there was a significant positive change in the perception of health risks related to consuming food irrigated with recycled water, ($M_{T1} = 3.41$, $M_{T2} = 3.64$; $p = 0.023$, $z = -2.275$, $r = 0.17$) thus supporting the hypothesis (H7). This message group's results were also significantly different to those of the other four message groups at T_2 for this single risk perception item (Kruskal-Wallis, *$p = 0.039, \chi^2 = 10.093$*). Post-hoc pair-wise comparisons showed that results for this message group were significantly higher (better) than the no message group, the relative risk message group, and the water treatment technology message group. However, the post-hoc comparisons were not significant when taking account of the significance levels adjusted for type I error. Finally, overall risk perceptions improved in the younger age group ($M_{T1} = 3.58$, $M_{T2} = 3.81$; $p = 0.021$, $z = -2.306$, $r = 0.17$). Message group participants agreed that the message was easy to understand (95%). Moreover, positive responses to the targeted comprehension statement, "the video helped me understand about water quality compliance", were significantly higher than those for the other three video messages ($\chi^2 = 21.10, p = 0.001$). The interpretation of this was that this message frame was relevant, could be identified and the participants were able to process the information. There were no clear themes in the qualitative feedback, although some respondents queried costs of recycled water "*would this cost more in our* *water rates?"* whist others had questions about technical challenges, "*I would like to know if any extra plumbing would be required*".

5.3.5 Relative risk message group

There were few changes in attitudes observed between T_1 and T_2 in this message group. Those that were evident were all in a negative direction, indicating that this message frame was not conducive to improving attitudes. Group participants agreed that the message was easy to understand (94%). For the targeted comprehension statement, "the video helped me understand about comparing every-day risks", the positive response rate was significantly higher than for the other three video message groups ($\chi^2 = 48.80$, $p=0.001$) – as anticipated when developing the comprehension statements for the survey. There were no significant changes in any of the five dependent variables over time. For those initially supportive of water reuse for the highest exposure use, there was a significant decrease in their overall support (4 items; $M_{T1} = 4.51$, $M_{T2} = 4.34$; $p = 0.034$, $z = -2.119$, $r = 0.21$). The results, therefore, provide some support for H5 (that the impact of message framing would depend on the participants' initial supportive positions) although respondent attitudes changed in a different direction to those in the general message group and water quality compliance message group. Finally, there was a significant decline in perceptions of health risks from eating irrigated crops ($M_{T1} = 3.57$, $M_{T2} = 3.31$; $p = 0.009$, $z = -2.603$, $r = 0.18$) – thus providing some support for hypothesis H7 but, again, in a different direction to other message groups (this time to the water quality compliance message group). No prominent themes emerged from the qualitative feedback. A number of participants considered the video and survey as informative whilst some also suggested that the video production could be improved. One participant highlighted the impact that prices may play on consumer behaviour stating that "*the only thing that is effective is when money is involved - putting the price of water up should encourage people to use less*".

5.3.6 Water treatment technology message group

Although the targeted comprehension statement for this message group received the highest response for all the message groups, this did not translate into changes in attitude variables over time. Despite this, the overall results for this message group showed that attitudes remained mostly stable over time. The only significant change was in a negative direction for risk perceptions in the younger age group ($M_{T1} = 3.79$, $M_{T2} = 3.57$; $p = 0.008$, $z = -2.663$, $r = 0.19$) – lending some support to H4 (the message would change responses). Group participants agreed that the message was easy to understand (92%) and 72% of the message group members agreed with the targeted comprehension statement, "the video helped me understand about water treatment technology", a significantly higher proportion than was the case in the other message groups (*$\chi 2 = 22.06$, $p = 0.001$*). Once again, the interpretation of this was that this message frame was relevant, could be identified and the participants were able to process the information. There was some evidence of a theme emerging around the potential for contamination, for example one participant in this group queried the assumption that safety standards were commonly known and suggested more information in this area would be helpful, whilst another participant raised concerns about contamination, *"When this water is used for irrigation what are the chances of vegetation being contaminated (for human consumption) by plants not functioning properly".*

5.3.7 Summary of framing effects

Based on these analyses, we advance the following summation of message frames and framing effects (Table 5-4) with reference to the conceptual framing typology. The analysis showed that, compared with the other groups, the water quality compliance message frame was associated with more significant changes in the dependent variables over time. In contrast with the general, contextual message, it appeared that certain focal characteristics – namely relative, every-day risks or water treatment technology – may have actually reduced the potential for the messages to have a positive impact on support for recycled water. Overall, however, the four video messages had more impact on risk perceptions and trust when compared with the no message (control) group. On the other hand, the lack of information (no message) was associated more with statistically significant declines in measures of acceptance over time.

Table 5-4 Results summarised as a preliminary typology of frames and framing effects

Frames		Framing effects (over time)				
Context frame	Attribute frame	Five attitude variables	Degree of exposure variables	Initial support (for highest exposure use)	Demographics	
Water supply context, causes and consequences of shortages. Water reuse as a solution, with risks from contaminants but benefit from sustaining water supplies	None	Gains in trust	No changes	Improved overall acceptance for recycled water uses for those initially opposed	No changes	Gains in trust for men
	Water quality compliance	Less risk perceived overall and gains in trust	Less risk perceived for consuming irrigated crops	Improved acceptance, less risk perceived and gains in trust for those initially opposed	Less risk perceived by younger age group	
	Relative risk	No changes	More risk perceived for consuming irrigated crops	Decline in overall support for recycled water uses in those initially supportive	No changes	
	Technology selection	No changes	No changes	No changes	More risk perceived by younger age group	
No message	None	Decline in acceptance and behavioural intentions	Decline in acceptance for low exposure uses	Decline in acceptance for those initially supportive	Decline in acceptance and support in older age group.	

5.4 Discussion

In the present study, we investigated the impact of message framing on public attitudes to recycled water. Findings demonstrate that a message frame focused on the achievement of water quality compliance was able to significantly, and positively, change initial attitudes over time. The impact was particularly pronounced in terms of decreasing perceptions of risk and increasing trust in the scheme and its management, and improving the attitudes of those initially opposed to using recycled water in high exposure contexts. The results support previous findings of positive impacts from information provision about recycled water safety (Fielding and Roiko, 2014). However, other studies have not isolated specific attributes of messages and instead have combined information on water quality compliance, advanced water treatment technology (Fielding and Roiko, 2014) and relative public health risks (Price et al., 2015). The value of separating these different focal characteristics of water safety messaging is evidenced by the contrasting results we found for the impact of the water quality compliance frame and the water treatment technology frame. Whilst previous studies have identified that information about how recycled water is treated is considered informative (Roseth, 2008) and can increase people's willingness to use recycled water (Dolnicar et al., 2010), this study challenges such trends. An explanation may be that those with more 'extreme' initial attitudes – i.e. those already comfortable with water reuse technology, or those who are very *un*comfortable with it – are unlikely to be influenced by more of this type of information (de Koster and Achterberg, 2015; Fielding et al., 2015). For a positive impact to be measured, it is more likely to come from those initially less comfortable with the concept of water reuse (and thus with initially more negative or ambivalent attitudes). These people may be more receptive to information focusing on the management practices that facilitate water quality compliance, rather than technological information.

The water quality compliance message was not unique in producing an impact. The general message (which framed the role of recycled water in the context of London's water resource management) improved overall trust and also acceptance among those initially opposed to high exposure uses (like swimming). Improvements in trust were also observed in the water quality compliance message group. Finally, considering the four video messages as a single information condition, there was an overall improvement in trust for the male participants. These improvements in trust are notable as previous studies have qualitatively highlighted a lack of trust in water safety as limiting people's willingness to used recycled water for different non-potable purposes (Roseth, 2008). Whilst a number of previous studies have shown an increase in trust in authorities to manage recycled water schemes following the receipt of information (Price et al., 2015; Roseth, 2008), these results were largely focused on potable reuse. The public's trust in the organisations managing water resources in London has been identified as an important factor underpinning perceptions of water reuse proposals (Aitken et al., 2014) – a factor also associated with customers' expectations of reducing water leakage and their perceptions of the financial motivations of the water company (Goodwin et al., 2017). More generally, trust building is considered fundamental for promoting water reuse (Khan and Gerrard, 2006). Therefore, some improvement in trust from viewing the video messages (even though it is limited to male respondents) is encouraging evidence for those with an interest in this, and related water management contexts.

The relative risk message frame produced some evidence of a negative impact on initial attitudes, with an increase in the perceived risks from consuming irrigated crops and some decrease in acceptance from those initially supportive of low exposure uses. Previous research has found that providing context on the relatively low risk of recycled water for drinking, compared to other every-day risks, can improve risk perceptions and public support (Price et al., 2015). In contrast, this study adds credence to an earlier finding that this kind of information may decrease a message's impact (Fielding and Roiko, 2014). This challenge was further highlighted by the decrease in acceptance observed in the group that was not exposed to any messaging. The reduction in levels of acceptance was pronounced in the cases of low exposure uses and those initially more supportive of reuse. This finding is consistent with others that have found decreases in support associated with no information provision (Fielding and Roiko, 2014; Roseth, 2008). It has been argued that public acceptance can wane if engagement efforts are underwhelming (Russell et al., 2008). The results of this study support this claim and also imply benefits from developing information that can engage more deeply with the public's understanding of the relative risks of using recycled water.

The results described above suggest that message framing (the purposeful selection and emphasis of certain focal characteristics in developing message content) can have an influence on public attitudes to recycled water. This finding supports previous studies showing that, depending on the specifics of content, information can have both positive and negative impacts on public attitudes (Dolnicar et al., 2010; Fielding and Roiko, 2014; Price et al., 2015; Roseth, 2008). This study's key finding, that employing different message frames in developing communications around water reuse can result in different impacts on responses, responds to previously identified gaps in our understanding (Mankad, 2012). This challenge is highlighted by research showing that only those initially supportive of potable water reuse respond positively to more complex messages (Price et al., 2015) and that those least likely to support recycled water may remain unaffected by information (de Koster and Achterberg, 2015). This study provides evidence to show that those initially opposed (particularly to higher exposure uses like swimming) can become more supportive and that those initially supportive (particularly of lower exposure uses like toilet flushing) can become less enthusiastic - depending on the message frame employed and the focal characteristics of the resulting message. Furthermore, this study indicates some irregularities in correlations between public acceptance and the degree of exposure to recycled water, particularly for clothes washing. Thus, public views of specific recycled water uses may relate to their expectations of information, perceptions of the degree of exposure and, feasibly, to perceptions of other non-health risk related consequences from using the water - for example, perceived impacts on the colour or durability of clothes (Hurlimann and McKay, 2007). Finally, applying the message framing typology allowed us to disaggregate message content in a structured way, and improves our understandings of responses within of discretised citizen groups. Further research is recommended to develop and apply the typology further and to build on evidence of framing effects relating to different types of recycled water use in different communities.

Whilst it is not possible to fully isolate the impact of the messages over the study time period, this study nonetheless suggests that the messaging was influential in changing attitudes (in lieu of any other significant attitude changing events). Possible explanations for the differences in results across the message groups include issue relevance or certain arguments being more persuasive (Petty and Cacioppo, 1986) and therefore resonating more with participants' concerns and experiences (Mankad, 2012; Nisbet, 2009). Qualitative feedback further indicated that the messages were relevant to the context and enabled the participants to relate the messages they had watched to their personal experiences and knowledge of water management in London. Whilst the channel of communication (video animation) may have also played a role (Milne et al., 2015), contrasting the findings from the different message groups highlights an impact of message framing for heterogeneous message groups. The findings give support to a framing perspective (Dewulf et al., 2009), suggesting that the audience response did depend on which aspects of information were included.

The findings presented here provide a platform for exploring attitude change in more detail, particularly in some of the harder to reach sub-sections of the community. Thus, there are opportunities for developing targeted messages, and more so, for involving the public to help co-construct frames that can help target specific concerns of different groups within the community (Hallahan, 1999; Mankad, 2012). The findings indicate feasible benefits to developing approaches that support more interactive, on-going frame development processes that aim to negotiate different points of view and expectations (Dewulf et al., 2009). Finally, whilst this study's findings are encouraging in that they found some impact from messages, these were modest and practitioners should be mindful of developing such communications as part of more comprehensive engagement strategies to achieve more meaningful shifts in public attitudes.

5.5 Conclusions

This study aimed to examine the impact of message framing on public attitudes towards non-potable water reuse through the use of video messages that selectively communicate information regarding the safety of non-potable recycled water use in London. The research provides evidence to show that those initially opposed to higher exposure uses for non-potable recycled water responded positively to short video animations framed in terms of water quality compliance. This finding contributes to existing knowledge through isolating the beneficial impacts of employing particular frames, and associated focal characteristics, in developing messages about water reuse. Moreover, the findings showed that, overall, the video messages improved the participants' trust in authorities to safely manage recycled water schemes. Through the conceptualisation of a message framing typology, this study advances understanding of public responses to information and provides an avenue for improving communication around reuse schemes by developing targeted message frames – potentially using more interactive and iterative approaches. The corroboration of benefits to communicating about recycled water safety within the water resource context is of considerable benefit to water industry practitioners developing public engagement information. Public concerns and preferences are likely to vary in different communities and also change over time in response to water resource (e.g. flooding, drought) and other social challenges (e.g. economic). Therefore, the targeting of messages to address specific community concerns will also need to respond to changes in the public's needs and expectations over time. The results of this present study contest, to some extent, previous suggestions of counter-productive effects from information campaigns. Given the growing popularity of video-based messages, this study suggests that video animations are a feasible way to communicate about the safety of recycled water.

5.6 Acknowledgements

This research was co-funded by the UK's Engineering and Physical Science Research Council (EPSRC) grant number EP/G037094/1 and Thames Water through the STREAM Industrial Doctorate Centre.

5.7 References

Aitken, V., Bell, S., Hills, S., Rees, L., 2014. Public acceptability of indirect potable water reuse in the south-east of England. Water Sci. Technol. Water Supply 1–11. doi:10.2166/ws.2014.051

Al-Othman, H., 2016. Thames Flooding: Cars and people trapped by rising waters after river bursts its banks. 11/4/2016 [WWW Document]. Evening Stand. URL http://www.standard.co.uk/news/london/cars-and-people-trapped-by-rising-tides-after-river-thames-bursts-its-banks-a3222906.html (accessed 4.11.16).

Arvai, J., Louie, R.I., 2014. Effective Risk Communication. Routledge, Abingdon, Oxon.

Bell, S., Aitken, V., 2008. The socio-technology of indirect potable water reuse. Water Sci. Technol. Water Supply 441–448. doi:10.2166/ws.2008.104

Bruvold, W.H., 1988. Public Opinion on water reuse options. J. Water Pollut. Control Fed. 60, 45–49.

Burns, W.J., Slovic, P., 2012. Modeling the Dynamics of Risk Perception and Fear: Examining Amplifying Mechanisms and Their Consequences, Research Project Summaries. Los Angeles, California.

Buyukkamaci, N., Alkan, H.S., 2013. Public acceptance potential for reuse applications in Turkey. Resour. Conserv. Recycl. 80, 32–35. doi:10.1016/j.resconrec.2013.08.001

Castell, S., Charlton, A., Clemence, M., Pettigrew, N., Pope, S., Quigley, A., Navin Shah, J., Silman, T., 2014. Public Attitudes to Science 2014. Ipsos MORI Social Research Institute, London.

Clark, T., Jeffrey, P., Stephenson, T., 2000. Complex agendas for new technology adoption in the UK water industry. Technovation 20, 247–256. doi:10.1016/S0166-4972(99)00131-5

Corbetta, P., 2003. Social Research: Theory, Methods and Techniques. SAGE Publications Ltd.

Corvello, V.T., Milligan, P.A., 2010. Risk Communication: Principles, Tools and Techniques. Washington D.C.

Costa-Font, M., Gil, J.M., 2009. Structural Equation Modelling of Consumer Acceptance of Genetically Modified (GM) food in the Mediterranean Europe: a cross country study. The Centre for Research in Agro-Food Economics and Development, Barcelona.

Dainton, M., 2004. Explaining Theories of Persuasion, in: Dainton, M., Zelley, E. (Eds.), Applying Communication Theory for Professional Life: A Practical Introduction. SAGE Publications Ltd, London, pp. 103–131.

de Koster, W., Achterberg, P., 2015. Comment on “Providing information promotes greater public support for potable recycled water” by Fielding, K.S. and Roiko, A.H., 2014 [Water Research 61, 86-96. Water Res. 84, 372–374. doi:10.1016/j.watres.2015.05.067

de Vaus, D.A., 2002. Surveys in Social Research (5th Ed.), 5th Edition. ed. Allen and Unwin, Crows Nest, NSW, Australia.

DESSIN, 2017. Video: DESSIN sewer mining easily explained [WWW Document]. URL https://dessin-project.eu/?p=2232 (accessed 5.3.17).

Dewulf, A., Craps, M., Bouwen, R., Taillieu, T., Pahl-Wostl, C., 2005. Integrated management of natural resources: Dealing with ambiguous issues, multiple actors and diverging frames. Water Sci. Technol. 52, 115–124.

Dewulf, A., Gray, B., Putnam, L., Lewicki, R., Aarts, N., Bouwen, R., van Woerkum, C., 2009. Disentangling approaches to framing in conflict and negotiation research: A meta-paradigmatic perspective, Human Relations. doi:10.1177/0018726708100356

Dolnicar, S., Hurlimann, A., Duc, L., 2010. The effect of information on public acceptance: The case of water from alternative sources. J. Environ. Manage. 91, 1288–1293. doi:10.1016/j.jenvman.2010.02.003

Dolnicar, S., Hurlimann, A., Grün, B., 2014. Branding water. Water Res. 57, 325–338. doi:10.1016/j.watres.2014.03.056

Dolnicar, S., Hurlimann, A., Grün, B., 2011. What affects public acceptance of recycled and desalinated water? Water Res. 45, 933–943. doi:10.1016/j.watres.2010.09.030

Dolnicar, S., Schäfer, A.I., 2009. Desalinated versus recycled water: public perceptions and profiles of the accepters. J. Environ. Manage. 90, 888–900. doi:10.1016/j.jenvman.2008.02.003

Doria, M.D.F., Pidgeon, N., Hunter, P.R., 2009. Perceptions of drinking water quality and risk and its effect on behaviour: a cross-national study. Sci. Total Environ. 407, 5455–64. doi:10.1016/j.scitotenv.2009.06.031

Dufour, A.P., Evans, O., Behymer, T.D., Cantú, R., 2006. Water ingestion during swimming activities in a pool: A pilot study. J. Water Health 4, 425–430. doi:10.2166/wh.2006.017

Entman, R.M., 1993. Framing: Toward Clarification of a Fractured Paradigm. J. Commun. 43, 51–58. doi:10.1111/j.1460-2466.1993.tb01304.x

Erber, M.W., Hodges, S.D., Wilson, T.D., 1995. Attitude Strength, Attitude Stability, and the Effects of Analyzing Reasons, in: Petty, R.E., Krosnick, J.A. (Eds.), Attitude Strength: Antecedents and Consequences. Psycology Press, New York.

Escobar, M.P., Demeritt, D., 2014. Flooding and the framing of risk in British broadsheets, 1985-2010. Public Underst. Sci. 23, 454–71. doi:10.1177/0963662512457613

European Commission, 2016. Guidelines on Integrating Water Reuse into Water Planning and Management in the context of the WFD. European Commission, Brussels.

Evans, W.. D., Bihm, J.W., Szekely, D., Nielsen, P., Murray, E., Abroms, L., Snider, J., 2014. Initial Outcomes from a 4-Week Follow-up Study of the Text4baby Program in the Military Women's Population: Randomized Control Trial. J. Med. Internet Res. 16, e131. doi:10.2196/jmir.3297

Field, A., 2009. Discovering statistics using IBM SPSS statistics, 3rd ed. SAGE Publications Ltd, London.

Fielding, K.S., Gardner, J., Leviston, Z., Price, J., 2015. Comparing Public Perceptions of Alternative Water Sources for Potable Use: The Case of Rainwater, Stormwater, Desalinated Water, and Recycled Water. Water Resour. Manag. 29, 4501–4518. doi:10.1007/s11269-015-1072-1

Fielding, K.S., Roiko, A.H., 2014. Providing information promotes greater public support for potable recycled water. Water Res. 61, 86–96. doi:10.1016/j.watres.2014.05.002

Friedler, E., Lahav, O., Jizhaki, H., Lahav, T., 2006. Study of urban population attitudes towards various wastewater reuse options: Israel as a case study. J. Environ. Manage. 81, 360–370.

Frijns, J., Smith, H.M., Brouwer, S., Garnett, K., Elelman, R., Jeffrey, P., 2016. How governance regimes shape the implementation of water reuse schemes. Water (Switzerland) 8. doi:10.3390/w8120605

GLAIntelligence, 2016. GLA 2015 round trend-based projections - Results. Greater London Authority, London.

Goodwin, D., Raffin, M., Jeffrey, P., Smith, H.M., 2017. Evaluating media framing and public reactions in the context of a water reuse proposal. Int. J. Water Resour. Dev. Under revi.

Goodwin, D.P., Raffin, M., Jeffrey, P., Smith, H.M., 2015. Public support for wastewater reuse explored through online commentary - A case study for London, in: 10th IWA International Conference on Water Reclamation and Reuse. IWA, Harbin, China.

Hallahan, K., 1999. Seven Models of Framing: Implications for Public Relations. J. Public Relations Res. 11, 205–242. doi:10.1207/s1532754xjprr1103_02

Hambly, a. C., Henderson, R.K., Baker, a., Stuetz, R.M., Khan, S.J., 2012. Cross-connection detection in Australian dual reticulation systems by monitoring inherent fluorescent organic matter. Environ. Technol. Rev. 1, 67–80. doi:10.1080/09593330.2012.696724

Hamilton, K.A., Haas, C.N., 2016. Critical review of mathematical approaches for quantitative microbial risk assessment (QMRA) of Legionella in engineered water systems: research gaps and a new framework. Environ. Sci. Water Res. Technol. 2, 599–613. doi:10.1039/c6ew00023a

Harris-Lovett, S., Binz, C., Sedlak, D.L., Kiparsky, M., Truffer, B., 2015. Beyond User Acceptance: A Legitimacy Framework for Potable Water Reuse in California. Environ. Sci. Technol. 49, 7552–7561. doi:10.1021/acs.est.5b00504

Hills, S., Germain, E., Birks, R., Wyber, A., Tormenta, S., Risdale, H., Raffin, M., 2009. A holistic approach to explore the potential of planned Indirect Potable Reuse for London, in: IWA Reuse Conference, Brisbane, September 2009. IWA Publishing, Brisbane, pp. 1–3.

Hills, S., Smith, A., Hardy, P., Birks, R., 2001. Water recycling at the millennium dome. Water Sci. Technol. 43, 287–294.

Howell, R. A., 2011. Lights, camera ... action? Altered attitudes and behaviour in response to the climate change film The Age of Stupid. Glob. Environ. Chang. 21, 177–187. doi:10.1016/j.gloenvcha.2010.09.004

Hull, S., 2014. Perceived Risk as a Moderator of the Effectiveness of Framed HIV Test Promotion Messages Among Women: A Randomized Controlled Trial. Heal. Psychol. 31, 114–121. doi:10.1037/a0024702.Perceived

Hurlimann, A., Dolnicar, S., 2016. Public acceptance and perceptions of alternative water sources : a comparative study in nine locations. Int. J. Water Resour. Dev. 32, 650–673. doi:10.1080/07900627.2016.1143350

Hurlimann, A., Dolnicar, S., 2010. When public opposition defeats alternative water projects - The case of Toowoomba Australia. Water Res. 44, 287–297. doi:10.1016/j.watres.2009.09.020

Hurlimann, A., McKay, J., 2007. Urban Australians using recycled water for domestic non-potable use--an evaluation of the attributes price, saltiness, colour and odour using conjoint analysis. J. Environ. Manage. 83, 93–104. doi:10.1016/j.jenvman.2006.02.008

Ishii, S.K.L., Boyer, T.H., 2016. Student support and perceptions of urine source separation in a university community. Water Res. 100, 146–156. doi:10.1016/j.watres.2016.05.004

Islam, A., Sakakibara, H., Karim, R., Sekine, M., 2015. Evaluation of risk communication for rural water supply management: a case study of a coastal area of Bangladesh. J. Risk Res. 14, 1237–1262. doi:10.1080/13669877.2011.574315

Jeffrey, P., 2002. Public Attitudes to In-House Water Recycling in England and Wales. Water Environ. J. 16, 214–217. doi:10.1111/j.1747-6593.2002.tb00397.x

Jeffrey, P., Jefferson, B., 2003. Public receptivity regarding “in-house” water recycling: results from a UK survey. Water Sci. Technol. Water Supply 3, 109–116.

Keramitsoglou, K.M., Tsagarakis, K.P., 2011. Raising effective awareness for domestic water saving: Evidence from an environmental educational programme in Greece. Water Policy 13, 828–844. doi:10.2166/wp.2011.103

Khan, S.J., Gerrard, L.E., 2006. Stakeholder communications for successful water reuse operations. Desalination 187, 191–202. doi:10.1016/j.desal.2005.04.079

Krantz, S.A., Monroe, M.C., 2016. Message Framing Matters: Communicating Climate Change with Forest Landowners. J. For. 114, 108–115.

Krosnick, J.A., Alwin, D.E., Krosniek, J.A., 1989. Aging and Susceptibility to Attitude Change. J. Pers. Soc. Psychol. 57, 416–425. doi:10.1037/0022-3514.57.3.416

Krosnick, J.A., Petty, R.E., 1995. Attitude strength: Antecedents and consequences. Psycology Press, New York.

Lee, H., Tan, T.P., 2016. Singapore’s experience with reclaimed water: NEWater. Int. J. Water Resour. Dev. 32, 611–621. doi:10.1080/07900627.2015.1120188

Leong, C., 2016. The Role of Emotions in Drinking Recycled Water. Water 8, 548. doi:10.3390/w8110548

Leong, C., 2010. Eliminating " Yuck ": A Simple Exposition of Media and Social Change in Water Reuse Policies. Int. J. Water Resour. Dev. 26, 111–124. doi:10.1080/07900620903392174

Levin, I.P., Schneider, S., Gaeth, G., 1998. All Frames Are Not Created Equal: A Typology and Critical Analysis of Framing Effects. Organ. Behav. Hum. Decis. Process. 76, 149–188. doi:10.1006/obhd.1998.2804

Lyytimaki, J., Assmuth, T., 2014. Down with the flow: public debates shaping the risk framing of artificial groundwater recharge. GeoJournal 80, 113–127. doi:10.1007/s10708-014-9540-3

Macpherson, L., 2014. Core Messages for Priority Contaminants of Emerging Concern. Water Research Foundation, Denver CO.

Macpherson, L., 2011. Talking About Water: Vocabulary and Images that Support Informed Decisions about Water Recycling and Desalination. WateReuse Research Foundation, Alexandria, VA.

Mainali, B., Ngo, H.H., Guo, W.S., Pham, T.T.N., Wang, X.C., Johnston, a., 2011. SWOT analysis to assist identification of the critical factors for the successful implementation of water reuse schemes. Desalin. Water Treat. 32, 297–306. doi:10.5004/dwt.2011.2714

Mankad, A., 2012. Decentralised water systems: Emotional influences on resource decision making. Environ. Int. 44, 128–140. doi:10.1016/j.envint.2012.01.002

Marks, J., 2006. Taking the Public Seriously: The Case of Potable and Non Potable Reuse. Desalination 187, 137–147. doi:10.1016/j.desal.2005.04.074

Marks, J., Martin, B., Zadoroznyj, M., 2008. How Australians order acceptance of recycled water: National baseline data. J. Sociol. 44, 83–99. doi:10.1177/1440783307085844

Matos, C., Friedler, E., Monteiro, A., Rodrigues, A., Teixeira, R., Bentes, I., Varajao, J., 2014. Academics perception towards various water reuse options: University of Tras-os-Montes e Alto-Douro - UTAD Campus (Portugal) as a case study. Urban Water J. 11, 311–322. doi:Doi 10.1080/1573062x.2013.775314

Menegaki, A.N., Mellon, R.C., Vrentzou, A., Koumakis, G., Tsagarakis, K.P., 2009. What's in a name: Framing treated wastewater as recycled water increases willingness to use and willingness to pay. J. Econ. Psychol. 30, 285–292. doi:10.1016/j.joep.2008.08.007

Met Office, 2016. Climate Summary - April 2016 [WWW Document]. URL http://www.metoffice.gov.uk/climate/uk/summaries/2016/april (accessed 12.22.16).

Miller, E., Buys, L., 2008. Water-recycling in South-East Queensland, Australia: What do men and women think? Rural Soc. 18.

Milne, A.E., Glendining, M.J., Lark, R.M., Perryman, S. a M., Gordon, T., Whitmore, A.P., 2015. Communicating the uncertainty in estimated greenhouse gas emissions from agriculture. J. Environ. Manage. 160, 139–153. doi:10.1016/j.jenvman.2015.05.034

Motion, J., Kearnes, M., 2014. Project Report Water Recycling and Media : Guidelines for Communication. Australian Centre for Water Recycling Excellence, Brisbane, Australia.

Nancarrow, B.E., Leviston, Z., Po, M., Porter, N.B., Tucker, D.I., 2008. What drives communities' decisions and behaviours in the reuse of wastewater. Water Sci. Technol. 57, 485–491. doi:10.2166/wst.2008.160

Nancarrow, B.E., Leviston, Z., Tucker, D.I., 2009. Measuring the predictors of communities ' behavioural decisions for potable reuse of wastewater. Water Sci. Technol. 60, 3199–3210. doi:10.2166/wst.2009.759

Nisbet, M.C., 2009. The Ethics of Framing Science. Commun. Biol. Sci. Ethical Metaphor. Dimens. 51–73.

NRMMC EPHC & AHMC, 2006. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1). Natural Resource Ministerial Management Council, Environment Protection and Heritage Council and Australian Health Ministers, Canberra.

Pan, Z., Kosicki, G., 1993. Framing analysis: An approach to news discourse. Polit. Commun. 10, 55–75. doi:10.1080/10584609.1993.9962963

Petty, R.., Cacioppo, J.., 1986. The elaboration likelihood model of persuasion, in: Berkowitz, L. (Ed.), Advances in Experimental Social Psychology. Academic Press Inc., pp. 123–183. doi:10.1558/ijsll.v14i2.309

Po, M., Nancarrow, B.E., Leviston, Z., Porter, N.B., Syme, G.J., Kaercher, J.D., 2005. Water for a Healthy Country Predicting Community Behaviour in Relation to Wastewater Reuse. Canberra.

Price, J., Fielding, K.S., Gardner, J., Leviston, Z., Green, M., 2015. Developing effective messages about potable recycled water: The importance of message structure and content. Water Resour. Res. 51, 2174–2187. doi:10.1002/2014WR016514.Received

Price, J., Fielding, K.S., Leviston, Z., 2012. Supporters and Opponents of Potable Recycled Water : Culture and Cognition in the Toowoomba Referendum. Soc. Nat. Resour. 25, 980–995. doi:10.1080/08941920.2012.656185

Roseth, N., 2008. Community Views on Recycled Water - the Impact of Information. Research Report 48. Salisbury, Australia.

Ross, V.L., Fielding, K.S., Louis, W.R., 2014. Social trust, risk perceptions and public acceptance of recycled water: Testing a social-psychological model. J. Environ. Manage. 137, 61–68. doi:10.1016/j.jenvman.2014.01.039

Rozin, P., Haddad, B., Nemeroff, C., Slovic, P., 2015. Psychological aspects of the rejection of recycled water: Contamination, purification and disgust. Judgement Decis. Mak. 10, 50–63.

Russell, S., Lux, C., 2009. Getting over yuck: moving from psychological to cultural and socio-technical analyses of responses to water recycling. Water Policy 11, 21–35.

Russell, S., Lux, C., Hampton, G., 2008. Beyond "Information": Integrating Consultation and Education for Water Recycling Initiatives. Soc. Nat. Resour. 22, 56–65.

Schets, F.M., Schijven, J.F., de Roda Husman, A.M., 2011. Exposure assessment for swimmers in bathing waters and swimming pools. Water Res. 45, 2392–2400. doi:10.1016/j.watres.2011.01.025

Simpson, J., Stratton, H., 2011. Talking about water : words and images that enhance understanding. National Water Commission, Canberra.

Smith, H.M., Rutter, P., Jeffrey, P., 2014. Public perceptions of recycled water: a survey of visitors to the London 2012 Olympic Park. J. Water Reuse Desalin. 1–7. doi:10.2166/wrd.2014.146

Storey, M. V., Ashbolt, N.J., Stenström, T.A., 2004. Biofilms, thermophilic amoebae and Legionella pneumophila - A quantitative risk assessment for distributed water. Water Sci. Technol. 50, 77–82.

Tang, Z., Zhang, L., Xu, F., 2015. Examining the role of social media in California's drought risk management in 2014. Nat. Hazards 79, 171–193. doi:10.1007/s11069-015-1835-2

USEPA, 2012. Guidelines for Water Reuse. United States Environmental Protection Agency, U.S. Agency for International Development. Washington, D.C.

Van Gorp, B., 2007. The constructionist approach to framing: Bringing culture back in. J. Commun. 57, 60–78. doi:10.1111/j.1460-2466.2006.00329.x

WateReuse, 2014. The Ways of Water [WWW Document]. URL www.watereuse.org/water-reuse-101/watereuse-videos/ (accessed 10.8.15).

Wester, J., Timpano, K.R., Cek, D., Broad, K., 2016. The psychology of recycled water: Factors predicting disgust and willingness to use. Water Resour. Res. 52, 3212–3226. doi:doi:10.1002/2015WR018340

Wester, J., Timpano, K.R., Çek, D., Lieberman, D., Fieldstone, S.C., Broad, K., 2015. Psychological and social factors associated with wastewater reuse emotional discomfort. J. Environ. Psychol. 42, 16–23. doi:10.1016/j.jenvp.2015.01.003

Winter, J.C.F. De, Dodou, D., 2012. Five-Point Likert Items : t test versus Mann-Whitney-Wilcoxon. Pract. Assess. Res. Eval. 15, 1–16.

Wintgens, T., Hochstrat, R., 2006. Integrated Concepts for Reuse of Upgraded Wastewater. WP3 D19. AQUAREC, Aachen, Germany.

WRRF, 2010. The Psychology of Water Reclamation and Reuse: Survey Findings and Research Road Map. WRF-04-008. Alexandria, USA.

Wu, X., Dodgen, L.K., Conkle, J.L., Gan, J., 2015. Plant uptake of pharmaceutical and personal care products from recycled water and biosolids: A review. Sci. Total Environ. 536, 655–666. doi:10.1016/j.scitotenv.2015.07.129

Chapter 6. Multi-criteria stakeholder evaluations of risk interventions for new non-potable recycled water uses

D. Goodwin[1], M. Raffin[2], P. Jeffrey[1], H. M. Smith[1]

[1]Cranfield Water Science Institute, Cranfield University, Bedfordshire, UK, MK43 0AL

[2]Thames Water Utilities Ltd, Innovation, Reading STW, Island Road, Reading, UK RG2 0RP

Abstract

Community-scale non-potable recycled water schemes can benefit sustainable urban water management through reducing demand for drinking water and providing wastewater treatment. Yet, scheme feasibility can be diminished due to potentially high capital and operating costs. Moreover, perceptions of health risks can elevate operating costs – more so if risk reduction measures are overly cautious. Conversely, a failure to anticipate the risk management expectations of interested stakeholder can also undermine scheme feasibility if it results in insufficient demand for recycled water. The aim of this study was to explore how stakeholders' perceptions and preferences for risk management and recycled water end-uses might influence decision-making and scheme design. Using a case study scheme in London, four risk intervention scenarios and six alternative end uses were evaluated using a stochastic PROMETHEE-based method that incorporated quantitative microbial risk assessment and stakeholder criteria weights. Through pair-wise criteria judgements, stakeholders prioritised health risk reductions. As such, the inclusion of quantitative health risk information led to the more conservative management intervention of adding more water treatment processes. In contrast, responses to attitudinal survey questions favoured the existing risk management practices of the case study but with more stakeholder engagement. Comparison of the results from the two methods provided analytical advantages through triangulating the findings. Moreover, findings highlighted the importance of understanding the social desirability of different design options. This study concludes that there may be benefits to providing flexibility in scheme designs to be adaptable to changing expectations, and that stakeholder inclusion can contribute to enhancing risk-based decision making and associated management frameworks.

Keywords: multi-criteria, stakeholder, risk management, non-potable, recycled water

6.1 Introduction

Community-scale non-potable recycled water schemes can contribute to sustainable urban water management (Marlow et al., 2013). This is because there are a number of benefits to developing schemes, for example, reducing potable water demand (Chen and Wang, 2009). However, additional infrastructure investment (Leverenz et al., 2011) and high operating costs can detract from a scheme's longer-term viability (West et al., 2016) – particularly where the water infrastructure cannot be easily adapted to changing conditions. Such inflexibility in technical water systems may result from design philosophies that attempt to reduce and control complexity (Pahl-Wostl et al., 2007). Such a reductionist view of complexity may also manifest when more traditional cost-benefit techniques are used (Domènech et al., 2013) that do not account for externalities like environmental benefits (Chen and Wang, 2009). Adding to the scheme evaluation challenge, overly precautious approaches to health risk mitigation may result in the specification of unnecessary treatment technologies that increase energy demand and operating costs (Turner et al., 2016). However, this may be brought about by uncertainty in understanding stakeholders' risk appetites (Pickering, 2013) and risk management preferences for different recycled water uses which can require different water qualities and risk control strategies (Turner et al., 2016).

Efforts have been made to incorporate a range of criteria into water reuse scheme evaluations. For example, Urkiaga et al. (2008) put forward indices for integrating assessments of social, environmental, economic and technical risks. Other approaches include incorporating environmental and social factors in economic assessments (Hernández et al., 2006) or through evaluating strengths, weaknesses, opportunities and threats of different options (Mainali et al., 2011). Benefits to using multi-criteria evaluations have been demonstrated for water reuse scheme design, for example, selecting disinfection techniques (Gomez-Lopez et al., 2009) and membrane-based treatments (Sadr et al., 2016). Moreover, multi-criteria evaluations are considered helpful for evaluating prospective recycled water uses along with uncertainties in the analysis (Chen et al., 2014; Gomez-Lopez et al., 2009). Many studies include stakeholder or public acceptability as independent evaluation criteria (e.g. Sa-nguanduan and Nititvattananon, 2011). However, direct participation of stakeholders can help evaluate how perceptions and preferences might influence decisions (Woltersdorf et al., 2017).

There is a need to consider the impact stakeholder preferences for different risk management interventions might have on the selection of new recycled water uses (Chen et al., 2014, 2013;

Qadir et al., 2010). Risk management interventions can include source control, selection of water treatment technology, monitoring (critical control points, water quality compliance), regulatory audits or exposure reductions (Chen et al., 2013; D. Goodwin et al., 2015). Quantitative microbial risk assessment (QMRA) is increasingly relevant to the evaluation of risks from recycled water uses (Barker et al., 2013; Lim et al., 2015) and associated risk management options (Beaudequin et al., 2016). Quantitative health risk assessments can integrate with multi-criteria assessments (Linkov et al., 2006; Topuz et al., 2011) and help evaluate potential trade-offs between factors such as population risk, individual risk and the costs of risk controls (Khadam and Kaluarachchi, 2003; Westrell et al., 2004). Moreover, given the uncertainty involved in such analysis, probabilistic based estimations are also recommended (Alvarez-Guerra et al., 2010; Khadam and Kaluarachchi, 2003; Moglia et al., 2012).

A multi-criteria framework has been proposed for assessing new recycled water uses and prioritising management options (Chen et al., 2014) and was demonstrated for evaluating management options for connecting residential washing machines (Chen et al., 2012). To date, however, an approach has not been appraised that considers how the evaluation of more universal risk management interventions (i.e. those with consequences for a range of customers and end-uses) might influence preferences for scheme design and management. Secondly, there is a need to further understandings of the implications of incorporating quantitative health risk assessments into multi-criteria evaluations of risk management options for recycled water uses, particularly including probabilistic inputs. Finally, whilst there may be benefits to simulating 'synthetic' criteria weights, for example, if decision makers lack confidence and introduce human errors (Chen et al., 2014), there are also benefits in understanding how stakeholders think about problems (Bouchard et al., 2010) and carry out decision making (Stefanopoulos et al., 2014). This last point is important in developing understandings of how various stakeholders approach health risk mitigation options for recycled water scheme designs and the associated costs and benefits (Turner et al., 2016) - more so because stakeholders will range in their specific knowledge and level of involvement with a particular scheme (Farrelly and Brown, 2011; Turner et al., 2016).

In light of the evidence presented, this study aims to explore how stakeholders' perceptions and preferences for risk management and recycled water end-uses might influence decision-making and scheme design. Moreover, this study seeks to understand: (1) to what extent a multi-criteria approach that incorporates probabilistic inputs and quantitative health risk assessment might aid the evaluation of different risk management interventions and the associated feasibility of a range of new recycled water uses; (2) to what extent the importance stakeholders assign to different evaluation criteria might influence the selection of risk controls and new recycled water uses; and (3) the implications for using these types of methods for involving stakeholders in risk-based evaluations of recycled water schemes for adapting schemes designs and as part of a ‘decision making framework’.

6.2 Methods

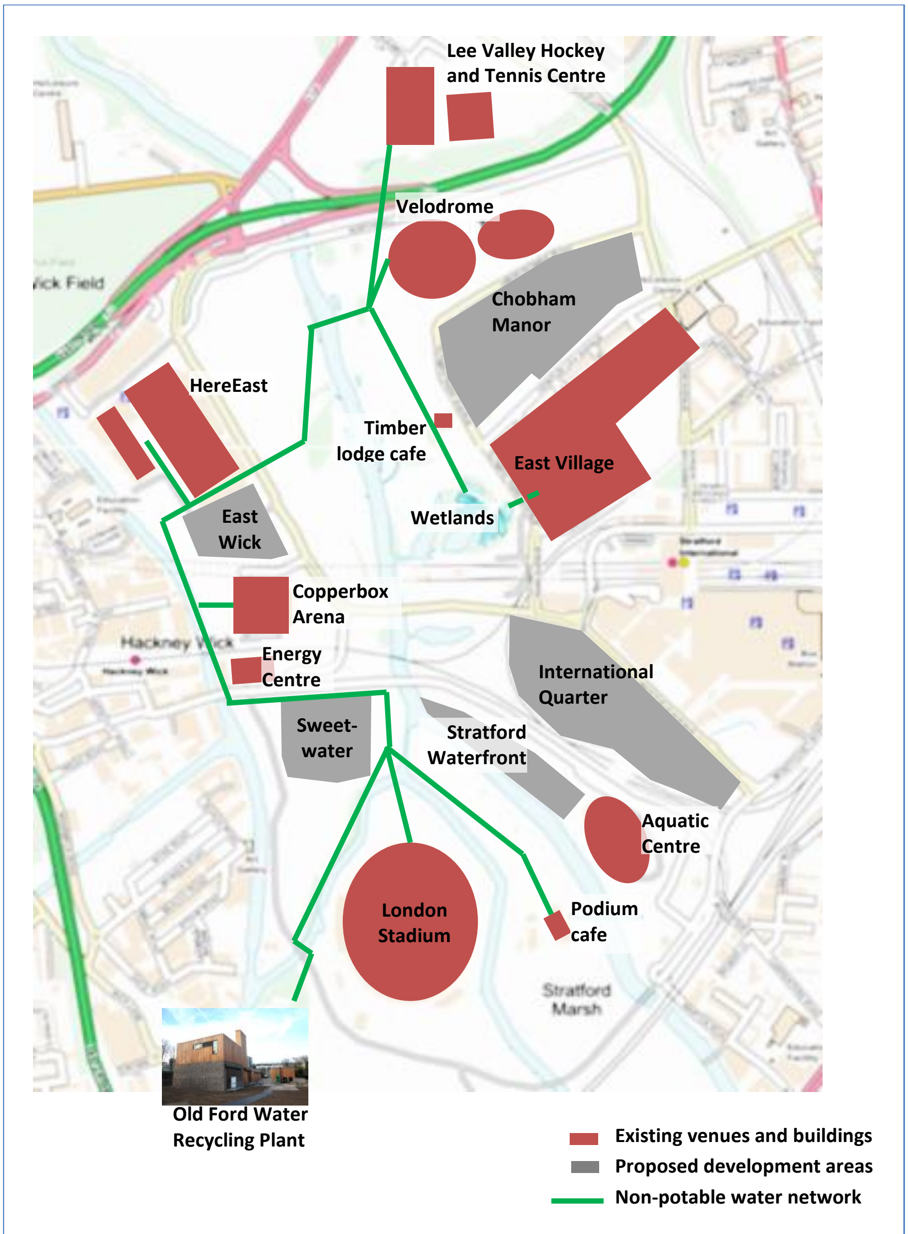


Figure 6-1 Layout of the non-potable recycled water network at the QEOP

Note: Contains OS data © Crown Copyright 2017

6.2.1 Case study details

This study considered the Old Ford Water Recycling Plant (OFWRP) and the supply of non-potable recycled water to existing and potential future customers at the Queen Elizabeth Olympic Park (QEOP) in East London (Figure 6-1). A number of publications can be referred to for more details of the recycled water scheme, including Goodwin et al. (2017a), Hills and James (2015) and Smith et al. (2014). The east of London is in a period of growth with an extra 600,000 people projected to be living in and surrounding the case study's location by 2040 (Greater London Authority, 2015). Planned development within the vicinity of the case study area includes residential housing, office space, retail space, schools, university campuses, a museum, a technology hub and potentially other industries such as concrete manufacturing (LLDC, 2015). As such, there are a number of opportunities for new recycled water customers.

6.2.2 Multi-criteria method

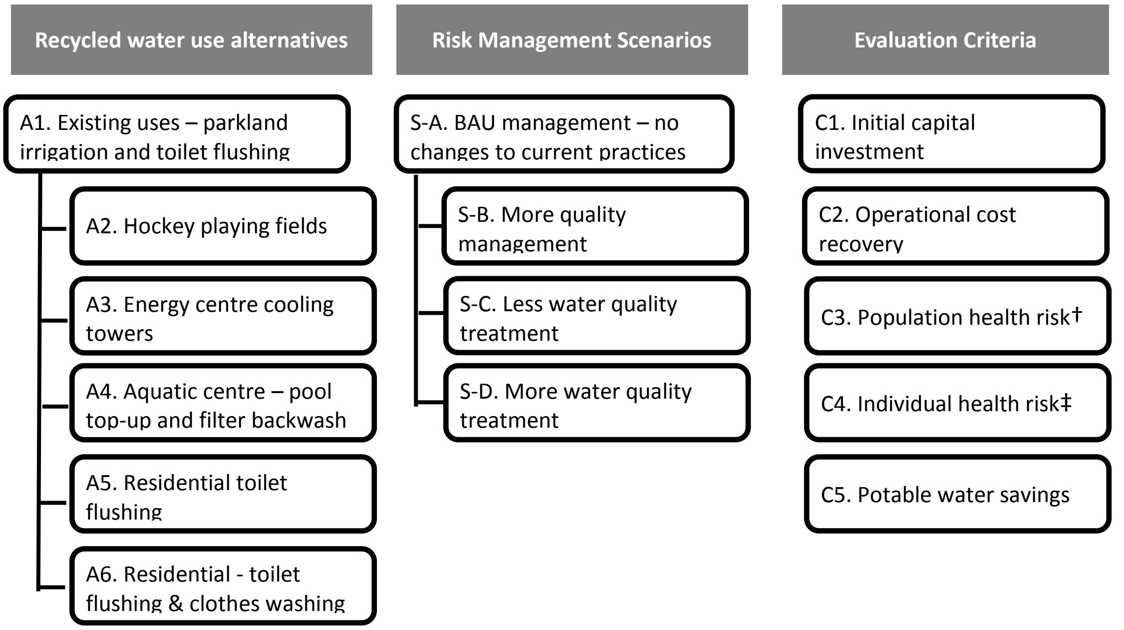
The "preference ranking organization method for enrichment of evaluations" (PROMETHEE) method formed the basis of the multi-criteria evaluation of alternatives. PROMETHEE was selected as the method is considered useful for stakeholder-based evaluations due to perceived transparent procedures and simplicity (Kodikara et al., 2010; Lai et al., 2016) and to put the results in the context of the previously proposed "framework for the assessment of new end uses in recycled water schemes" (Chen et al., 2014). Moreover, through a survey of the use of multi-criteria methods for water reuse studies (Refer to Appendix D), PROMETHEE is shown to be suitable in this context (e.g. Sadr et al., 2016; Sapkota et al., 2016). PROMETHEE preference functions (V-shaped Type III and linear Type V) were used based on recommendations for quantitative criteria assessments (Chen et al., 2012b) and also for studies with stakeholder input (Kodikara et al., 2010). The PROMETHEE model results were 'sense checked' using the "technique for order performance by similarity to ideal solution" (TOPSIS) method - also used in water reuse studies (Gomez-Lopez et al., 2009). Where PROMETHEE uses preference functions when comparing alternatives, TOPSIS is based on calculating the distance between each alternative and an ideal alternative (best on each dimension) and the negative ideal alternative (worst) using methods such as Euclidean distance (Huang et al., 2011). A second multi-criteria method was used because it is recommended to help test the sensitivity of model results (Hajkowicz and Collins, 2007). A

TOPSIS model was used to help understand the sensitivity of PROMETHEE preference function and threshold values choices on the results.

The multi-criteria method facilitated stochastic analysis of: (1) the input data for the evaluations of alternative end-uses and the risk management scenarios, and (2) criteria weights - follows the concept of stochastic multi-criteria acceptability analysis (Alvarez-Guerra et al., 2010). Probability distributions were included in Microsoft Excel versions of PROMETHEE (Hyde, 2006; Klauer et al., 2006) and TOPSIS (Kolios et al., 2016). The input data for the end-use alternatives used triangular distributions (Alvarez-Guerra et al., 2010), whilst the criteria weights for stakeholder groupings were simulated using triangular (skewed where necessary) or uniform distributions. The stochastic inputs were facilitated through Palisade @Risk software version 7.5 with 10,000 iterations (Alvarez-Guerra et al., 2010). Prior to stochastic simulation, the outputs (Phi preference flows) from the deterministic PROMETHEE Excel model (and preference functions) were checked against a Visual-PROMETHEE v1.4 model to ensure consistency.

6.2.3 Recycled water end-use alternatives

Six recycled water use alternatives were considered in the multi-criteria model (Figure 6-2), the first, Alternative 1, was the existing recycled water customers (parkland irrigation and toilet flushing at QEOP venues). Next, five potential new customer connections were considered (as additional flows adding to the BAU scenario). More details of the alternatives are discussed in Goodwin et al., (2017b) provided in Appendix E. The rationale for considering these alternatives was based on realistically available options for the case study along with related literature. Cooling towers are typical users of recycled water in many international locations (Miller, 2006; Storey et al., 2004). The use of water-based hockey fields is relatively untried, although recycled stormwater is practised (Adams, 2007) and recycled water is used for ice hockey (Jerome, 2014). For use in swimming pools, there are also few reported cases, however, Chen et al. (2014) indicate its feasibility for this use and both municipalities (Huxedurp et al., 2014) and residents (Crook et al., 2005; Marks and Zadoroznyj, 2005) have contemplated (even practiced) this end-use option. Finally, use in residential developments is well established and whilst washing clothes is somewhat more contentious than flushing toilets it is both feasible and practised (Chen et al., 2012; Mainali et al., 2011).



†Cumulative population exposure for all end-uses considered in a scenario, ‡Highest individual exposure for all end-uses considered in a scenario.

Figure 6-2 Summary of risk management scenarios, alternative recycled water uses and evaluation criteria

6.2.4 Risk management scenarios

Four risk management scenarios were developed (Figure 6-2), drawing from previous stakeholder research for this case study (Goodwin et al., 2017a): Scenario A – Business as usual (no changes to current risk management practices); Scenario B - improving quality management (assumed enhanced signage and information, water network sampling and flushing, auditing, dye testing, and exposure reductions); Scenario C – lower-treatment (removed existing GAC and poly-aluminium chloride dosing processes); and Scenario 4 - higher-treatment intervention (added reverse osmosis treatment process). More details of the improved quality management and the higher-treatment interventions can be found in Goodwin et al. (2017b). For the lower-treatment Scenario C, there were operational costs savings (less energy demand and chemicals along with lower estimates than BAU for labour and water quality analysis costs). However, the health risk results for the lower-treatment intervention were assumed to be the same as the business as usual scenario. It was assumed in the calculations that the removal of GAC and poly-aluminium chloride dosing from the treatment process did not alter the health risk (quantified for norovirus) (Chaudhry et al., 2015; Matsushita et al., 2013; Purnell et al., 2016). However, it is noted that assumptions of lower staffing levels and less frequent water quality analysis could increase the potential for hazardous events to go undetected for Scenario C.

6.2.5 Evaluation criteria

Criteria were selected to represent the potential trade-offs between costs, environmental benefits and health risks impacts. The criteria selection also drew from a review of previous recycled water multi-criteria studies and previous stakeholder research for this case study. As such, five evaluation criteria (Figure 6-2) were considered: (C1) initial capital investment; (C2) operational cost recovery (including cost-benefits from selling non-potable water and providing a wastewater treatment service for customers); (C3) population health risk (exposure to norovirus); (C4) individual health risk (exposure to norovirus); and (C5) potable water savings. Details of the data and calculations used for capital and operating costs, health-risks and potable water savings can be found in Goodwin et al. (2017b) and are also summarised in Table 6-1, showing triangle distributions for minimum, most probably and maximum estimated values.

A number of studies recommend incorporating qualitative health risk assessment into multi-criteria evaluations (Bichai et al., 2015; Khadam and Kaluarachchi, 2003; Topuz et al., 2011). For this study, Quantitative Microbial Risk Assessments (QMRA) and Disability Adjusted Life Year (DALY) calculation methods for norovirus were used to assess health risks. Norovirus was selected as it makes a significant contribution to the disease burden and healthcare costs in the UK (Tam and O'Brien, 2016), due to its use in related studies (Beaudequin et al., 2016; Lim et al., 2015) and due to its relevance across the recycled water uses considered in this study (Westrell et al., 2004). Moreover, log reduction values for norovirus removal had recently been quantified for this case study in research by Purnell et al. (2016). For reference, a DALY is equivalent to the loss of one year of full health and the health-based target of $1x10^{-6}$ (µDALY) is referred to in this study. The analysis was undertaken for DALY per person per year (pppy) and DALY per total population exposed to investigate potential trade-offs (Goodwin et al., 2017b; Westrell et al., 2004). Due to the magnitude of differences between the DALY per total population, the multi-criteria models used logarithmically transformed values.

Table 6-1 Summary of data used in the multi-criteria evaluation (triangular distributions)

Criteria	Objective	PROMETHEE preference function‡	Risk Scenario	Alternative 1 Existing uses	Alternative 2 Hockey fields	Alternative 3 Energy centre	Alternative 4 Aquatic centre	Alternative 5 Residential (WCs)	Alternative 6 Residential (WCs & WMs)
C1. ('000 £)	Maximise (costs are negative)	V-shaped p = 500	A	-330; -300; -270	-440; -400;-360	-440; -400;-360	-550; 500; -450	-2500; -2000; -1500	-2500; -2000; -1500
			B	-330; -300; -270	-440; -400;-360	-440; -400;-360	-550; 500; -450	-2500; -2000; -1500	-2500; -2000; -1500
			C	-330; -300; -270	-440; -400;-360	-440; -400;-360	-550; 500; -450	-2500; -2000; -1500	-2500; -2000; -1500
			D	-430; -400; -370	-540; 500; -460	-540; 500; -460	-650;-600; -550	-2600; -2100; -1600	-2600; -2100; -1600
C2. ('000 £.year^{-1})	Maximise benefits	V-shaped p = 100	A	-57; -50; -47	13; 15; 17	50; 85; 120	-22; -20; -18	40; 100; 160	60; 130; 200
			B	-73; -68; -60	-5; 0; 5	78; 87; 96	-38; -34.5; -31	60; 66; 73	94; 104; 115
			C	-17; 15.5; -14	46; 52; 56	124; 138; 152	12; 13.5; 15	108; 120; 132	144; 160; 176
			D	-75; -68; 61	-6; -2.5; 1	72; 80; 88	-42; -38; -34	**53; 59; 65**	**85; 95; 105**
C3. (log10[µDALY.year^{-1}])	Minimise	Linear q = 1.3 p = 5.0	A	1.81;1.99;2.14	4.29; 4.46; 4.63	1.81; 2.00; 2.15	4.96; 5.15; 5.34	3.18; 3.38; 3.53	3.18; 3.38; 3.54
			B	1.91; 1.96; 2.00	4.29; 4.46; 4.63	1.92; 1.96; 2.00	4.96; 5.15; 5.34	2.89; 2.94; 2.98	2.91; 2.95; 2.99
			C	1.81; 1.99; 2.14	4.29; 4.46; 4.63	1.81; 2.00; 2.15	4.96; 5.15; 5.34	3.18; 3.38; 3.53	3.18; 3.38; 3.54
			D	1.15; 1.19; 1.23	3.33; 3.38; 3.42	1.15; 1.19; 1.23	4.19; 4.24; 4.28	2.51; 2.55; 2.59	2.51; 2.56; 2.60
C4. (µDALY.pppy^{-1})	Minimise	Linear q = 0.3 p = 1.0	A	0.26; 0.39; 0.60	0.74; 1.10; 1.60	0.45; 0.67; 1.00]	1.0; 1.6; 2.5	0.43; 0.63; 1.00	0.43; 0.65; 1.00
			B	0.13; 0.15; 0.17	0.74; 1.10; 1.60	0.24; 0.26; 0.29	1.0; 1.6; 2.5	0.30; 0.33; 0.37	0.30; 0.34; 0.37
			C	0.26; 0.39; 0.60	0.74; 1.10; 1.60	0.45; 0.67; 1.00]	1.0; 1.6; 2.5	0.43; 0.63; 1.00	0.43; 0.65; 1.00
			D	0.05; 0.055; 0.060	0.11; 0.12; 0.14	0.07; 0.08; 0.09	0.21; 0.23; 0.25	0.085; 0.095; 0.10	0.086; 0.095; 0.11
C5. (ML.year^{-1})	Maximise	V-shaped p = 60	A	60; 70; 84	84;90;96	123;135; 150	72; 75; 80	114; 147; 180	140; 190; 240
			B	60; 70; 84	84;90;96	123;135; 150	72; 75; 80	114; 147; 180	140; 190; 240
			C	60; 70; 84	84;90;96	123;135; 150	72; 75; 80	114; 147; 180	140; 190; 240
			D	60; 70; 84	84;90;96	123;135; 150	72; 75; 80	114; 147; 180	140; 190; 240

‡Strict preference threshold (p), indifference threshold (q)

6.2.6 Stakeholder response elicitation

A questionnaire was designed to elicit stakeholder responses and used Likert-type questions, pair-wise criteria judgements and qualitative feedback questions. The Likert-type questions used a six-point scale (1 = completely disagree, 2 = somewhat disagree, 3 = neither agree nor disagree, 4 = somewhat agree, 5 = completely agree, 6 = no opinion). The questionnaire began by asking participants to: (1) provide details of their knowledge of and prior involvement with the case study; (2) select the most relevant stakeholder group from a pre-defined list (with the option to enter their own definition); and (3) provide details of their roles and responsibilities in relation to the Olympic Park and its water management. Following these initial questions, overview information was provided on the water recycling system, the recycled water quality and current risk management practices. Next, participants were asked to state how much they agreed or disagreed with: (1) the recycled water being used for the alternative non-potable water uses; and (2) with descriptions of risk management scenarios. Participants were also asked to provide qualitative feedback on whether they had other preferences for recycled water uses and what factors their preferences might depend on (e.g. water quality) as well as perspectives on risk management requirements and the sharing of risk management responsibilities.

For the next stage of the questionnaire, participants were presented with a brief narrative describing the five evaluation criteria before subjective weights for each of the five criteria were elicited on a pair-wise basis using the Analytic Hierarchy Process (AHP) methodology (1 = the criteria are about the same importance, 3 = slightly more important, 5 = moderately more important, 7 = much more important, 9 = extremely more important), following Curiel-Esparza et al., (2014), Gdoura et al., (2015) and Sadr et al., (2016). Finally, the participants were asked for qualitative feedback on (1) the criteria comparisons, including whether they thought important criteria were missing, and (2) their thoughts on future research needs relating to the use of recycled water at the Olympic Park and more broadly (in London or in the UK).

Following ethical approval, participants were purposively recruited to reflect the breadth of stakeholders directly involved with the case study and indirectly, on the fringe or outside the 'local network' (Turner et al., 2016). Of 192 invitations, 58 (30.2%) surveys were started (and completed the initial stakeholder question) and 37 (19.3%) validly completed. The pre-defined stakeholder groupings follow similar stakeholder research grouping used in water reuse studies (Baggett et al., 2006) and multi-criteria water governance (Salgado et al., 2009). Recruited stakeholders completing the survey included water company representatives (n=13); water resource practitioners involved in water resource management in London (n=11); recycled water customers and users (n=7); and, local government planners and environmental regulators (n=6). The rate of attrition was 36% overall. Attrition was highest in the local government planners and environmental regulators group (50% not completing) and lowest in the water company representatives group (23% not completing). A breadth of stakeholders were represented in terms of their involvement with the scheme and their general knowledge of recycled water schemes (Figure 6-3). The majority of participants had some knowledge of the Olympic Park scheme.

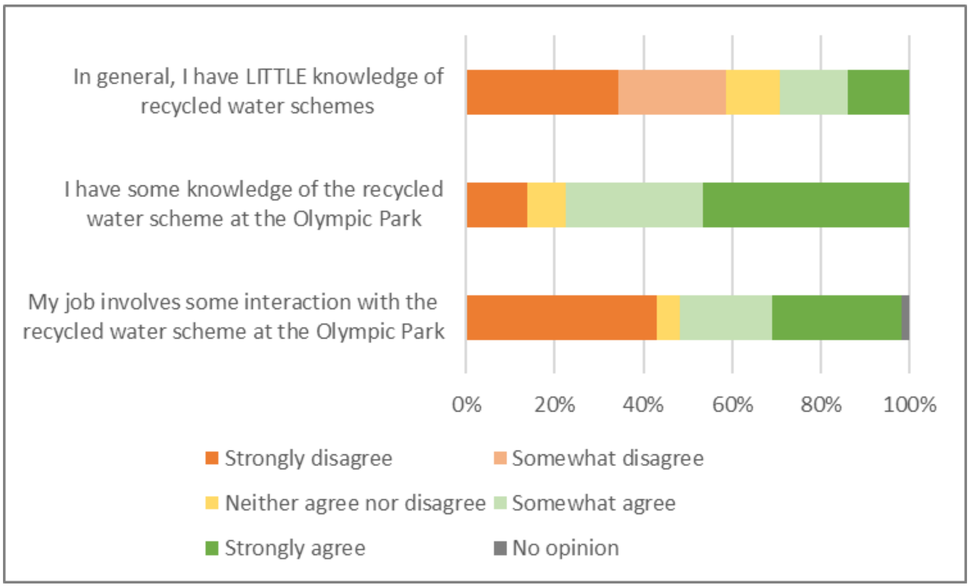


Figure 6-3 Stakeholders' knowledge of and involvement with the case study and recycled water (58)

Of those that completed the survey, 10 were then excluded from the multi-criteria assessment based on AHP method consistency ratio criteria. Whilst a consistency ratio for the AHP methods of 0.10 is typically recommended, values up to 0.25 have been used for multi-stakeholder studies (Knoeri et al., 2011). For this study, a threshold of CR ≤ 0.20 was used for individual evaluations (Moreno-Jiménez et al., 2008), to account for the range of stakeholders invited (including 'non-experts'), the cognitive challenge of the task (Derak and Cortina, 2014) and due to a single iteration being used. A CR of ≤ 0.10 was used for the overall group average, however, it is stressed that the process aimed to contrast the range of stakeholder perspectives rather than derive a single correct answer (Huang et al., 2011), thus it was conceived as valuable to include some less consistent responses (i.e. 0.10 ≤ CR ≤ 0.20) in order to represent stakeholder diversity.

6.2.7 Analysis

The first step was the multi-criteria evaluation based on equal weighting (Alvarez-Guerra et al., 2010) and using stochastically generated inputs for the quantitative criteria evaluation data. The outputs were a range of ranks (reported for each five-percentile interval from the 5th percentile to the 95th percentile) for each alternative recycled water use (Alternative 1 – 6) under each risk management scenario (Scenario A – D). As the distributions were non-normal (Shapiro-Wilk, $p < 0.05$ for all four risk management scenarios), the ranks (dependent variable) for each of the four risk management scenarios were compared using the independent samples Kruskal Wallis H-test with post-hoc tests (χ^2 significance level of 0.05 for three degrees of freedom was $\chi^2_{0.05}$ [3] = 7.815) using IBM SPSS Statistics version 22.0.

For simulating the weight ranges for stakeholders, data for the criteria were fit to the most suitable distributing - aided by 'Akaike information criteria' rankings in Palisade @Risk. C1, C2, C4 & C5 used triangular distributions whilst C3 used a uniform distribution. As with the equal weight scenario, the ranks for each risk management scenario were compared. The hypothesis (H1) was that the mean ranks of the risk management scenarios would differ (under the different weight scenarios). For the next step of the analysis, agreement statements from the questionnaire were evaluated with all completed responses (n=37) being considered valid. The Pearson Chi-squared test was used to compare the relative frequency of the response categories to explore stakeholder sub-groupings. Finally, the results of the multi-criteria evaluation and the agreement statements were compared and contrasted - also drawing on qualitative responses from the questionnaire.

6.3 Results

6.3.1 Developing the multi-criteria model

The PROMETHEE-based multi-criteria model was developed alongside a TOPSIS model to help evaluate the sensitivity of inputs. This step of analysis identified that the PROMETHEE-based model was sensitive to the definition of the preference function, and particularly the setting of the indifference and strict preferences thresholds for the two risk criteria (C3 & C4). This calibration led to linear preference functioned being selected for the two risk criteria. The indifference functions were incremented and the results cross-compared to the TOPSIS results. At the conclusion of this process, there remained differences between the two methods. Of the 24 possible options (6 end-use alternatives and 4 risk management scenarios), the deterministic models provided equivalent rankings for 17 (71%). The largest rank order difference was for Alternative 2 (hockey) under risk management Scenario C (lower technology), ranking 15th using TOPSIS and 18th using PROMETHEE. Using the Mann-Whitney U-test, the mean ranks for each of the four risk management scenarios did not differ significantly between the two methods. The most pronounced difference was for Scenario D ($z = -1.832$, $p = 0.067$) which was more likely to rank as the preferred risk management scenario in PROMETHEE. These results identified that firstly the selection of the multi-criteria model and secondly, the calibration of PROMETHEE preference functions could influence the results.

6.3.2 Equal criteria weighting

The stochastic PROMETHEE-based model was first simulated with equal criteria weights. The six alternatives and four scenarios meant there was a possibility of being ranked between 1 (best) and 24 (worst). The results (Figure 6-4) showed that across the four management scenarios, Alternative 3 ($M_{rank} = 2.6$) was the best performing recycled water use, followed by Alternative 6 ($M_{rank} = 6.5$) and Alternative 5 ($M_{rank} = 10.5$). The aquatic centre was typically the lowest ranking alternative ($M_{rank} = 22.3$), however, under Scenario D, the best results for the aquatic centre ($Rank_{95\%} = 19$, Alternative 4, Scenario D) compared with the worst ranks for the hockey centre ($Rank_{5\%} = 20$, Alternatives 2, Scenario A and $Rank_{5\%} = 21$, Alternative 2, Scenario B). Comparing the four risk management scenarios using the Kruskal-Wallis H-test, the results showed significant differences between the rankings ($\chi^2 = 10.635$, $p = 0.014$). Scenario D was significantly better overall than Scenario A ($z = 2.789$, $p = 0.032$) but not compared to any other scenarios (with adjusted significance for the post-hoc tests).

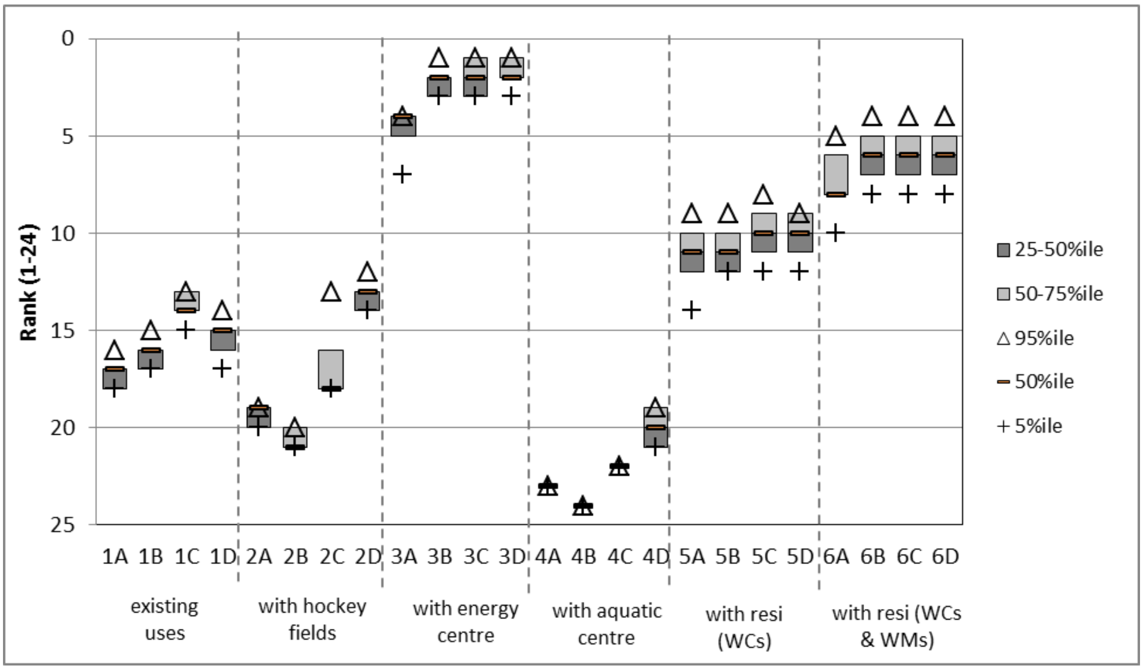


Figure 6-4 Multi-criteria (PROMETHEE) results for equal criteria weighting.

Alternative uses: 1 = existing uses (BAU), 2 = hockey, 3 = energy centre, 4 = aquatic centre, 5 = residential (WCs), 6 = residential (WCs & WMs). Risk Management Scenarios: A = existing risk management (BAU), B = enhanced risk management, C = lower technology, D = higher technology (RO)

6.3.3 Stakeholder weights

The stakeholder weight results showed that minimising individual risks (C4) was the most important criteria. Across all valid responses (n = 27), the preference order for the criteria was: C4 (M = 35.3%, SD = 12.2%) > C3 (M = 25.1%, SD = 11.2%) > C5 (M = 19.1%, SD = 12.4%) > C2 (M = 10.9%, SD = 6.5%) > C1 (M = 9.5%, SD = 6.8%). This preference order was largely consistent across stakeholder sub-groups, although there were some small differences. For example, 'planners and regulators' ordered both C5 (potable water savings) and C4 as equally the most important. The stakeholder weights were simulated in the PROMETHEE-based model after fitting the responses to statistical distributions. The six alternatives and four scenarios meant there was a possibility of being ranked between 1 (best) and 24. The results showed that (across all of the risk management scenarios) the preferred recycled water uses, as with the equally weighted scenario, was Alternative 3 (energy centre, M_{rank} = 4.7). This was more closely followed by Alternative 6 (residential option with WCs and washing machines connected, M_{rank} = 5.7). Next was Alternative 5 (residential with WCs only, M_{rank} = 10.6), Alternative 1 (BAU uses, M_{rank} = 14.2), Alternative 2 (hockey, M_{rank} = 18.0) and Alternative 4 (aquatics, M_{rank} = 21.7). Comparing the four risk management scenarios using the Kruskal-Wallis H-test, the results showed significant differences between the rankings (χ^2 = 40.719, p = 0.001). Scenario D was significantly better overall than Scenario A (z = 6.139, p = 0.001), Scenario B (z = 3.888, p = 0.001) and Scenario C (z = 4.537, p = 0.001) - all with adjusted significance for the post-hoc tests.

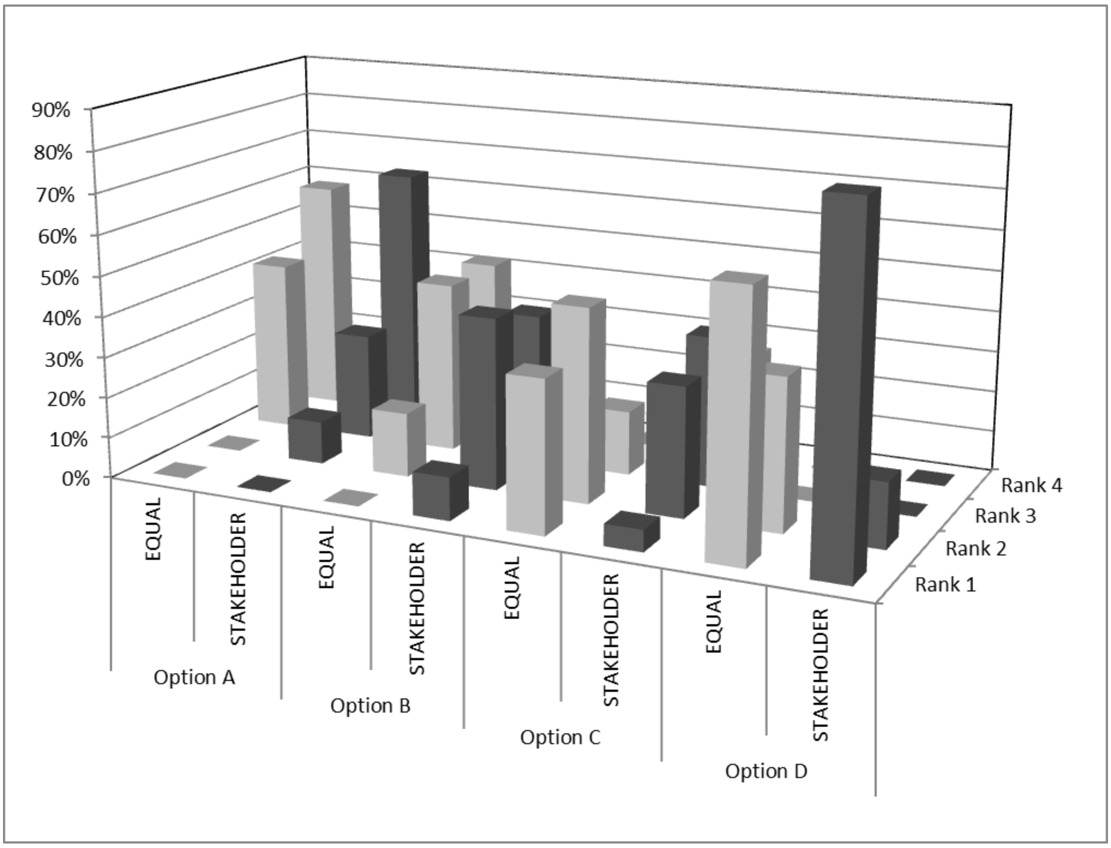


Figure 6-5 Comparison of the probability of rank order for risk management scenarios for equal and stakeholder weights (PROMETHEE model)

Each rank (e.g. rank 1) sums to 100% for each model (e.g. equal weights)

Comparing the relative rank of the four management scenarios highlighted how the risk reduction management scenarios (Scenarios B and D) were promoted with stakeholder criteria weight preferences (Figure 6-5). For instance, the results showed that Scenario D became more likely to be ranked in the best performing quartile range (rank 1 = 84%) than with equal criteria weights (rank 1 = 63%). The other risk reduction scenario (Scenario B) was most frequently in the lower quartile ranks with equal weight (rank 3 = 42%, rank 4 = 42%). With stakeholder weights, however, this became the second preferred scenario (rank 1 = 11%, rank

2 = 42%). On the other hand, Scenario 3 was the second best performing option with equal weights (rank 1 = 37%), however, this became less likely to rank in the higher quartiles using stakeholder weights. The change in criteria weights had less influence on Scenario A (BAU), which was the most likely to be in the worst performing quartile range for both equal weights (rank 4 = 58%) and stakeholder weights (rank 4 = 63%).

6.3.4 Stakeholder attitudes

Across all responses (N=37), the highest level of agreement was for 'topping up wetlands or environmental flow' and for 'the energy centre (cooling towers)', both receiving 97% positive responses (Figure 6-6). Following this, existing uses, 'university campus and school developments (flushing toilets and landscape irrigation)' and 'concrete manufacturing (making concrete blocks or ready-mix)' all received 94% agreement. The proposed recycled water uses that received the highest levels of disagreement were the aquatic centre (47%) followed by residential washing machines (36%) and water-based hockey fields (31%). Results worth noting included 37% agreement for use in the aquatic centre (for topping up the pool and backwashing filters) and only 50% agreement for use in residential washing machines (lower than many other studies). There were no significant differences between any of the stakeholder sub-groupings for their levels of agreement with the various recycled water uses - evidenced by comparing the relative frequency of the response categories using Pearson Chi-squared tests.

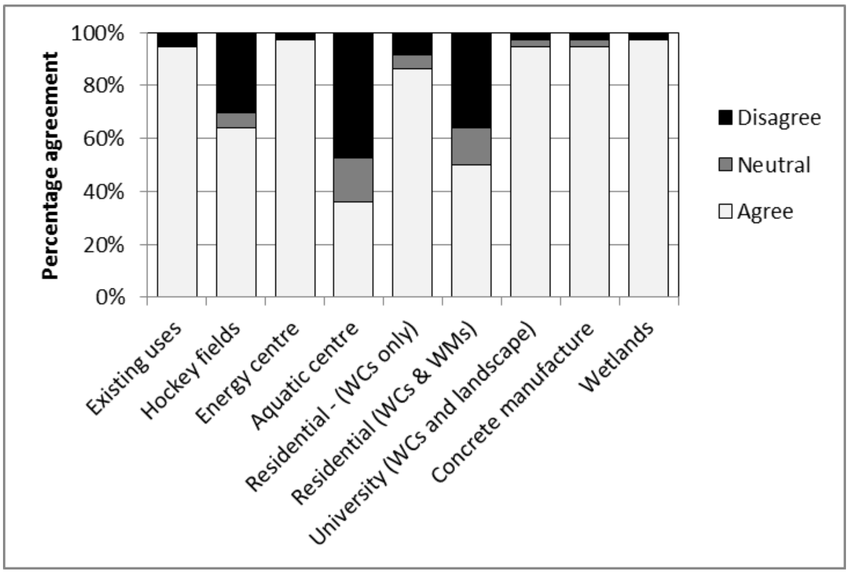


Figure 6-6 Agreement with recycled water used for different purposes

Regarding risk management preferences, the statements receiving the highest levels of overall agreement (Figure 6-7) were that existing risk management is sufficient (76%) and that there should be more stakeholder involvement (51%). Many of the other statements elicited predominantly neutral responses, particular towards changing tariffs and towards improving quality management where 59% neither agreed nor disagreed. The strongest level of disagreement was to the question of 'removing some water treatment steps' (68% disagreed). There were some differences between stakeholder sub-groupings, for example, for the statement that 'risk management should be improved by adding more water treatment technology', the water company respondents were more strongly split between agreeing (38%) and disagreeing (39%) than all other respondents who were more neutral (54%) and agreed less (12%).

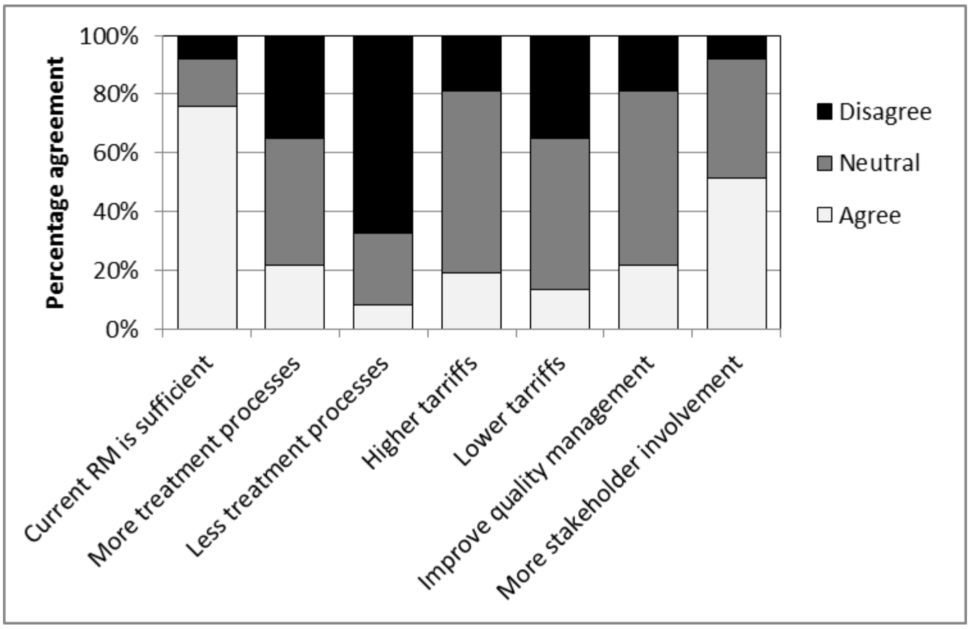


Figure 6-7 Stakeholder agreement with management scenarios

6.3.5 Comparing multi-criteria and attitudinal results

The energy centre as a preferred recycled water use was ubiquitously favoured across both the multi-criteria model and attitudinal results. There was more contrast between the two methods for the results for Alternative 6 (residential developments with WCs and WMs). Whilst the multi-criteria approach evaluated this end-use as the second most preferred, the attitudinal results showed only 50% of respondents agreed. For the residential end-use (Alternative 5) with toilet flushing only, there was high support for this from the stakeholders

(86% agreed). However, this alternative did not perform so well in the multi-criteria evaluation, particularly due to relatively worse cost recovery and lower potable water savings when compared with Alternative 6. The other new end-uses of the aquatic centre and hockey fields scored low using both methods. However, hockey fields achieved more favourable ratings in the agreement statements than with the multi-criteria approach.

For risk management, the multi-criteria method preferred the technology intervention (Scenario D). This contrast somewhat with the attitude results where there was little agreement with the need for more water treatment processes (22% agreed). In terms of removing water treatment process, a high proportion disagreed with this (68%). This result, to some extent, can be compared with the multi-criteria approach where the stakeholder weights reduced the favourability of Scenario C (lower technology) when compared to the equal weight results. Thus, the agreement statements helped to triangulate and validate, to a degree, the choice of the PROMETHEE-based model and the use of stakeholder weightings. This result also helps to validate the choice of PROMETHEE, as Scenario C achieved more favourable ranking results in the TOPSIS model.

There was little stakeholder agreement for improving quality management (24% agreed). However, a preference for the quality management standpoint was given some support by the 51% agreeing that more stakeholder involvement (a prerequisite for quality management) could help manage risk. Some respondents qualified the trade-off between quality management procedures and water treatment processes for example, *"I think risk management should be higher if water treatment stages were removed."* (Respondent 5 – water company). Regarding the pair-wise criteria comparisons, some respondents indicated that they found the task difficult. Moreover, others indicated that other criteria could be included, for example, benefits to upstream potable water networks, whole-life costing or regulatory certainty. Only 73% of the respondents were consistent in their pair-wise comparisons of the criteria. More iterations could have helped to improve the data quality and to give people the *"chance to think and be involved"* (Respondent 17 – water management consultant).

6.4 Discussion

The incorporating of quantitative microbial risk assessment is a growing area of interest in the assessment of recycled water uses (Lim et al., 2015) and their associated risk management (Beaudequin et al., 2016). Moreover, there is a keen interest in linking quantitative risk assessments with multi-criteria assessments (Linkov et al., 2006; Topuz et al., 2011). This study showed that the PROMETHEE-based model was sensitive to inputs for the risk criteria – particularly the indifference and strict preference thresholds used in comparing data. Through comparing the multi-criteria results with attitude statement results, it appears the model was more conservative towards the treatment of risk, consistently ranking the technology management intervention first. Attitudinal data also indicated a 'do something' preference for adapting current risk management, however, it only showed more stakeholder involvement as desirable. The other proposed management changes elicited largely neutral responses, perhaps with the exception of removing any existing treatment processes, which was broadly undesirable. These results help support the use of the PROMETHEE-based method over the TOPSIS method which didn't account for sensitivities around risk threshold values. The results also demonstrated an identified challenge with QMRA (Bichai and Ashbolt, 2017), in that the estimates used may lead to prioritising water quality treatment that is not necessarily needed for safe use. The inclusion of criteria for both population and individual risk, whilst useful for evaluating this trade-off (Khadam and Kaluarachchi, 2003; Westrell et al., 2004) likely contributed to emphasising risk mitigation measures in the multi-criteria model.

One finding was the favourable ranking of residential developments, with recycled water used for flushing toilets and washing clothes, through the multi-criteria method, which contrasts with low support (50%) for this alternative, elicited through the attitudinal questions. The literature suggests that health risks through exposure to recycled water used for washing clothes can be low (Page et al., 2013) and this was supported by a quantitative assessment for this case study. This finding highlights knowledge gaps in both exposure data for clothes washing and also other quality and risk perceptions feasibly affecting stakeholders' judgements of this particular end-use (and in this case study location). This finding implies benefits to openly exploring perceptions of scheme design configurations to understand which design elements raise more concerns and which are considered socially acceptable.The finding also implies benefits to providing some flexibility in scheme designs that can appeal to a range of perceived social needs. The findings further suggest that drawing from a wider range of stakeholder perspectives, whilst acknowledging complexity (Pahl-Wostl et al., 2007), may lead to more socially legitimate scheme design configurations (Gikas and Tchobanoglous, 2009).

The results support the observation that water utility practitioners may perceive higher risks for water reuse schemes (Dobbie and Brown, 2014). Whilst the risk criteria were also the most important to other stakeholder groups, they also apportioned more importance to potable water savings. Whilst, for this case study, the range of criteria weights did not have much bearing on the multi-criteria results, it did indicate a range of feasible preferences potentially influencing the evaluative process. An implication is that visual and statistical contrasts of what the stakeholders considered feasible could be used to facilitate debate around the importance they assigned to criteria and thus delineate a space for informed discussions. In contrast to other suppositions, whilst more cautious risk management can increase operating costs (Turner et al., 2016) – they may also improve operating cost-benefits in the longer-term if it leads to more demand for the recycled water. This finding supports previous research (Alvarez-Guerra et al., 2010) indicating that the range of inputs can help evaluate the robustness of alternatives and help guide the selection of risk control configurations as part of a scheme's design.

Multiple criteria approaches can help identify viable recycled water end-uses and then assess and prioritise risk controls and management options (Chen et al., 2014). Findings of this present study, whilst limited by using a single round of stakeholder input, showed value in incorporating human judgement in the process – as opposed to attempting to avoid 'human error' (Chen et al., 2014). The results of this study indicate benefits to using this type of process to help stakeholders unpick how they think about the problem (Bouchard et al., 2010). Moreover, engaging a diverse group of interested stakeholders (Farrelly and Brown, 2011; Turner et al., 2016) can bring insight to the evaluative task by putting forward different points of view. An implication for a risk-based decision-making framework is that iterative and deliberative stakeholder involvement may bring benefits to the process, to help understand objectives and risk management preferences. An implication for the design of schemes is that information derived from ongoing evaluations of stakeholders' performance expectations may aid the adaption of water supply and wastewater infrastructure to changing circumstances.

Finally, the probabilistic multi-criteria, incorporating data from QMRA, was able to evaluate risk management interventions with consequences for a range of end-uses. Through reviewing the results of such evaluative processes, scheme designers and decision-makers may account for a wider range of expectations in the design and configuration of a scheme. Thus, the findings support the benefits of using multi-criteria evaluation to aid stakeholders with water reuse scheme design (Gomez-Lopez et al., 2009; Sadr et al., 2016) through the evaluation and selection of risk reduction measures. This study has demonstrated a new approach for assessing recycled water schemes that draws on statistical inference and triangulation with attitudinal responses to survey questions. The results provide insight into stakeholder preferences, methodological choices and methods for evaluating and managing recycled water schemes. This study puts forwards evidence of benefits to encouraging stakeholder diversity as part of a 'framework for decision making in new end-use management' (Chen et al., 2014).

6.5 Conclusions

This study aimed to explore how stakeholders' perceptions and preferences for risk management and recycled water end-uses might influence decision-making and scheme design. Results of a multi-criteria evaluation indicated stakeholders prioritised a higher level of water quality treatment for adapting an existing water reuse scheme to accommodate new recycled water end-uses. Contrastingly, survey responses showed that stakeholders favoured existing risk management practices and more stakeholder engagement but were mostly neutral to other design and management changes. One notable finding was the favourable ranking of residential developments (with recycled water used for flushing toilets and washing clothes) through the multi-criteria method, in contrast with low support for this alternative elicited through the attitudinal survey questions. As such, the findings indicated analytical advantages to using and comparing multiple elicitation methods.

Stakeholders prioritised health risk reduction, as such, the inclusion of quantitative health risk information in the multi-criteria assessment will likely favour more conservative risk control interventions. However, although the enhanced risk reduction had cost implications, these could be offset by longer-term economic benefits through securing more recycled water customers. A conclusion of this study is that a benefit of probabilistic multi-criteria evaluation is that it may encourage stakeholders to unpack the reasoning behind their preferences through the consideration of uncertainty. The findings support the exploration of perceptions of scheme design configurations to understand the social acceptance of different options. The findings implied potential benefits to providing flexibility in scheme designs so they appeal to a range of perceived social needs as well as being more adaptable to future challenges. Moreover, the findings implied benefits to encouraging the inclusion of stakeholder input as a necessary condition for risk-based decision making and management frameworks. Further work should look at extending this study to consider more deliberative methods that can help stakeholders unpack their reasoning and perspectives around risk mitigation preferences.

6.6 Acknowledgements

This research was co-funded by the UK's Engineering and Physical Science Research Council (EPSRC) grant number EP/G037094/1 and Thames Water through the STREAM Industrial Doctorate Centre.

6.7 References

Adams, B., 2007. waterMAP – Case Studies Local Government and Open Space. South East Water, Melbourne.

Alvarez-Guerra, M., Canis, L., Voulvoulis, N., Viguri, J.R., Linkov, I., 2010. Prioritization of sediment management alternatives using stochastic multicriteria acceptability analysis. Sci. Total Environ. 408, 4354–4367. doi:10.1016/j.scitotenv.2010.07.016

Anane, M., Bouziri, L., Limam, A., Jellali, S., 2012. Ranking suitable sites for irrigation with reclaimed water in the Nabeul-Hammamet region (Tunisia) using GIS and AHP-multicriteria decision analysis. Resour. Conserv. Recycl. 65, 36–46. doi:10.1016/j.resconrec.2012.05.006

Baggett, S., Jeffrey, P., Jefferson, B., 2006. Risk perception in participatory planning for water reuse. Desalination 187, 149–158. doi:10.1016/j.desal.2005.04.075

Barker, S.F., Packer, M., Scales, P.J., Gray, S., Snape, I., Hamilton, A.J., 2013. Pathogen reduction requirements for direct potable reuse in Antarctica: Evaluating human health risks in small communities. Sci. Total Environ. 461–462, 723–733. doi:10.1016/j.scitotenv.2013.05.059

Beaudequin, D., Harden, F., Roiko, A., Mengersen, K., 2016. Utility of Bayesian networks in QMRA-based evaluation of risk reduction options for recycled water. Sci. Total Environ. 541, 1393–1409. doi:10.1016/j.scitotenv.2015.10.030

Bichai, F., Ashbolt, N., 2017. Public health and water quality management in low-exposure stormwater schemes: A critical review of regulatory frameworks and path forward. Sustain. Cities Soc. 28, 453–465. doi:10.1016/j.scs.2016.09.003

Bichai, F., Ryan, H., Fitzgerald, C., Williams, K., Abdelmoteleb, A., Brotchie, R., Komatsu, R., 2015. Understanding the role of alternative water supply in an urban water security strategy: an analytical framework for decision-making. Urban Water J. 12, 175–189. doi:10.1080/1573062X.2014.895844

Bouchard, C., Beauchamp, N., Lamontagne, L., Desrosiers, J., Rodriguez, M., 2010. Multicriteria decision analysis for the selection of a small drinking water treatment system. J. Water Supply Res. Technol. 54, 230–242. doi:10.2166/aqua.2010.071

Chaudhry, R.M., Nelson, K.L., Drewes, J.E., 2015. Mechanisms of pathogenic virus removal in a full-scale membrane bioreactor. Environ. Sci. Technol. 49, 2815–2822. doi:10.1021/es505332n

Chen, R., Wang, X.C., 2009. Cost-benefit evaluation of a decentralized water system for wastewater reuse and environmental protection. Water Sci. Technol. 59, 1515–22. doi:10.2166/wst.2009.156

Chen, Z., Ngo, H.H., Guo, W., 2013. Risk Control in Recycled Water Schemes. Crit. Rev. Environ. Sci. Technol. 43, 2439–2510. doi:10.1080/10643389.2012.672085

Chen, Z., Ngo, H.H., Guo, W., Lim, R., Wang, X.C., O'Halloran, K., Listowski, A., Corby, N., Miechel, C., 2014. A comprehensive framework for the assessment of new end uses in recycled water schemes. Sci. Total Environ. 470–471, 44–52. doi:10.1016/j.scitotenv.2013.09.061

Chen, Z., Ngo, H.H., Guo, W.S., Listowski, A., O'Halloran, K., Thompson, M., Muthukaruppan, M., 2012. Multi-criteria analysis towards the new end use of recycled water for household laundry: A case study in Sydney. Sci. Total Environ. 438, 59–65. doi:10.1016/j.scitotenv.2012.08.019

Crook, J., Mosher, J.J., Casteline, J.M., 2005. Status and Role of Water Reuse: An international Review. London.

Curiel-Esparza, J., Cuenca-Ruiz, M.A., Martin-Utrillas, M., Canto-Perello, J., 2014. Selecting a sustainable disinfection technique for wastewater reuse projects. Water (Switzerland) 6, 2732–2747. doi:10.3390/w6092732

Derak, M., Cortina, J., 2014. Multi-criteria participative evaluation of Pinus halepensis plantations in a semiarid area of southeast Spain. Ecol. Indic. 43, 56–68. doi:10.1016/j.ecolind.2014.02.017

Dobbie, M.F., Brown, R.R., 2014. Transition to a water-cycle city: sociodemographic influences on Australian urban water practitioners' risk perceptions towards alternative water systems. Urban Water J. 11, 37–41. doi:10.1080/1573062X.2013.794846

Domènech, L., March, H., Saurí, D., 2013. Degrowth initiatives in the urban water sector? A social multi-criteria evaluation of non-conventional water alternatives in Metropolitan Barcelona. J. Clean. Prod. 38, 44–55. doi:10.1016/j.jclepro.2011.09.020

Farrelly, M., Brown, R., 2011. Rethinking urban water management: Experimentation as a way forward? Glob. Environ. Chang. 21, 721–732. doi:10.1016/j.gloenvcha.2011.01.007

Garcia-Montoya, M., Sengupta, D., Napoles-Rivera, F., Ponce-Ortega, J.M., El-Halwagi, M.M., 2016. Environmental and economic analysis for the optimal reuse of water in a residential complex. J. Clean. Prod. 130, 82–91. doi:10.1016/j.jclepro.2015.06.109

Gdoura, K., Anane, M., Jellali, S., 2015. Geospatial and AHP-multicriteria analyses to locate and rank suitable sites for groundwater recharge with reclaimed water. Resour. Conserv. Recycl. 104, 19–30. doi:10.1016/j.resconrec.2015.09.003

Gomez-Lopez, M.D., Bayo, J., Garcia-Cascales, M, S., Angosto, J, M., 2009. Decision support in disinfection technologies for treated wastewater reuse. J. Clean. Prod. 17, 1504–1511. doi:10.1016/j.jclepro.2009.06.008

Goodwin, D., Raffin, M., Jeffrey, P., Smith, H.M., 2017a. Collaboration on risk management: the governance of a non-potable water reuse scheme in London. J. Hydrol. 143, 22–37. doi:10.1016/j.jhydrol.2017.07.020

Goodwin, D., Raffin, M., Jeffrey, P., Smith, H.M., 2017b. Evaluating urban non-potable water reuse opportunities - Costs and benefits of risk management interventions. Inst. Water J. 1, 6–13.

Goodwin, D., Raffin, M., Jeffrey, P., Smith, H.M., 2015. Applying the water safety plan to water reuse: towards a conceptual risk management framework. Environ. Sci. Water Res. Technol. doi:10.1039/C5EW00070J

Greater London Authority, 2015. GLA 2014 round of trend-based population projections - Results. Update 03-2015. Greater London Authority, London.

Hajkowicz, S., Collins, K., 2007. A Review of Multiple Criteria Analysis for Water Resource Planning and Management. Water Resour. Manag. 21, 1553–1566. doi:10.1007/s11269-006-9112-5

Hernández, F., Urkiaga, A., Fuentes, L. De, Bis, B., Chiru, E., 2006. Feasibility studies for water reuse projects : an economical approach. Desalination 187, 253–261. doi:10.1016/j.desal.2005.04.084

Hills, S., James, C., 2015. The Queen Elizabeth Olympic Park Water Recycling System, London, in: Memon, F.A., Ward, S. (Eds.), Alternative Water Supply Systems. IWA Publishing, London, pp. 309–328.

Huang, I., Keisler, J., Linkov, I., 2011. Multi-criteria decision analysis in environmental sciences : Ten years of applications and trends . Sci Total Environ. Sci. Total Environ. 409, 3578–3594. doi:10.1016/j.scitotenv.2011.06.022

Huxedurp, L.M., Pálsdóttir, G.Þ., Altavilla, N., 2014. Risk-based planning for water recycling in an Australian context. Water Sci. Technol. Water Supply 14, 971. doi:10.2166/ws.2014.058

Hyde, K.M., 2006. Uncertainty Analysis Methods For Multi-Criteria Decision Analysis. The University of Adelaide.

Jerome, S., 2014. First Recycled Water Hockey Arena In U.S. Opens [WWW Document]. Water Online. URL https://www.wateronline.com/doc/first-ever-recycled-water-hockey-arena-in-u-s-opens-0001 (accessed 3.2.17).

Khadam, I.M., Kaluarachchi, J.J., 2003. Multi-criteria decision analysis with probabilistic risk assessment for the management of contaminated ground water. Environ. Impact Assess. Rev. 23, 683–721. doi:10.1016/S0195-9255(03)00117-3

Klauer, B., Drechsler, M., Messner, F., 2006. Multicriteria analysis under uncertainty with IANUS - Method and empirical results. Environ. Plan. C Gov. Policy 24, 235–256. doi:10.1068/c03102s

Knoeri, C., Binder, C.R., Althaus, H.J., 2011. Decisions on recycling: Construction stakeholders' decisions regarding recycled mineral construction materials. Resour. Conserv. Recycl. 55, 1039–1050. doi:10.1016/j.resconrec.2011.05.018

Kodikara, P.N., Perera, B.J.C., Kularathna, M.D.U.P., 2010. Stakeholder preference elicitation and modelling in multi-criteria decision analysis - A case study on urban water supply. Eur. J. Oper. Res. 206, 209–220. doi:10.1016/j.ejor.2010.02.016

Kolios, A., Mytilinou, V., Lozano-Minguez, E., Salonitis, K., 2016. A comparative study of multiple-criteria decision-making methods under stochastic inputs. Energies 9, 1–21. doi:10.3390/en9070566

Kumar, V., Del Vasto-Terrientes, L., Valls, A., Schuhmacher, M., 2015. Adaptation strategies for water supply management in a drought prone Mediterranean river basin: Application of outranking method. Sci. Total Environ. 540, 344–357. doi:10.1016/j.scitotenv.2015.06.062

Lai, E., Lundie, S., Ashbolt, N.J., 2016. Review of multi-criteria decision aid for integrated sustainability assessment of urban water systems. Urban Water J. 5, 315–327. doi:10.1080/15730620802041038

Leverenz, H.L., Tchobanoglous, G., Asano, T., 2011. Direct potable reuse: a future imperative. J. Water Reuse Desalin. 1, 2. doi:10.2166/wrd.2011.000

Lim, K.Y., Hamilton, A.J., Jiang, S.C., 2015. Assessment of public health risk associated with viral contamination in harvested urban stormwater for domestic applications. Sci. Total Environ. 523, 95–108. doi:10.1016/j.scitotenv.2015.03.077

Linkov, I., Satterstrom, F.K., Kiker, G., Batchelor, C., Bridges, T., Ferguson, E., 2006. From comparative risk assessment to multi-criteria decision analysis and adaptive management : Recent developments and applications 32, 1072–1093. doi:10.1016/j.envint.2006.06.013

LLDC, 2015. Local Plan 2015 to 2031. London.

Mainali, B., Ngo, H.H., Guo, W.S., Pham, T.T.N., Wang, X.C., Johnston, A., 2011. SWOT analysis to assist identification of the critical factors for the successful implementation of water reuse schemes. Desalin. Water Treat. 32, 297–306. doi:10.5004/dwt.2011.2714

Marks, J., Zadoroznyj, M., 2005. Managing Sustainable Urban Water Reuse: Structural Context and Cultures of Trust. Soc. Nat. Resour. An Int. J. 18, 37–41. doi:10.1080/08941920590947995

Marlow, D.R., Moglia, M., Cook, S., Beale, D.J., 2013. Towards sustainable urban water management: A critical reassessment. Water Res. 47, 7150–7161. doi:10.1016/j.watres.2013.07.046

Matsushita, T., Suzuki, H., Shirasaki, N., Matsui, Y., Ohno, K., 2013. Adsorptive virus removal with super-powdered activated carbon. Sep. Purif. Technol. 107, 79–84. doi:10.1016/j.seppur.2013.01.017

Miller, G.W., 2006. Integrated concepts in water reuse: managing global water needs. Desalination 187, 65–75. doi:10.1016/j.desal.2005.04.068

Moglia, M., Sharma, A.K., Maheepala, S., 2012. Multi-criteria decision assessments using Subjective Logic : Methodology and the case of urban water strategies. J. Hydrol. 452–453, 180–189. doi:10.1016/j.jhydrol.2012.05.049

Moreno-Jiménez, J.M., Aguarón, J., Escobar, M.T., 2008. The core of consistency in AHP-group decision making. Gr. Decis. Negot. 17, 249–265. doi:10.1007/s10726-007-9072-z

Page, D., Miotliński, K., Toze, S., Barron, O., 2013. Human health risks of untreated groundwater third pipe supplies for non-potable domestic applications. Urban Water J. 1–6. doi:10.1080/1573062X.2013.831912

Pahl-Wostl, C., 2007. Transitions towards adaptive management of water facing climate and global change. Water Resour. Manag. 21, 49–62. doi:10.1007/s11269-006-9040-4

Pickering, P., 2013. Economic viability of recycled water schemes. Australian Centre for Water Recycling Excellence, Brisbane.

Purnell, S., Ebdon, J., Buck, A., Tupper, M., Taylor, H., 2016. Removal of phages and viral pathogens in a full-scale MBR: Implications for wastewater reuse and potable water. Water Res. 100, 20–27. doi:10.1016/j.watres.2016.05.013

Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P.G., Drechsel, P., Bahri, A., Minhas, P.S., 2010. The challenges of wastewater irrigation in developing countries. Agric. Water Manag. 97, 561–568. doi:10.1016/j.agwat.2008.11.004

Sa-nguanduan, N., Nititvattananon, V., 2011. Strategic decision making for urban water reuse application: A case from Thailand. Desalination 268, 141–149. doi:10.1016/j.desal.2010.10.010

Sadr, S.M.K., Mashamaite, I., Saroj, D., Ouki, S., Ilemobade, A., 2016. Membrane assisted technology appraisal for water reuse applications in South Africa. Urban Water J. 13, 536–552. doi:http://dx.doi.org/10.1080/1573062X.2014.994008

Sadr, S.M.K., Saroj, D.P., Kouchaki, S., Ilemobade, A.A., Ouki, S.K., 2015. A group decision-making tool for the application of membrane technologies in different water reuse scenarios. J. Environ. Manage. 156, 97–108. doi:10.1016/j.jenvman.2015.02.047

Salgado, P.P., Quintana, S.C., Pereira, Â.G., Ituarte, L. del M., Mateos, B.P., 2009. Participative multi-criteria analysis for the evaluation of water governance alternatives. A case in the Costa del Sol (Málaga). Ecol. Econ. 68, 990–1005. doi:10.1016/j.ecolecon.2006.11.008

Sapkota, M., Arora, M., Malano, H., Moglia, M., Sharma, A., George, B., Pamminger, F., 2016. An Integrated Framework for Assessment of Hybrid Water Supply Systems. Water 8, 4. doi:10.3390/w8010004

Smith, H.M., Rutter, P., Jeffrey, P., 2014. Public perceptions of recycled water: a survey of visitors to the London 2012 Olympic Park. J. Water Reuse Desalin. 1–7. doi:10.2166/wrd.2014.146

Stefanopoulos, K., Yang, H., Gemitzi, A., Tsagarakis, K.P., 2014. Application of the Multi-Attribute Value Theory for engaging stakeholders in groundwater protection in the Vosvozis catchment in Greece. Sci. Total Environ. 470–471, 26–33. doi:10.1016/j.scitotenv.2013.09.008

Storey, M. V., Ashbolt, N.J., Stenström, T.A., 2004. Biofilms, thermophilic amoebae and Legionella pneumophila - A quantitative risk assessment for distributed water. Water Sci. Technol. 50, 77–82.

Tam, C.C., O'Brien, S.J., 2016. Economic cost of campylobacter, norovirus and rotavirus disease in the United Kingdom. PLoS One 11, 1–12. doi:10.1371/journal.pone.0138526

Topuz, E., Talinli, I., Aydin, E., 2011. Integration of environmental and human health risk assessment for industries using hazardous materials: A quantitative multi criteria approach for environmental decision makers. Environ. Int. 37, 393–403. doi:10.1016/j.envint.2010.10.013

Turner, A., Mukheibir, P., Mitchell, C., Chong, J., Retamal, M., Murta, J., Carrard, N., Delaney, C., 2016. Recycled water – Lessons from Australia on dealing with risk and uncertainty. Water Pract. Technol. 11, 127–138. doi:10.2166/wpt.2016.015

Urkiaga, A., de las Fuentes, L., Bis, B., Chiru, E., Balasz, B., Hernández, F., 2008. Development of analysis tools for social, economic and ecological effects of water reuse. Desalination 218, 81–91. doi:10.1016/j.desal.2006.08.023

van Til, J., Groothuis-Oudshoorn, C., Lieferink, M., Dolan, J., Goetghebeur, M., 2014. Does technique matter; a pilot study exploring weighting techniques for a multi-criteria decision support framework. Cost Eff. Resour. Alloc. 12, 22. doi:10.1186/1478-7547-12-22

West, C., Kenway, S., Hassall, M., Yuan, Z., 2016. Why do residential recycled water schemes fail? A comprehensive review of risk factors and impact on objectives. Water Res. 102, 271–281. doi:10.1016/j.watres.2016.06.044

Westrell, T., Schönning, C., Stenström, T.A., Ashbolt, N.J., 2004. QMRA (quantitative microbial risk assessment) and HACCP (hazard analysis and critical points) for management of pathogens in wastewater and sewage sludge treatment and reuse. Water Sci. Technol. 50, 23–30.

Woltersdorf, L., Zimmerman, M., Deffner, J., Gerlach, M., Liehr, S., 2017. Benefits of an integrated water and nutrient reuse system for urban areas in semi-arid developing countries. Resour. Conserv. Recycl. doi:10.1016/j.resconrec.2016.11.019

Chapter 7. Discussion and conclusion

7.1 Summary of findings - Stakeholder engagement with risk management

The findings of this research, as summarised in the following paragraphs, respond to a number of gaps in knowledge relating to (1) how to interpret, inform and influence stakeholder attitudes to water reuse, (2) how stakeholders preference for risk mitigation might influence scheme design, and (3) how to document and measure the impacts of what stakeholder engagement with risk works in certain contexts, how and why.

Objective 1: To produce a critical review of the state-of-the-art risk management for water reuse.

The review of the state-of-the-art in risk management for water reuse was undertaken to meet the first objective of the research project. This review sought to investigate the desired scope for risk management as well as areas identified as needing attention. This review highlighted a number of feasible improvements for existing risk management frameworks (specifically to the WSP). Firstly, the review identified opportunities for improving activities that support communication and engagement stakeholders. Secondly, the review highlighted a desire in the literature to improve methods that can support decision-making through accounting for uncertainty, risk interactions and risk prioritisation. Thirdly, the review highlighted a desire to develop overarching management frameworks that help to link day-to-day risk management processes to broader governance contexts. The findings indicated that more integrated management could help managers and operators anticipate potential scheme risks and opportunities. These findings are pertinent to the case study of London, particularly due to the UK water industry regulators requirement for proportionate, stakeholder-led and risk-based management for water resource management. The findings of the critical review illuminate areas where water management practitioners associated with the case study could work to integrate stakeholders into the risk management process through developing engagement strategies linked to the proportionate management of risk.

Objective 2: To evaluate how stakeholders perceive risk management and governance challenges and to understand their preferred solutions for addressing the challenges.

Using data from semi-structured interviews and documents, an embedded case study of the Old Ford Water Recycling Plant identified three thematic risk management and governance challenges perceived by stakeholders. These were: (1) developing mutual understandings of diverse expectations; (2) clarifying roles and responsibilities; and (3) improving awareness, knowledge and capabilities in risk management. This component of the research found stakeholders perceived that collaboration and learning opportunities (focused on risk and risk management activities) had the potential to help overcome these challenges. In particular, common risk management activities were perceived as providing opportunities for forging informal networks and for providing informal modes of collaboration. This research indicated that more learning-by-doing based engagement had the potential to help facilitate dialogue around divergent objectives, help build relationships and maintain trust. Finally, the research implied that collaborative and learning processes could help the governance of schemes become more responsive to changing risks and stakeholder dynamics. Thus, the findings help to respond to the knowledge gaps identified, specifically, through improving knowledge of practical ways to interpret, inform and influence stakeholders' perceptions (Fielding and Roiko, 2014; Russell et al., 2008). Moreover, the results contribute towards building knowledge of how to put management concepts into practice (Cook and Spray, 2012; Medema et al., 2008).

Objective 3: To explore how perceptions of water management problems, risks and trust in the management of recycled water supply might be influenced.

To meet the third objective, a case study of an IPR scheme proposed for London was used and this investigated the influence the news media might have on shaping public opinion on the scheme's management. This study found that people's perceptions of more general causes of water management problems, environmental values and prior knowledge of the water-cycle, were plausibly influencing how they reacted to media coverage of the water reuse scheme. However, this sub-study did not find evidence that the media's framing of single news events had a strong influence on the comments posted online. Thus, the findings implied that online comments were useful for highlighting themes describing positive sentiments towards the principle of water reuse and towards risk management and governance for the specific reuse proposal. Moreover, the findings implied that individual media events could offer useful opportunities for water resource planners, public relations experts and academics to explore the impact of different issue-specific message framing, particularly around popular knowledge of the water-cycle and water safety initiatives for mitigating perceived risks. These findings, therefore, add more evidence towards developing in-depth considerations of practical ways to interpret, inform and influence stakeholder attitudes to water reuse (Fielding and Roiko, 2014; Russell et al., 2008). Moreover, the findings provide some indication of how stakeholders' perceptions of a water reuse scheme might influence its design as well as more strategic-level water management decisions (Ferguson et al., 2013).

Objective 4: To explore methods of public communication and, particularly, to evaluate the impact of message framing on public attitudes towards non-potable water reuse.

To achieve this fourth objective, an embedded sub-study was carried out to explore the pros and cons of engaging stakeholders with the risk management of water reuse schemes using video animations. This study provided evidence that showed survey respondents who were initially opposed to higher exposure uses for non-potable recycled water responded positively to short video animations framed in terms of water quality compliance. This finding contributed to existing knowledge through helping to isolate focal characteristics of risk management messages about water reuse, thus helping to understand what works in certain contexts and how (Moglia et al., 2011; Ormerod and Scott, 2012). Moreover, the findings showed that, overall, the video messages improved the participants' trust in authorities to safely manage recycled water schemes. Through the conceptualisation of a message framing typology, this study advanced the understanding of practical ways to inform and influences public perceptions of water reuse and corroborated benefits to communicating about recycled water safety within a specific water resource context.

Objective 5: To explore how stakeholders' perceptions and preferences for risk management and recycled water end-uses might influence decision-making and scheme design.

Finally, to achieve this fifth objective, a multi-criteria evaluation method was used to assess how stakeholders' perceptions of the importance of different criteria influenced preferences for recycled water end-uses and appropriate risk management. The case study results showed that stakeholders favoured risk reductions over both costs saving and potable water savings. Using the stakeholders' criteria importance preferences, the multi-criteria evaluation prioritised an upgrade from the existing water treatment processes to modify the existing scheme design through connecting new recycled water end-uses. Conversely, the study found that stakeholders' responses to agreement statements favoured existing risk management practices, feasibly with more stakeholder engagement to help control a changing profile of risks. The two different evaluation methods gave differing accounts and, therefore, this finding indicated analytical advantages to method triangulation. As the stakeholders prioritised health risk reductions, the inclusion of quantitative health risk information in the multi-criteria evaluation pointed to more conservative risk management interventions. The findings indicated that the evaluation method might influence decision making but that differences in stakeholders' perceptions were more useful for delineating the boundaries around acceptable options. The findings implied that a benefit of the multi-criteria method is through encouraging stakeholders to deliberate the reasoning behind their preferences to help account for uncertainty and risk complexities. In summary, the findings contributed to developing knowledge of how stakeholders' preferences for risk mitigation might influence scheme design (Chen et al., 2014b; Farrelly and Brown, 2011; Turner et al., 2016).

7.2 Implications for improving scheme governance

This study proposes three thematic conditions as necessary (not necessarily sufficient – Dul, 2016) for improving scheme governance in the context of London's water resource management circumstances. These are: (1) evidence of improving public perceptions, improving information systems and learning; (2) evidence of improving the coordination of rules and regulations, roles and responsibilities; and, (3) evidence of improving the efficiency (e.g. improved cost-benefits or reduced risk), equity and capacity to make management decisions. The proposition is that improvements in these areas can help facilitate the handling of uncertainty and enhance adaptive capacity (Frijns et al., 2016; Lebel et al., 2013; Meehan et al., 2013; Pahl-Wostl et al., 2012). However, the findings are not able to verify whether these conditions are sufficient for the outcome of enhanced scheme governance, as there are likely other conditions that contribute to enhancing scheme governance. For example, the presence of legal frameworks, access to financial resources (Pahl-Wostl et al., 2012) and improving awareness of complexity (Pahl-Wostl et al., 2007) have been identified as necessary conditions for enhancing governance. What the evidence highlights is the importance of ongoing interpretation, framing and re-framing (Dewulf et al., 2009) of risks and their safe management to develop mutually desirable solutions. The findings help to fill out some weakness in extant knowledge, particularly around understanding what works in certain contexts, how (Moglia et al., 2011; Ormerod and Scott, 2012) and why (Muro et al., 2012). For example, findings of this present research highlight the importance of time demands for different types of stakeholders and benefits of more informal, activity-based collaboration and easily accessible forms of communication like video animations.

Summarising the first emergent theme, this thesis puts forward evidence of improving public perceptions, improving information systems and learning. For example, this thesis puts forward evidence demonstrating how information might be used to influence public perceptions of water reuse and also contributes to the understanding of how to measure the impact of engagement (van der Wal et al., 2014). The findings on risk perceptions and stakeholder acceptance for different water reuse design and management configurations were firmed up across the embedded case studies. For instance, Chapter 3 found that inter-stakeholder trust might be maintained through collaboration on risk management activities and Chapter 4 found that online communications might help build the public's confidence in water safety initiatives to manage perceived risks – thus strengthening the construct's validity. These findings have implications for improving scheme governance, where there is a recognised need to improve public perceptions (e.g. less perceived risk or more perceived benefits - Urkiaga et al., 2008) and develop information systems and learning (Lebel et al., 2013). The findings also illuminated some new avenues of investigation, for example, through using online surveys, the internet, the news media, social media and video animations to help open up dialogue on water reuse scheme design and management.

Secondly, across the embedded studies, there was evidence that linked engagement with the management of risk with better coordination of rules and responsibilities. For instance, there was evidence of stakeholders perceiving the development of more informal networks and modes of collaboration as ways of potentially improving the coordination of risk management. In addition, there was evidence that existing risk management frameworks for water reuse could be feasibly modified to improve the handling of uncertainty. Furthermore, the research showed that stakeholders were willing to take part in risk management evaluations and that this had implication for enhancing the coordination of management processes and responsibilities. Finally, the research showed that stakeholders' knowledge and trust could be bolstered both through informal collaboration as well as through water reuse communications. These findings contribute to existing knowledge of the advantages of developing collaboration capacity (Schneider et al., 2015) that can lead to better coordination (and fairness) of management processes and practices (McDaniels et al., 1999), rules and regulations (Schneider et al., 2015), and roles and responsibilities (Engle and Lemos, 2010; Pahl-Wostl et al., 2012).

The third theme summarises the necessary condition of improving the efficiency, equity and capacity to make management decisions. Using a multi-criteria evaluation method, findings from this research had implications for how more mutually desirable management decisions might be negotiated and supported existing knowledge (Schneider et al., 2015). However, whilst the results illuminated conditions for enhancing equity and the capacity to make decisions, they also showed potential efficiency trade-offs. For example, the high importance stakeholders assigned to risk reduction incurred some cost increases (through adding additional water treatment processes). The findings, therefore, supported existing knowledge describing a desire to improve capabilities to make management decisions (Engle and Lemos, 2010). Finally, this research generated evidence demonstrating how stakeholders might improve their trust in organisations responsible for making management decisions. This finding was triangulated across embedded sub-studies that conferred stakeholders could perceive the water company as a competent authority capable of getting on with risk management, thus enhancing construct validity.

7.3 Implications for scheme design – configuration and risk control barriers

Engaging stakeholders in the management of risk has specific implications for the development and design of new schemes (or the modification or expansion of existing schemes). This study proposes three thematic conditions as necessary for enhancing the social acceptability of scheme designs in the context of London's water resource management circumstances. These are: (1) encourage stakeholders to participate in the evaluation of risk reduction measures to aid catchment to tap scheme design and to confer on what risk barriers are perceived as more beneficial and where (e.g. source control), (2) openly exploring perceptions of scheme design configurations to understand which design elements raise more concerns and which are considered socially acceptable, and (3) providing some flexibility in scheme designs that can appeal to a range of perceived social needs and to emphasis scheme benefits.

Firstly, a risk-based approach (which is a guiding requirement for many regulatory agencies) stipulates multiple risk barriers that are implemented from the water supply catchment to the tap (or point of use). There are considerable difficulties, however, in judging the advantages and disadvantages of different configurations for risk reduction – particularly when considering a range of stakeholders' views. Results presented in Chapter 6 highlighted that preferences for minimising health risks could result in more conservative technological approaches to risk reduction. However, that, although the enhancement of water treatment processes had cost implications, these might be offset by longer-term economic benefits through securing more recycled water customers. The findings support the benefits of using multi-criteria evaluation to aid stakeholders to guide water reuse scheme design (Gomez-Lopez et al., 2009; Sadr et al., 2016) through the evaluation and selection of risk reduction measures. Further evidence supporting the benefits of stakeholder participation in evaluating risk was presented in Chapter 3. The sub-study found that stakeholders perceived benefits to co-learning through common tasks as important for building stakeholders knowledge and capabilities in design and construction. This was perceived as important as some design decisions intended to reduce risk could, inadvertently, introduce others.

The second thematic condition for making scheme design improvements describes the open exploration of stakeholders' perceptions of scheme configurations. This research puts forward evidence to suggest that the framing of communications about hypothetical reuse schemes might influence the levels of scrutiny afforded by stakeholders (including the public). For instance, Chapter 4 identified that the media framing of specific elements of scheme design could lead to perceptions of possible problems. In this IPR case study, the emphasis of the closeness of the point where recycled water was returned back to the environment to the existing drinking water abstraction had the potential to raise concerns. The potential repercussion is that stakeholder engagement with the management of risk can help identify perceptions of particular design configurations and then look at opportunities for acceptably managing any concerns. Challenges around stakeholder acceptability of different scheme designs were also highlighted in Chapters 5 and 6 which provided contrasting accounts of the acceptability of using recycled water for washing clothes. The results showed that stakeholders involved in scheme design or governance looked less favourably on this recycled water use than the general public.

The third scheme design theme describes the perceived benefits to integrating more flexibility into schemes designs that are then capable of meeting more diverse stakeholder needs. Given the acceptable design of risk reduction measures, such as through the use of multiple risk barriers and more advanced water treatment technologies, economical non-potable reuse water supply options (Bieker et al., 2010) may be more socially acceptable then potable reuse schemes. However, there may also be advantages to scheme designs that incorporate a mix of potable and non-potable end-uses (such as NeWater, Singapore), that appeal to social needs, can help develop local economies (e.g. through supporting the growth of water-dependent industries) and, are adaptable to existing water infrastructure constraints (such as over-capacity and ageing water distribution networks in parts of London). The provision of some flexibility in the configuration of a scheme and its risk controls may facilitate more seamless transitions to changing performance expectations or to other more exogenous influences like climate change (Anderson et al., 2002).

7.4 Towards more adaptive practices

Findings of this research support the potential to develop more adaptive pathways to water reuse scheme risk management. Opportunities could include experimenting with risk management implementation at a local scheme level and engaging with a community of practice (Attwater and Derry, 2005). Areas of management where the level of risk is low can provide the environment to undertake 'safe' experimentation (Allen and Gunderson, 2011). Such an adaptive approach is not proposed as a universal panacea, rather, that the premise can be taken forward into practice (Medema et al., 2008) in a systematic, small-steps approach (García, 2008) focused on evaluating what does and what doesn't work in order to bridge the 'implementation gap' (Cook and Spray, 2012). Through accumulating evidence on what works in a systematic way, it will be possible to cross-examine context-sensitive findings so that common conditions might be transferable to other similar situations. As management interventions are likely to work differently in different contexts, an adaptive philosophy may help to systematically document the impacts of different options. This research supports the use of the Water Reuse Safety Plan as a viable pathway for achieving these objectives. Furthermore, as a next step, the findings of this research imply benefits to developing a conceptual framework that supports more stakeholder participation – including methods investigated as part of this project.

The findings have implications for enhancing the flexibility of scheme designs. Whereas past design rationales have been typified by attempts to reduce and control complexity through rigid and inflexible technical systems (Pahl-Wostl et al., 2007), stakeholder engagement in risk management could direct practices toward more adaptive philosophies. The findings from this

London-based case study, have implications for incrementally evolving and adapting scheme designs based on lessons learnt (Tao et al., 2014). In this way, designs may incorporate changing needs for risk mitigation that are negotiated through inclusive engagement practices. A general pattern of replication across the embedded case studies of this present research suggests benefits to more adaptive practices that may help guide the development of similar schemes grappling with similar conditions in other areas of the UK and perhaps further afield. Finally, through local-scale design experimentation (e.g. pilot projects –Ferguson et al., 2013), case studies would help to systematically document stakeholder perceptions and performance characteristics of measurable scheme design variations. Evidence from such research would guide future 'scaling up' of reuse in London, particularly through developing knowledge of a designs adaptability to existing water infrastructure constraints.

The furthering of knowledge of what works would be aided by the development of common sets of indicators and thresholds for management actions to allow for objective comparisons of cases across contexts. The basis for developing such indicators could leverage from evaluation processes such as the City Blueprint indicator approach (Leeuwen and Sjerps, 2016) and build on other sets of social, economic and environmental indicators already developed for evaluating water reuse schemes (Urkiaga et al., 2008). The development of suitable common indicators would help facilitate the transfer of learnings to other schemes through overarching management guidance. The development of an overarching management framework that incorporates indicators of success and recommendations for integrative evaluation would be supported by the synthesis of case study evidence to understand suitable thresholds for management actions. Furthermore, the development of indicators may draw from knowledge of practical indicators for evaluating the performance of water safety plans such as indicators of change (e.g. change in policy) and of impacts (e.g. improvements in the reliability of water supply or in the consistency of water quality) (Lockhart et al., 2014). As this research puts forward evidence in support of using stakeholder engagement to inform the governance and design of water reuse schemes, indicators of the effectiveness of engagement would be integral to the process (Akhmouch and Clavreul, 2016). As a starting point, it is suggested that the evaluation of engagement would including ongoing monitoring of stakeholders' knowledge, awareness and perceptions of water reuse schemes through a range of methods including social media monitoring and more controlled stakeholder engagement experiments.

7.5 Limitation and future research opportunities

Case study protocol was followed for the mixed-method data collection to enhance the reliability of the inter-related sub-studies as well as the repeatability of the experiments. Limitations to the research stem from methodological choices as well as constraints put on the project through it being sponsored by industry. For the former, the research may have benefited from adopting more deliberative methods that delved more deeply into stakeholder perceptions of risks and their management expectations. For the later, a shift in focus to other reuse contexts may have helped validate the findings and explore their transferability. As an example of methodological limitations, the multi-criteria evaluation may have benefited from additional rounds of stakeholder input. Other examples of limitations (which are discussed in individual chapters) include the recognised shortcomings to using online comments as data and limitations to the generalisability of results from questionnaires. A final point on method, it is acknowledged that using percentage agreement to judge inter-coder reliability is an imperfect method, although perhaps more appropriate for qualitative rather than quantitative content analysis. Nonetheless, despite the limitations, the findings remain valuable for extending knowledge in the field.

In term of furthering the research, opportunities include further exploration of the relationship between stakeholder intentions and actual behaviours, for example, where knowledge sharing is envisioned but not necessarily practised. Moreover, there are opportunities to evaluate practice-based mechanisms for collaboration and deliberation. There are opportunities to further explore and evaluate how message themes around water safety initiatives and short-term benefits might impact on public support for water reuse schemes – particularly through more interactional research methods. Finally, there are opportunities to explore the impact of a range of stakeholder engagement initiatives through combining principles of randomised control trial methodologies (or quasi-experimental designs) with in-depth qualitative explorations of practice-based experiences and perceptions in a step-wise manner to document evidence of what works and why. Collating evidence in these areas will help progress contemporary management principles and practices and will have further implications for areas of water reuse regulation, policy development and scheme design and implementation guidance. This will ultimately be aided by evaluating, comparing and contrasting a number of varied cases to better understand what works in what circumstances and to translate theory into practice.

7.6 Conclusion

This present research aimed to understand the nature of stakeholder perceptions and expectations in the context of water reuse schemes, and to critically evaluate how stakeholder engagement with risk management can enhance the governance and design of water reuse schemes. Through an embedded case study design, a mixed methods research design was used to explore perceptions of water reuse as a feasible water management intervention in London. The research drew from sociological risk perspectives to bring into focus ways to communicate information, interpret and influence risk perceptions and to develop management processes that can accommodate context-sensitive expectations.

The findings contribute to filling a number of gaps in knowledge identified in the immediate field of research. Firstly, the findings illuminate areas where water management practitioners could work to integrate stakeholders through promoting more collaborative learning-by-doing risk management. Secondly, the findings help to improve knowledge of practical ways to interpret, inform and influence stakeholders' perceptions through mediums such as online news and social media. Thirdly, findings contribute to knowledge on what forms of communication are effective through showing an impact on public perceptions predicated on isolating focal characteristics of risk management messages about water reuse – thus helping to build on knowledge of what engagement works in certain contexts. Fourthly, the findings show that perceptions of water reuse schemes might influence their design through identifying preferences for different types of recycled water uses and the potential for certain scheme design configurations to heighten perceptions of problems. Finally, the findings support the benefits of understanding the social desirability of different design options, and including stakeholders in multi-criteria evaluations of risk-based decisions.

This research contributes to current knowledge by identifying thematic conditions necessary for enhancing scheme governance and design. Necessary conditions identified for enhancing the context-sensitive scheme governance included producing evidence of improving public perceptions, the coordination of rules and regulations, roles and responsibilities, and improving management decisions. Necessary conditions identified for enhancing the social acceptability of scheme designs in the context of London's water resource management included encouraging stakeholders to confer on what risk barriers are perceived as more beneficial, exploring perceptions of design configurations to understand if any components raise concerns, and providing flexibility in scheme designs that can appeal to a range of perceived social needs. These thematic conditions, alongside the development of suitable indicators for evaluating success, assist in developing knowledge aimed at overcoming some of the challenges of translating overarching management or design theory into practice.

Utilising case study replication and pattern matching concepts, this research highlights implication for advancing contemporary risk management frameworks through developing more adaptive approaches. Further research should look to compare and contrast more varied case studies to build contemporary knowledge of suitable indicators of what works in different circumstances and to continue to help translate theory into practice. This evidence will contribute to the development of local and regional capability for water reuse risk management with implications for developing water reuse policy and strategic water resource management.

7.7 References

Akhmouch, A., Clavreul, D., 2016. Stakeholder Engagement for Inclusive Water Governance: "Practicing What We Preach" with the OECD Water Governance Initiative. Water (Switzerland) 8, 1–17. doi:10.3390/w8050204

Allen, C.R., Gunderson, L.H., 2011. Pathology and failure in the design and implementation of adaptive management. J. Environ. Manage. 92, 1379–1384. doi:10.1016/j.jenvman.2010.10.063

Anderson, B.C., Watt, W.E., Marsalek, J., 2002. Critical issues for stormwater ponds: Learning from a decade of research. Water Sci. Technol. 45, 277–283.

Attwater, R., Derry, C., 2005. Engaging communities of practice for risk communication in the Hawkesbury Water Recycling Scheme. Action Res. 3, 193–209. doi:10.1177/1476750305052144

Bieker, S., Cornel, P., Wagner, M., 2010. Semicentralised supply and treatment systems: Integrated infrastructure solutions for fast growing urban areas. Water Sci. Technol. 61, 2905–2913. doi:10.2166/wst.2010.189

Chen, Z., Ngo, H.H., Guo, W., Lim, R., Wang, X.C., O'Halloran, K., Listowski, A., Corby, N., Miechel, C., 2014. A comprehensive framework for the assessment of new end uses in recycled water schemes. Sci. Total Environ. 470–471, 44–52. doi:10.1016/j.scitotenv.2013.09.061

Cook, B.R., Spray, C.J., 2012. Ecosystem services and integrated water resource management: Different paths to the same end? J. Environ. Manage. 109, 93–100. doi:10.1016/j.jenvman.2012.05.016

Dewulf, A., Gray, B., Putnam, L., Lewicki, R., Aarts, N., Bouwen, R., van Woerkum, C., 2009. Disentangling approaches to framing in conflict and negotiation research: A meta-paradigmatic perspective, Human Relations. doi:10.1177/0018726708100356

Dul, J., 2016. Necessary Condition Analysis (NCA). Organ. Res. Methods 19, 10–52. doi:10.1177/1094428115584005

Engle, N.L., Lemos, M.C., 2010. Unpacking governance: Building adaptive capacity to climate change of river basins in Brazil. Glob. Environ. Chang. 20, 4–13. doi:10.1016/j.gloenvcha.2009.07.001

Farrelly, M., Brown, R., 2011. Rethinking urban water management: Experimentation as a way forward? Glob. Environ. Chang. 21, 721–732. doi:10.1016/j.gloenvcha.2011.01.007

Ferguson, B.C., Brown, R.R., Frantzeskaki, N., de Haan, F.J., Deletic, A., 2013. The enabling institutional context for integrated water management: lessons from Melbourne. Water Res. 47, 7300–14. doi:10.1016/j.watres.2013.09.045

Fielding, K.S., Roiko, A.H., 2014. Providing information promotes greater public support for potable recycled water. Water Res. 61, 86–96. doi:10.1016/j.watres.2014.05.002

Frijns, J., Smith, H.M., Brouwer, S., Garnett, K., Elelman, R., Jeffrey, P., 2016. How governance regimes shape the implementation of water reuse schemes. Water (Switzerland) 8. doi:10.3390/w8120605

García, L.E., 2008. Integrated water resources management: A “small” step for conceptualists, a giant step for practitioners. Int. J. Water Resour. Dev. 24, 23–36. doi:10.1080/07900620701723141

Gomez-Lopez, M.D., Bayo, J., Garcia-Cascales, M, S., Angosto, J, M., 2009. Decision support in disinfection technologies for treated wastewater reuse. J. Clean. Prod. 17, 1504–1511. doi:10.1016/j.jclepro.2009.06.008

Leeuwen, K. and Sjerps, R., 2016. Istanbul: the challenges of integrated water resources management in Europa’s megacity. Environment, development and sustainability, 18(1), pp.1-17.

Lebel, L., Nikitina, E., Pahl-wostl, C., Knieper, C., 2013. Institutional Fit and River Basin Governance: a New Approach Using Multiple Composite Measures. Ecol. Soc. 18. doi:http://dx.doi.org/10.5751

Lockhart, G., Oswald, W.E., Hubbard, B., Medlin, E., Gelting, R.J., 2014. Development of indicators for measuring outcomes of water safety plans. J. Water, Sanit. Hyg. Dev. 4, 171. doi:10.2166/washdev.2013.159

McDaniels, T.L., Gregory, R.S., Fields, D., 1999. Democratizing risk management: Successful public involvement in local water management decisions. Risk Anal. 19, 497–510. doi:10.1023/A:1007060931193

Medema, W., McIntosh, B.S., Jeffrey, P., 2008. From Premise to Practice : a Critical Assessment of Integrated Water Resources Management and Adaptive Management Approaches in the Water Sector. Ecol. Soc. 13, 29. doi:29

Meehan, K., Ormerod, K.J., Moore, S.A., 2013. Remaking Waste as Water : The Governance of Recycled Effluent for Potable Water Supply. Water Altern. 6, 67–85.

Moglia, M., Alexander, K.S., Sharma, A., 2011. Discussion of the enabling environments for decentralised water systems. Water Sci. Technol. 63, 2331–2340. doi:10.2166/wst.2011.443

Muro, M., Hrudey, S.E., Jude, S., Heath, L., Pollard, S., 2012. Making It Real: What Risk Managers Should Know About Community Engagement. J. Environ. Assess. Policy Manag. 14, 1–21. doi:10.1142/S146433321250010X

Ormerod, K.J., Scott, C.A., 2012. Drinking Wastewater : Public Trust in Potable Reuse. Sci. Technol. Human Values 1–23. doi:10.1177/0162243912444736

Pahl-Wostl, C., Lebel, L., Knieper, C., Nikitina, E., 2012. From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. Environ. Sci. Policy 23, 24–34. doi:10.1016/j.envsci.2012.07.014

Pahl-Wostl, C., Sendzimir, J., Jeffrey, P., Aerts, J., Berkamp, G., Cross, K., 2007. Managing Change toward Adaptive Water Management through Social Learning. Ecol. Soc. 12.

Russell, S., Lux, C., Hampton, G., 2008. Beyond "Information": Integrating Consultation and Education for Water Recycling Initiatives. Soc. Nat. Resour. 22, 56–65. doi:10.1080/08941920801910666

Sadr, S.M.K., Mashamaite, I., Saroj, D., Ouki, S., Ilemobade, A., 2016. Membrane assisted technology appraisal for water reuse applications in South Africa. Urban Water J. 13, 536–552. doi:http://dx.doi.org/10.1080/1573062X.2014.994008

Schneider, F., Bonriposi, M., Graefe, O., Herweg, K., Homewood, C., Huss, M., Kauzlaric, M., Liniger, H., Rey, E., Reynard, E., Rist, S., Schädler, B., Weingartner, R., 2015. Assessing the sustainability of water governance systems: the sustainability wheel. J. Environ. Plan. Manag. 58, 1577–1600. doi:10.1080/09640568.2014.938804

Tao, W., Bays, J., Meyer, D., Smardon, R., Levy, Z., 2014. Constructed Wetlands for Treatment of Combined Sewer Overflow in the US: A Review of Design Challenges and Application Status. Water 6, 3362–3385. doi:10.3390/w6113362

Turner, A., Mukheibir, P., Mitchell, C., Chong, J., Retamal, M., Murta, J., Carrard, N., Delaney, C., 2016. Recycled water – Lessons from Australia on dealing with risk and uncertainty. Water Pract. Technol. 11, 127–138. doi:10.2166/wpt.2016.015

Urkiaga, A., de las Fuentes, L., Bis, B., Chiru, E., Balasz, B., Hernández, F., 2008. Development of analysis tools for social, economic and ecological effects of water reuse. Desalination 218, 81–91. doi:10.1016/j.desal.2006.08.023

van der Wal, M., De Kraker, J., Offermans, A., Kroeze, C., 2014. Measuring Social Learning in Participatory Approaches to Natural Resource Management. Environ. Policy Gov. 24, 1–15. doi:10.1002/eet.1627

Appendices

Appendix A Summary of interviews and documents

Table A-1 Interviewees and document data for generalised stakeholder groups

Stakeholder Group	Interviewees	Documents
Governmental & Regulatory 5 interviews 9 documents	Water policy and water resource officers; Regulation and compliance officers	1) Meeting minutes with regulatory bodies (2011)†; 2) Health Protection Agency review report (2011)†; 3) Environment Agency Position Statement (2012)†; 4) Case study – supporting the Olympics report (WRAS, 2012); 5) "London's 2012 green build on track" interviews with ODA, Olympics Minister and Mayor of London (Action Sustainability, 2012); 6) "Breaking the tape – pre games review" (CfSL, 2012); 7) BBC articles "Olympics plan to combat summer drought" including extracts from interview with environment secretary (Mower, 2012); 8) "the best building on the park" including interview with chair of the CfSL (Huffington Post, 2012); 9) The London Plan (Greater London Authority, 2015c)
Park Planning & Management 6 interviews 8 documents	Landscape project and operations managers; Sustainability officers; Project managers	10) Old Ford learning legacy paper (Knight et al., 2012b); 11) UK Green Building Council, London 2012 Sustainability Lessons learnt - Presentation slides (Knight et al., 2012a); 12) London Lessons Learnt – non-potable water (King, 2012); 13) Guardian article "London's 10,000 toilets and one unique challenge" (Jones, 2012); 14) Draft Local Plan Consultation (LLDC, 2013); 15) Environmental Sustainability Report (LLDC, 2014a); 16) WEF article "London Strives To Make Olympics Sustainable Through Water-Reuse System" (Fulcher, 2012); 17) Conference paper on OFWRP (Anderson et al., 2014)
Water Company 13 interviews 13 documents	Stakeholder engagement and risk management officers; Research Scientists and Engineers; Commercial and plant managers; Water regulations and network management officers; Plant technicians	18) Report on Olympic Park rainwater harvesting systems, company document (2009)†; 19) Internal regulatory report (October 2010)†; 20) Presentation slides "How to deliver water efficiency in 21st Century drought conditions" (Clarke, 2012); 21) Hills, (2013) Conference presentation, IWA Namibia; 22) CIWEM Conference presentation (Rutter, 2013); 23) OFWP Business case (2013)†; 24) Olympic Park dye testing report (September, 2013)†; 25) Olympic Park learning report (2014)†; 26) Old Ford Water Recycling Plant Annual Report (2014)†; 27) Reclaimed Water Safety Plan Review, company document (2014)†; 28) WatEf Conference presentation (Tupper, 2014); 29) EU Horizon 2020 presentation slides (2015)†; 30) QEOP Water Recycling System, book chapter (Hills and James, 2015)
Customers, End Users & Contractors 6 interviews 6 documents	Facilities managers; Construction contractors; Project managers	31, 32) Meeting minutes, potential end users (August and September 2009)†; 33) HortWeek article (Appleby, 2012); 34) Pitch Irrigation Guidance (English Hockey Board, 2009); 35) Public perceptions of recycled water - A survey of visitors to the London 2012 Olympic Park (November, 2012)†; 36) Park non-potable water users survey (2014)†

†Confidential company documents

A.1 References

Action Sustainability, 2012. London 2012s green build on track [WWW Document]. URL www.actionsustainability.com/news/236/London-2012s-green-build-on-track/ (accessed 4.7.15).

Anderson, R., Neill, M.O., Fairbairn, J., Bloor, J., Kingdom, U., 2014. Over Kill? The Regulatory Impact on Delivery of Innovative Water Infrastructure, in: OzWater 2014.

Appleby, M., 2012. Interview - Des Smith, head gardener, Olympic Park gardens [WWW Document]. URL www.hortweek.com/interview-des-smith-head-gardener-olympic-park-gardens/article/1130666 (accessed 8.21.15).

CfSL, 2012. Breaking the tape: pre-Games review. Commission for a Sustainable London. London.

Clarke, P., 2012. How to deliver water efficiency in 21st Century drought conditions, in: Siemens W13 Water Efficiency. Thames Water.

English Hockey Board, 2009. Pitch Irrigation.

Fulcher, J., 2012. London Strives To Make Olympics Sustainable Through Water-Reuse System [WWW Document]. URL http://news.wef.org/london-strives-to-make-olympics-sustainable-through-water-reuse-system-2/ (accessed 4.7.15).

Greater London Authority, 2015. The London Plan. Greater London Authority, London.

Hills, S., 2013. Applying a Water Safety Plan Approach for Reclaimed Water Use at the 2012 Olympic Park in London, in: IWA Reuse Conference Namibia.

Hills, S., James, C., 2015. The Queen Elizabeth Olympic Park Water Recycling System, London, in: Memon, F.A., Ward, S. (Eds.), Alternative Water Supply Systems. IWA Publishing, London, pp. 309–328.

Huffington Post, 2012. The best building on the Park? [WWW Document]. URL www.huffingtonpost.co.uk/shaun-mccarthy/the-best-building-on-the-_b_1750406.html (accessed 8.21.15).

Jones, S., 2012. London Olympic Park's 10,000 toilets and one unique challenge [WWW Document]. URL www.theguardian.com/sport/2012/jul/26/london-2012-olympic-park-sustainability (accessed 4.7.15).

King, D., 2012. London 2012 Learning Legacy: Non Potable Water. Olympic Delivery Authority, London, UK.

Knight, H., King, D., McCann, E., 2012a. London 2012 Sustainability Lessons Learned: Master Class 3 - Water, in: London 2012 Sustainability Lessons Learned. UK Green Building Council, London, UK, pp. 1–49.

Knight, H., Maybank, R., Hannan, P., King, D., Rigley, R., 2012b. Lessons learned from the London 2012 Games Construction Project – The Old Ford Water Recycling Plant and Non-Potable Water Distribution Network. Olympic Delivery Authority. London.

LLDC, 2014. Your Park, Our Planet: Environmental Sustainability Report 2014. London, UK.

LLDC, 2013. Draft Local Plan Consultation Document. London, UK.

Mower, J., 2012. London 2012: Olympics plan to combat summer drought [WWW Document]. URL www.bbc.co.uk/news/uk-17373803 (accessed 8.20.15).

Rutter, P., 2013. Old Ford Water Recycling Plant, in: CIWEM Conference 2013. Chartered Institute of Water and Environmental Management.

Tupper, M., 2014. Implementing Water Reuse, in: Water Reuse in the UK. Water Efficiency in Buildings Network, Brighton.

WRAS, 2012. Case Study – Supporting the Olympics. Crumlin, Gwent, UK.

Appendix B Summary of news articles and online comments

Table B-1 Online news cases: Summary of internet sources for news articles and online comments and reason for their inclusion or exclusion from analysis

Case	Article and Comment Sources	Ref‡	Date	Title	Source incl?	Notes on inclusion or exclusion	Comments Excl.	Coded / total	%
1. BBC	BBC article	C1.S1.A1	10/5/13	London 'could drink treated sewage' - Thames Water	Y	UK wide news source. No comments	-	0/0	n/a
	BBC London – Facebook	C1.S2	10/5/13	London 'could drink treated sewage'	Y†	Open forum with link to article. Extra introduction text analysed	-	8/11	73%
	BBC Radio 2 – Facebook	C1.S3	10/5/13	London 'could drink treated sewage'	Y†	As above	-	6/31	19%
	BBC Radio London – Facebook	C1.S4	10/5/13	London 'could drink treated sewage'	Y†	As above	-	2/3	67%
	Reddit: London forum (link to BBC article)	C1.S5	10/5/13	BBC News - London 'could drink treated sewage'	Y*	Included as comments	-	12/15	80%
	This is big brother - UK forum	C1.S6	10/5/13	London 'could drink treated sewage - Thames Water	N	Copies BBC article. Few comments, some only images. Restricted forum	7	-	-
	Twitter (Tweets with article link)	C1.S7	10/5 – 28/6/13	n/a	Y*	Included as comments	-	11/45	31%
2. Daily Mail	Daily Mail article	C2.S8.A2	10/5/13	Would you drink sewage? What millions will be asked as suppliers desperately try to beat water shortages	Y	UK wide news source: Article with comments		200/ 685	29%
	Daily Mail – Facebook	C2.S9	10/5/13	Debate: Would you drink recycled toilet water?	Y†	Open forums with link to article. Extra introduction text analysed		51/ 116	44%
	Daily Mail article	C2.S10.A3	23/10/14	Would YOU drink water recycled from toilet waste? Two in three back plans to look at using treated sewage . . .	N	Excluded. Reports on Guardian article (Case 5 - 10/5/2013). Published in 2014	76	-	-
	Twitter (Tweets with article link)	C2.S7	10/5/13	n/a	Y*	Included as comments		3/12	25%
3. Evening Standard	Evening Standard article	C3.S11.A4	9/5/13	Drinking treated sewage could be the answer to the capital's water shortage, says Thames Water	Y	London based news source: Article with comments		28/28	100 %
	TNT article	C3.S12.A5	10/5/13	Londoners could be asked to drink recycled sewage . . .	N	UK news source (aimed at antipodean expats): Reports on E.S. Only 1 comment	1	-	-

Case	Article and Comment Sources	Ref‡	Date	Title	Source incl?	Notes on inclusion or exclusion	Comments Excl.	Coded / total	%
	TNT – Facebook (link to TNT article)	C3.S13	10/5/13	Londoners could be asked to drink recycled sewage water. . .	N	Link to TNT article. Insufficient comments	3	-	-
	Population Matters – Facebook	C3.S14	11/5/13	New water source proposed for crowded London - your toilet!	N	UK based environmental site. Exclusive forum. Few comments. Link to E.S. article	9	-	-
	Navitron (UK renewables forum	C3.S15	10/5/13	Thames Water to recycle sewage to drinking water	N	Restricted use of site. Link to E.S. article.	8	-	-
	Twitter (Tweets with article link)	C3.S7	10-22/5/13	n/a	Y*	Included as comments		11/32	34%
4. Express	Express article	C4.S16.A6	10/5/13	So, would you like to drink recycled sewage? - Weird – News	Y	Article and comments included		9/9	100 %
	Express – Facebook	C4.S17	10/5/13	So, would you like to drink recycled sewage?	Y	Open forums with link to article. Extra introduction text analysed		25/42	60 %
	Twitter (Tweets with article link)	C4.S7	10-11/5/13	n/a	N	No comments coded (no valid content)	9	-	-
5. Guardian	Guardian article	C5.S18.A8	10/5/13	Poll: are you happy to drink recycled sewage water?	Y	UK wide news source: Article with comments		67/98	68%
	Guardian (Greenslade blog)	C5.S19.A9	10/5/13	Telegraph debunk urban myth	N	Blog comments on Telegraph article. Comments not responding to an article	12	-	-
	Inhabitat - International web-blog.	C5.S20.A10	10/5/13	Thames water to transform London's sewage into drinking water	N	Reported on Guardian. Few comments	1	-	-
	Inhabitat – Facebook	C5.S21	10/5/13	Thames water to transform London's sewage into drinking water	N	Non-UK source.	31	-	-
	Green-alerts: Environmental news.	C5.S22.A11	15/5/13	London set to drink recycled sewage	N	Reports on Guardian article. No comments	0	-	-
	Grist-blog: Environmental news.	C5.S23A.12	14/5/13	London May soon be drinking recycled sewage	N	Non-UK. Reports on Guardian article	5	-	-
	MNN: Environmental news.	C5.S24.A13	15/5/13	In the future, will treated toilet water flow through London's taps?	N	Non-UK. Reports on the Guardian & BBC article. No comments	0	-	-
	Nairaland Forum	C5.S25	22/5/13	London To Transform Sewage Water In To Drinking Water	N	Online forum based in Nigeria. Copies report from Inhabitat	80	-	-

Case	Article and Comment Sources	Ref‡	Date	Title	Source incl?	Notes on inclusion or exclusion	Comments Excl.	Coded / total	%
	Heath News NG	C5.26.A14	23/5/13	Stakeholders Debate Hygiene As London Plans To Convert Sewage Into Drinking Water	N	Nigerian health news site. Content derived from the Guardian. No comments	0	-	-
	Care2: Environmental news.	C5.S27A15	13/5/13	Would you drink recycled water to conserve water?	N	Non-UK. Reports on the Guardian article	134	-	-
	Twitter (Tweets with article link)	C5.S7	10/5-14/6/13	n/a	Y*	Included as comments	-	15/66	23%
6. Telegraph	Telegraph article	C6.S28.A16	9/5/13	Householders asked if they would drink treated sewage water	Y	UK wide news source: Article with comments	-	87/ 107	81%
	Twitter (Tweets with article link)	C6.S7	9/5-6/6/13	n/a	Y*	Included as comments	-	2/23	9%
7. UK – Other	The Bucks Herald & Berkhamsted	C7.S29.A17	10/5/13	Thames Water asks: 'Would you drink treated effluent?	N	Limited readership. Few comments.	12	-	-
	London Loves Business	C7.S30.A18	9/5/13	Londoners could be drinking recycled sewage in years to come	N	Only one comment. Specific to London but site with limited reach	1	-	-
	London Loves Business – Facebook	C7.S31	9/5/13	Londoners could be drinking recycled sewage in years to come. But don't poo poo the plans till you see them..	N	Links to L.L.B article. No comments	0	-	-
	BBC article	C1.S32.A19	20/5/13	Southern Water could recycled wastewater	N	Not specific to London, no comments	0	-	-
	Reddit – London based forum	C7.S33	9/5/13	What are your views on drinking sewage water?	N	No link- not specific to any article.	5	-	-
8.Int.	FNB News	C8.S34.A20	13/5/13	Thames Water seeks views on plan to recycle sewage . . .	N	Online news site in India. No comments.	0	-	-
	Domain-b	C8.S35.A21	11/5/13	Thames Water proposes recycled water for Londoners . . .	N	Business news (India). No comments.	0	-	-
	Primary articles included	6/21		Included internet sources	13/35	Comments excluded	394		
						Comments coded/total included	537/ 1,323		41%

‡C=Case, A = Article, S=Source. †Additional introduction text on Facebook included in analysis of article. *Only comments included in analysis.

Appendix C Links to video animations

C.1 General message

https://streaming.cranfield.ac.uk/Watch/Xm54LjGe

C.2 Compliance message

https://streaming.cranfield.ac.uk/Watch/Xm54LjGe

C.3 Relative risk message

https://streaming.cranfield.ac.uk/Watch/k9GWd67M

C.4 Technology message

https://streaming.cranfield.ac.uk/Watch/k3D5SwBi

Appendix D Multi-criteria studies for water reuse

Table D-1 A summary of water reuse related multi-criteria studies

Study	Purpose	Multi-criteria method	Criteria (main)	Criteria weighting	Multi-stakeholder method
Anane et al. (2012)	Ranking irrigation sites	Fuzzy AHP	Land suitability; resources conflicts; economic; social, environmental	Pairwise comparisons using 9 point preference scale	None (based on expert judgement)
Chen et al. (2014, 2012)	Selecting new recycled water uses (Sydney, Australia)	Outranking – PROMETHEE	Water supply; operability; water quality; water savings; energy consumption; GHG emissions; ecology; community acceptance; political support; education opportunities; cost (capital and operating).	Monte Carlo rank order weights supposed preference order	None
Curiel-Esparza et al. (2014)	Selecting disinfection technologies	AHP combined with the VIKOR technique	Pathogen reduction; costs (capital and operating); reliability; simplicity; additional treatments; environmental impacts; resource consumption; safety risk	Pairwise comparisons using 9 point preference scale	**Two stage Delphi** method with technical experts (n=12).
Domènech et al. (2013)	social multi-criteria evaluation of non-conventional water alternatives (Barcelona, Spain)	C-K-Y-L * ranking procedure (pair-wise) And NAIADE**	Capital and operating costs; public acceptability; health risk; local government empowerment; energy consumption; environmental impacts; simplicity; reliability; time of implementation	Two weighting scenarios for growth and de-growth. Stakeholder survey: Indicate the importance of the following criteria according to your opinion (from very important to very insignificant)	Public acceptance from two surveys of n=640 members of the public (C-K-Y-L assessment) Stakeholder Survey (n=63) (NAIADE assessment)
Garcia-Montoya et al. (2016)	Reuse options for a residential complex	Multi-objective optimisation	Economic; Environmental (life-cycle assessment)	No weights	None
Gdoura et al. (2015)	Selecting ground water recharge sites	AHP	Technical (soil, geology); Economic; Environmental (distance from urban	Pairwise comparisons using 9 point preference scale	None (based on expert judgement)

Study	Purpose	Multi-criteria method	Criteria (main)	Criteria weighting	Multi-stakeholder method
			area, groundwater quality)		
Gomez-Lopez et al. (2009)	Selecting disinfection technologies	TOPSIS (distance to ideal point)	pH; implementation; costs; enterprise image; energy saving; residues; emissions	Linguistic variables. Very Low (0) to Very High (1) and Very Bad (0) to Very Good (1)	Wastewater reuse experts (n=3), one stage survey.
Kumar et al. (2015)	Water supply management options in a drought prone river basin (Tarragona, Spain)	Outranking - ELECTRE (hierarchical structure from pairwise comparisons)	Cost of water per sector; Water Supply Index per sector; Ecological impact per river	Equal weights of elementary criteria. Sub-criteria weights to three weight scenarios (balanced, cost first, environment first) and three outcome scenarios (optimistic, neutral, pessimistic)	"Conducted in collaboration with experts and stakeholders." No details given of type or number of experts and stakeholders involved.
Sadr et al. (2015)	Selecting membrane treatment	Group-based fuzzy logic	Land required; water quality; adaptability; complexity; costs (capital and operating); energy consumption; environmental impact; community acceptance	Fuzzy linguistic variables Very Low to Very High	Water reuse and wastewater treatment experts (n=20). One stage survey
Sadr et al. (2016)	Selecting membrane treatment	AHP-PROMETHEE (using D-Sight software)	Land required; water quality; adaptability; complexity; costs (capital and operating); energy consumption; environmental impact; community acceptance	Relative weights developed in AHP with pairwise comparisons using 9 point preference scale. Weights then used in PROMETHEE	None
Sa-nguanduan and Nititvattananon (2011)	Selecting water reuse supplied to different areas for different potable and non-potable purposes (Pattaya City, Thailand)	Multi-attribute utility theory (MAUT) - expected utility function	Water balance; environmental impact; capital and operational costs; economic benefit; environmental benefit; health impacts; public acceptance; water quality; water quantity; reliability;	Importance order of criteria (IOC) method. Assigning weight based on giving a mean value to each of the criteria from the results of 5-rating scale	N=33 stakeholder interviews for weighting N=200 survey of public (for public acceptance criteria)

Study	Purpose	Multi-criteria method	Criteria (main)	Criteria weighting	Multi-stakeholder method
			government support; institutional cooperation	questions in stakeholder surveys (sum of weights = 100)	
Sapkota et al. (2016)	Comparing centralised and decentralised urban water supply options (Melbourne, Australia)	Outranking – PROMETHEE (D-Sight software), with pair-wise comparison.	Potable water demand; contaminant loads; wastewater discharges; stormwater flows; supply reliability	Relative importance of each criteria (total of six criteria proportioned to add to 1)	Survey of stakeholders (n=37)
Woltersdorf et al. (2017)	Water and nutrient reuse options for semi-arid developing countries (Outapi, Namibia)	AHP	Ecological; economic; social; institutional and political; technical	Using AHP 1-9 scale. Six different weighting scenarios by researchers	Expert team (n=12)

*Condorcet–Kemeny–Young–Levenglick, ** Novel Approach to Imprecise Assessment and Decision Environments

Appendix E Evaluating urban non-potable water reuse opportunities - Costs and benefits of risk management interventions

D. Goodwin[1], M. Raffin [2], P. Jeffrey [1], H. M. Smith [1]

[1] Cranfield Water Science Institute, Cranfield University, Bedfordshire, UK, MK43 0AL
[2] Thames Water Utilities Ltd, Dace Road, Bow, London, UK, E3 2NW
Corresponding author: d.goodwin@cranfield.ac.uk

Abstract

Non-potable water reuse schemes can help address water supply stresses in the UK. However, the feasibility of schemes is questionable due to potentially high capital and operating costs. Perceptions of health risks can contribute to high operating costs through conservative scheme designs. Conversely, a failure to anticipate customers' water quality expectations can undermine scheme feasibility if there is insufficient water demand. Cost-benefit and health risk analyses are undertaken on a range of existing and potential customers for the Old Ford Water Recycling Scheme in London. Following this, the impacts of different risk reduction interventions are assessed and discussed. Findings show that new connections can improve the economic feasibility. However, increased health risks would require further detailed analysis for the preferred options. Whilst interventions can reduce health risks, the costs of implementing these mean that the potential of sharing risk responsibilities between interested stakeholders should be explored further.

Key words: cost-benefit, health risk, non-potable water, risk management

E.1 Introduction

Due to stresses on existing water resource management regimes, water reuse schemes are of increasing relevance in the UK. There are clear benefits to mobilising new infrastructure that combines wastewater treatment with water supply. However, such schemes can also be challenged by economic viability (Leverenz et al., 2011) and stakeholder support (Hernández et al., 2006). Reviews of international cases have highlighted the impact insufficient customer buy-in can have on non-potable reuse scheme cost-benefits (West et al., 2016). Moreover, whilst the range of feasible urban uses for non-potable water (e.g. flushing toilets in housing developments) might seem conducive to developing schemes, there is uncertainty in understanding stakeholders' preferences for managing risks (Turner et al., 2016). There is, therefore, a need to consider the impact different risk reduction interventions might have on the assessments of both health risks and cost-benefits (Lindhe et al., 2011; Qadir et al., 2010). Furthermore, there is a need to understand how this information might be useful to stakeholders evaluating non-potable reuse opportunities (Chen et al., 2014a).

This paper considers the Old Ford Water Recycling Plant (OFWRP) at the Queen Elizabeth Olympic Park (QEOP) in London. The OFWRP currently abstracts raw sewage from the Northern Outfall Sewer, treats it through a membrane bio-reactor (MBR) process (ultrafiltration) followed by granular activated carbon (GAC) and disinfection. The non-potable water, meeting bespoke water quality standards, is distributed in a dedicated pipe network. The quality standard was tailored so the non-potable water could be used for irrigation, toilet flushing and cooling towers and the scheme implements a comprehensive Water Safety Plan approach to risk management (Hills, 2013). However, whilst there were initial proposals to irrigate sports fields (stadium and water-based hockey) and provide cooling tower water (energy centre), perceptions of water quality health risks may have prevented these connections from going ahead, thus impacting on scheme cost-benefits (CfSL, 2012; Hills and James, 2015).

This article will summarise the case study results that compare a business-as-usual scenario with a range of feasible customer connections. Following this, the impact of risk reduction interventions are considered, using enhanced risk management and technology upgrade scenarios. The principle query guiding the study is: what are the impacts of risk reduction measures on cost-benefit and health risk assessments for non-potable water uses? Consideration is also given to how stakeholders might make use of such information when evaluating non-potable reuse scheme design and governance proposals. It is hoped that development of this research can contribute to improving the viability of new and existing water reuse schemes in the UK.

E.2 Methods

Cost-benefit analysis (CBA) and quantitative microbial risk assessment (QMRA) methods were used. The study first considered: (1) a business as usual (BAU) scenario with existing treatment processes and existing customers (parkland irrigation and toilet flushing at QEOP venues).

Next, it considered four potential customer connections: (2) an energy centre (cooling towers), (3) water-based hockey playing fields, (4) an aquatic centre (pool make-up and filter backwash), and (5) a residential development (5,000 unit connections were assumed). The residential option included two sub-options: (a) toilet flushing only, (b) toilet flushing and washing machines. All of these proposed customer connections have been realistically considered as potential customers for the case study except for the aquatic centre, which was included for comparative purposes. Due to uncertainty in estimates, probability distributions were included in the CBA and QMRA using Palisade @Risk software version 7.5 and 10,000 iterations.

Customer demand

Operational data (2013 to 2015) for the OFWRP was used to approximate a typical annual profile of volumes of water treated and supplied for the existing customer demand (Figure E-1). Due to summer irrigation, existing demand is seasonal. However, the plant continues to operate in winter with much of the treated water diverted to waste. There is uncertainty in the future demand for irrigation, therefore a 5 to 15% longer-term reduction was assumed in the calculations. Demand for potential customers was estimated and is summarised in Table E-1. The timing for new customer connections varies as some can connect relatively quickly, as most of the infrastructure is already in place (hockey centre and energy centre) whilst other options would be staged over time.

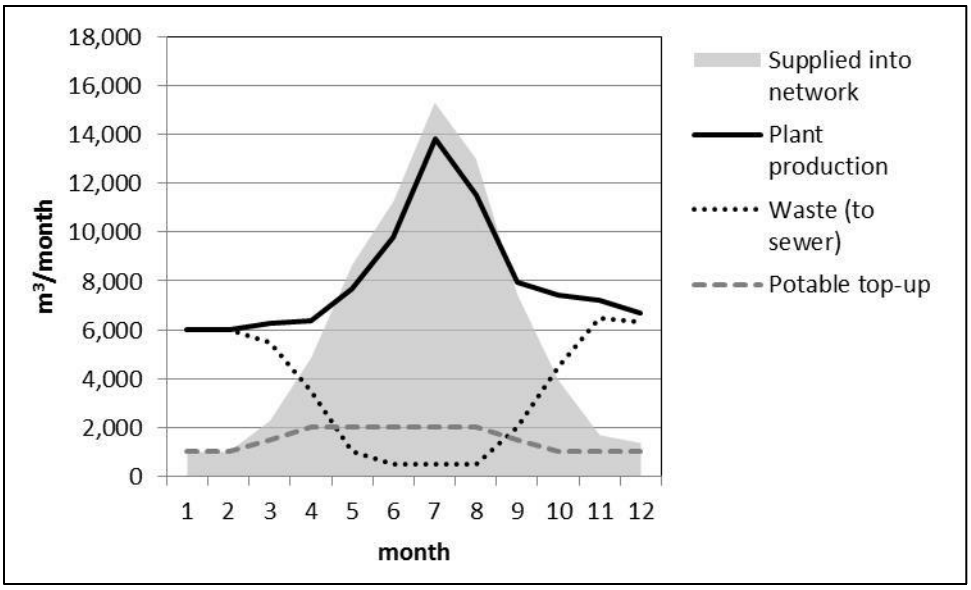


Figure E-1 Summary of BAU typical monthly flow data

Table E-1 Additional non-potable water demand for potential customers

Customer/ use	Demand† (m^3. mth^{-1})	Notes and references
Water-based hockey	2,000; 3,000	Epstein et al. (2011)
Aquatic centre	1,000; 1,600	Olympic Delivery Authority (2012) for pool make- up and filter backwash
Energy centre	5,250; 7,500	Knight et al. (2012)
Residential (toilets)	4,500; 9,900	5,000 units assumed based on 24,000 new homes being planned for construction by 2031 (LLDC, 2014b). Approximate occupancy of 1.5 people per unit. 100 $L.person^{-1}.day^{-1}$, 30% for toilets (Parker and Wilby, 2013).
Residential (toilets and washing machines	6,900; 15,180	As above, 16% for washing machines (Parker and Wilby, 2013).

†Uniform distribution, minimum and maximum values. Every value in this range is equally likely, the value is not known but assumed to be within this range.

Cost-benefit analysis

The CBA used a 30 year time period (Khan, 2013; Verrecht et al., 2010). Net present value (NPV) was calculated using the following formula (Eq. 1) where: B = benefits (Opex), C = costs (Capex and Opex), t = time in years, r = discount rate and K = initial investment.

$$NPV = -K + \sum_{t=1}^{t}\left(\frac{B_t - C_t}{(1+r)^t}\right) \qquad \text{Eq. 1}$$

The analysis did not take account of previous investment (i.e. constructing the scheme) and only investigated costs and benefits accrued going forward. The boundary of the costs accrued is the provision of sufficient infrastructure to connect the non-potable water network to a new customer. Membranes were assumed to be replaced every 10 years (Verrecht et al., 2010). A discount rate of 3.5% was used (HM Treasury, 2011), whilst long-term inflation was assumed to be 2% (Verrecht et al., 2010). Sensitivity analysis was performed on the time period and discount rate. The cost model accounted for operational costs (chemicals, energy, sludge removal, staff, analysis and maintenance) and benefits (non-potable water supply, wastewater treatment) (Table E-2). Additional Capex and Opex were added for the new customer options (Table E-3).

Table E-2 Business as usual costs and benefits

	Cost-benefit item	Total (£)	Notes
Benefits	Sale of non-potable water	£1.19 m^{-3}	90% of potable water supply charge (varies per customer depending on usage but fixed rate assumed)
	Treatment of wastewater	£0.82 m^{-3}	Residential rate for customers paying for wastewater treatment in North London (N.O.S. catchment). Applies only to the volume of water supplied to customers.
Costs -flow dependent	Treatment (incl. MBR, GAC) and distribution	2.50 kWh m^{-3}; -£0.11 kWh^{-1}	Unit energy derived from a combination of monthly energy use data and specification for equipment
	Chemicals	-£0.13 m^{-3}	Includes Sodium hypochlorite, poly-aluminium, water softening salts and granular activated carbon (replaced approx. every 2 years). From record data and Rutter (2013)*.
	Sludge removal	-£0.10 m^{-3} water treated	Record data and Rutter (2013)*
Costs - non-flow dependent	Labour	-£40,000; -£60,000; -£80,000 yr^{-1}	Triangle distribution. Most probable is two full time technicians and part-time staff. **
	Water quality analysis	-£50,000 yr^{-1}	From record data**
	Maintenance	-£50,000 yr^{-1}	From record data**

*note Rutter, (2013) was estimated using an annual flow of 200,000m^3. **Excludes all research related costs

Table E-3 Additional costs for potential customer connections

Cost item	Cost (£)	Notes
Capex: Connection for aquatic centre	-£50,000	New pipe connection, 100m x £300 m^{-1} plus connections (AECOM, 2015)
Capex: Connections for houses	-£1,500,000; -£2,500,000†	Assume network extensions and supply to metered break tanks in development. Estimate £300-£500/dwelling (Fisher-Jeffes, 2015; Pickering, 2013).
Opex: Residential Options	-£70,000 yr^{-1}	Additional staff costs, Network and meter maintenance. Additional water quality analysis. Additional regulation checks. Estimate based on record values and Verrecht et al. (2012)

†Uniform distribution

Health risk assessment

Health risk assessments were undertaken using Quantitative Microbial Risk Assessments (QMRA) and Disability Adjusted Life Year (DALY) calculation methods for norovirus (Table E-4). Norovirus was selected due to the significant contribution it makes to the disease burden and healthcare costs in the UK (Tam and O'Brien, 2016) and due to the relevance of viruses across the range of exposures considered (Westrell et al., 2004). A DALY is equivalent to the loss of one year of full health and the health-based target of $1x10^{-6}$ (μDALY) is referred to. The analysis was undertaken for DALY per person per year (pppy) and DALY per total population exposed. This was done due to a potential trade-off between these two calculations (Westrell et al., 2004). Summary data for exposures and populations for each connection option are provided in Table E-5.

Table E-4 Values used in QMRA calculations

Parameters	Values	Notes & References
Norovirus – initial concentration	$2x10^3$ gene copies per litre	GI and GII $10^{1.5}$ – 10^3 each (Purnell et al., 2016). 10^1 – 10^4 (NRMMC EPHC & AHMC, 2006).
Log-reduction value (LRV)	4.5; 6.0† LRV	2.3 (MBR only) but none detected post chlorination (except one sample) (Purnell et al., 2016); 4.6 to 5.7 (Chaudhry et al., 2015); 4.2 (Simmons and Xagoraraki, 2011)
Log reduction - other	Swimming pool disinfection 0.5; 0.75; 1.0: Hockey and energy centre dosing 0.1; 0.2; 0.3	Triangle distributions. Additional treatment steps included for aquatic centre (Cl & UV), Energy Centre and Hockey Fields. See NRMMC EPHC & AHMC (2006) for LRVs
DALY per person per year	*DALY/year = $P_{illnessyear}$ x DALY/case x susceptibility*	See Appendix 2 NRMMC EPHC & AHMC, (2006)
DALY per case	3.30×10^{-3}	Barker (2014)
Susceptibility	80%	Barker (2014).
Probability of infection (P_{inf})	$P_{inf,NoV} = 1 - {}_1F_1$ (α, α+β, -$Dose_{NoV}$)	Calculated using the Kummer confluent hypergeometric function ${}_1F_1$ (Mok et al., 2014; Teunis et al., 2009)
P_{inf} fit parameters	α = 0.04 and β = 0.055	Mok et al. (2014)
Disease given infection (P_{ill})	0.67 x P_{inf}	Sales-Ortells & Medema (2014)

†Uniform distribution

Table E-5 Summary of values used for exposure to recycled water

Recycled water use (exposure)	Exposure† (mL)	Events. Person^{-1}. Year^{-1}	Population affected†	Comments
BAU* – Irrigation staff	0.06; 3.8	40	15; 25	Sinclair et al., (2016). Assume operative undertaking manual water twice per week, 20 weeks per year.
BAU* – Venue toilets	0.005; 0.01	2	800,000; 1,300,000	NRMMC EPHC & AHMC, (2006). Assume an individual visitor flushes a toilet twice per year (on average). Approximately 1,000,000 visitors per year (QEOP, 2016)
Residential – toilets	0.005; 0.01	1460	5,000; 11,000	NRMMC EPHC & AHMC, (2006)
Residential – cross connection	1,000; 2,000	Assume 1 in 5,000 houses	5,000; 11,000**	Storey et al. (2007) and; NRMMC EPHC & AHMC, (2006). Assume 180 days undetected (6 months).
Residential – washing machine	0.005; 0.01	100	5,000	NRMMC EPHC & AHMC, (2006); Page et al., (2013)
Energy Centre – staff	0.05; 1.0	50	4; 8	Hamilton & Haas, (2016) 0.5 µL (high-pressure hose). Storey et al., (2004) 0.06 mL (showering).
Swimming* - swimmer	16; 51	50	50,000; 150,000	16-37mL (Dufour et al., 2006); 31-51mL (Schets et al., 2011). Assume regular swimmer, average visit once per week. For visitor numbers see GLL (2015), assuming multiple visits by some swimmers. No dilution factor included.
Hockey* - player	3.0; 7.0	48	30,000; 40,000	4mL for child on field drip or spray irrigated; 5mL for pressure washing car (DOEE, 2013). Assume person exposed 2 times per week for 24 weeks. Player numbers – best estimate provided by the venue.

*Calculations based on the group assumed to be more at risk (based on population, exposure and number of events.year^{-1}), thus some calculations are for staff and others for the general community – this is a simplification. Vulnerable groups were not considered independently.
**Note that DALY pppy can be estimated for one single household with an assumed cross-connection, however, the calculation used assumed the cross-connection is randomly allocated across the entire population affected.
†Uniform distribution

Risk reduction interventions

Two risk reduction intervention scenarios were investigated: (1) technology intervention, consisting of the addition of a reverse osmosis (RO) process, (2) a risk management intervention, consisting of enhanced risk managed practices – assuming additional regulation inspections, auditing, enhanced water quality testing, risk management practices and increased stakeholder engagement. The RO intervention consists of more upfront investment and flow-dependent Opex, whilst the enhanced risk management intervention consists principally of increased non-flow dependent Opex (e.g. labour) over time. Data used to estimate the impact of the risk reduction interventions in the CBA and QMRA are summarised in Table E-6.

Table E-6 Additional costs and health risk reductions for risk interventions

Risk Reduction	Item	Units
Technology upgrade (RO)	Capex: New RO treatment	-£500,000; -£750,000. Install new RO process (574m^3.day^{-1}). £600 m^{-3} to £1,200 per daily capacity (Pankratz, 2015; Singh, 2013).
	Opex: RO energy	1.0 kWh m^{-3} (Chen et al., 2012b); -£0.11 kWh^{-1}
	Opex: RO chemicals	-£0.05 m^{-3}. Pre-treatment and processing chemicals Fritzmann et al., (2007)
	Additional RO maintenance	-£12,000 yr^{-1}. Estimated based on existing treatment process and Fritzmann et al., (2007).
	RO additional log-reduction for viruses	1 LRV (NRMMC EPHC & AHMC, 2006)
Enhanced Risk Management	Capex: Signage and educational material	-£20,000. Based on recorded data.
	Staff – Regulation, Risk management and Engagement	-£40,000 yr^{-1}. Includes water regulation checks, dye testing, network sampling and customer engagement (education, briefing etc.). Assume additional time for reporting, liaison.
	Exposure reduction	Irrigation maximum exposure of 2mL (reduced by 50%)
	Reduce exposed population	Irrigation, max 15 ppl; energy centre, max 6 ppl.
	Reduced events per year	Irrigation, max 20 events.yr^{-1}; Energy centre staff exposure max 25.yr^{-}1; cross-connection detection 30 days max (detected through enhanced audits, water quality testing, etc)

E.3 Results & Discussion

Cost-benefit

The results showed that, based on median values, most of the new connection would improve the scheme's economic performance, with the exception of the residential options with toilets only (Figure E-2). The most beneficial new connection was the energy centre, which returned net benefits overall. The second highest NPV was for the hockey fields option which, like the energy centre, had no up-front infrastructure investment required (but lower non-potable water demand). The residential option that included washing machines returned the third highest median value result. However, there was a larger range due to more cost uncertainty. With the exception of the energy centre, no single option would be considered favourable to the scheme's longer-term feasibility.

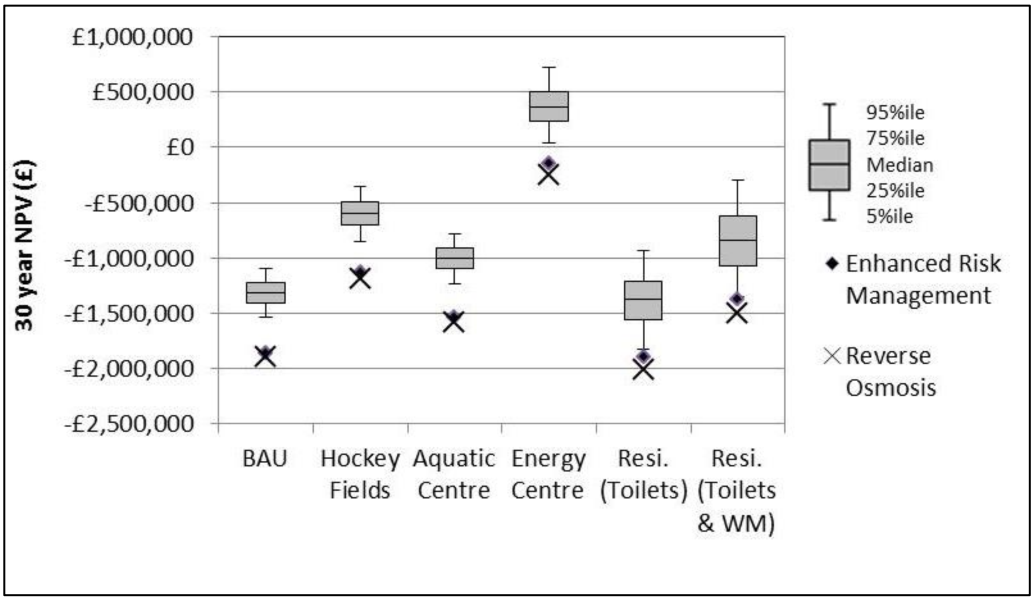


Figure E-2 CBA for BAU and new connection options box and whisker graph showing percentiles. Risk interventions show median values only.

The CBA highlights the potential to achieve more beneficial economic outcomes. However, adding further risk reduction measures (i.e. RO or enhanced risk management) would make this more challenging. The CBA results for a scheme of this nature are not surprising and concur with literature discussing similar undesirable results (Turner et al., 2016). Whilst unanticipated Capex and Opex (e.g. higher maintenance or water quality monitoring cost) are known to adversely affect economic feasibility (West et al., 2016), customer perceptions of water supply risks and their ultimate buy-in to the scheme may have had bigger economic repercussions in this particular case.

A limitation of this analysis is that it hasn't attempted to monetise more subjective items such as other social or environmental benefits (Mattheiss and Zayas, 2016; Pickering, 2013). Therefore, it is acknowledged that different approaches could improve the measured economic performance of the BAU scheme and connection options. Moreover, the results are influenced by non-flow dependent costs, particularly staff – which has been previously shown for small-scale MBR schemes (Verrecht et al., 2012). Such a finding highlights the challenge to setting the boundaries for CBA when assessing small water schemes. For example, due to economies of scale, it may be difficult to compare with much larger-scale plants where the proportion of labour costs are much lower (Fritzmann et al., 2007).

Sensitivity analysis

Longer time periods (e.g. 45 year NPV) improved the results for options with Capex (in particular, the residential options). On the other hand, the options consisting of only operational expenditure were less sensitive to the length of the analysis time period. Increasing the discount rate to 6.0% (Khan, 2013; Verrecht et al., 2010) reduced costs and benefits over time, thus reducing the magnitude of the difference between the options (i.e. the residential options perform better and the energy centre slightly worse).

Health risk assessment

The results showed most of the existing and proposed uses to be below the health-based target of $1x10^{-6}$ DALY pppy (Figure E-3). The exceptions were a single household with a cross-connection, the aquatic centre (regular swimmers) and possibly an individual (regular) hockey player. Residential toilets and washing machines returned low individual health risks (i.e. < 10^{-6} DALY pppy). However, residential options are complicated by the possibility of a cross-connection with the drinking water supply. Furthermore, the impact of a cross-connection was well above the health-based target when considering the impact on the occupants of a single affected household (however, it is below the acceptable threshold if the DALY risk is spread across the affected population). The results are broadly consistent with previous studies. For example, Page et al., (2013) showed residential toilets flushed with non-potable water to be below the $1x10^{-6}$ health-based target. For swimming in tertiary-treated wastewater, Westrell et al. (2004) report $6x10^{-4}$ DALY pppy, in comparison, this study estimated $4.83x10^{-7}$ – $3.30x10^{-6}$ for swimmers (with comparatively more exposure events assumed but a higher quality of water).

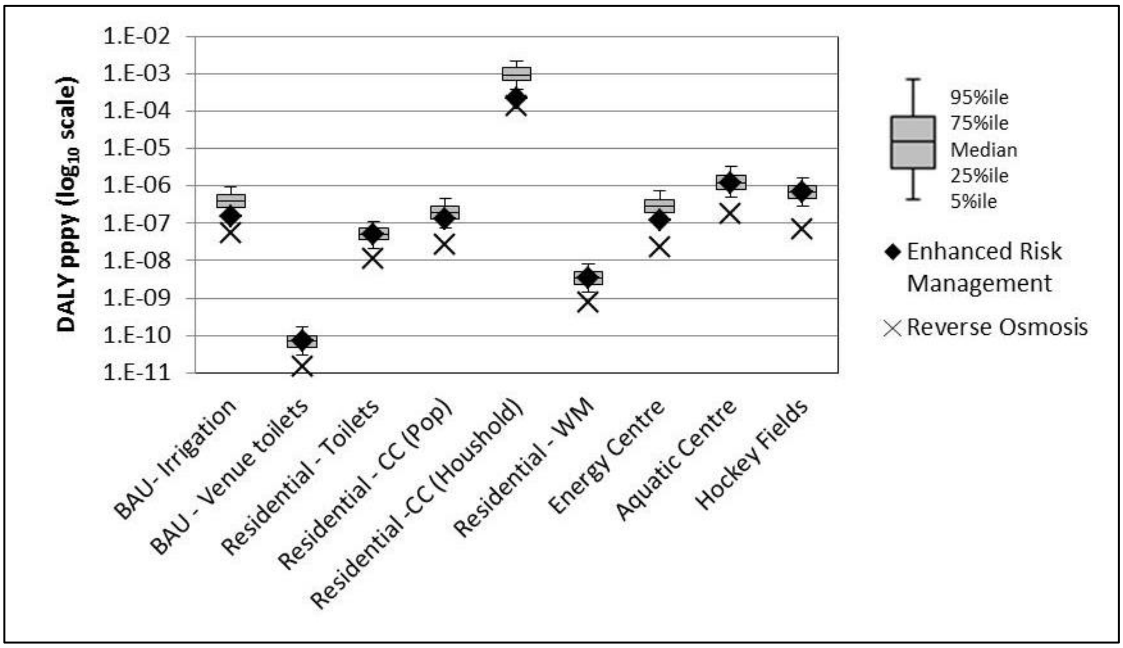


Figure E-3 Health risk assessment DALY pppy box and whisker graph showing percentiles. Risk interventions show median values only.

The picture was different when the total health burden on the affected population was considered (Figure E-4). Under these scenarios, the aquatic centre (swimmers; 4.62×10^{-2} – 3.99×10^{-1} DALY) and the hockey fields (players; 1.03×10^{-2} – 6.90×10^{-2} DALY) had the highest total population risk burdens. This was essentially due to the larger populations that would be exposed over the course of a year. The energy centre and BAU (irrigation) had the lowest total population risk burdens, due to the small populations affected (small number of staff). Taking into account uncertainty in the calculations, the two cross-connection estimates provided similar results for the total disease burden on the affected population (as was expected).

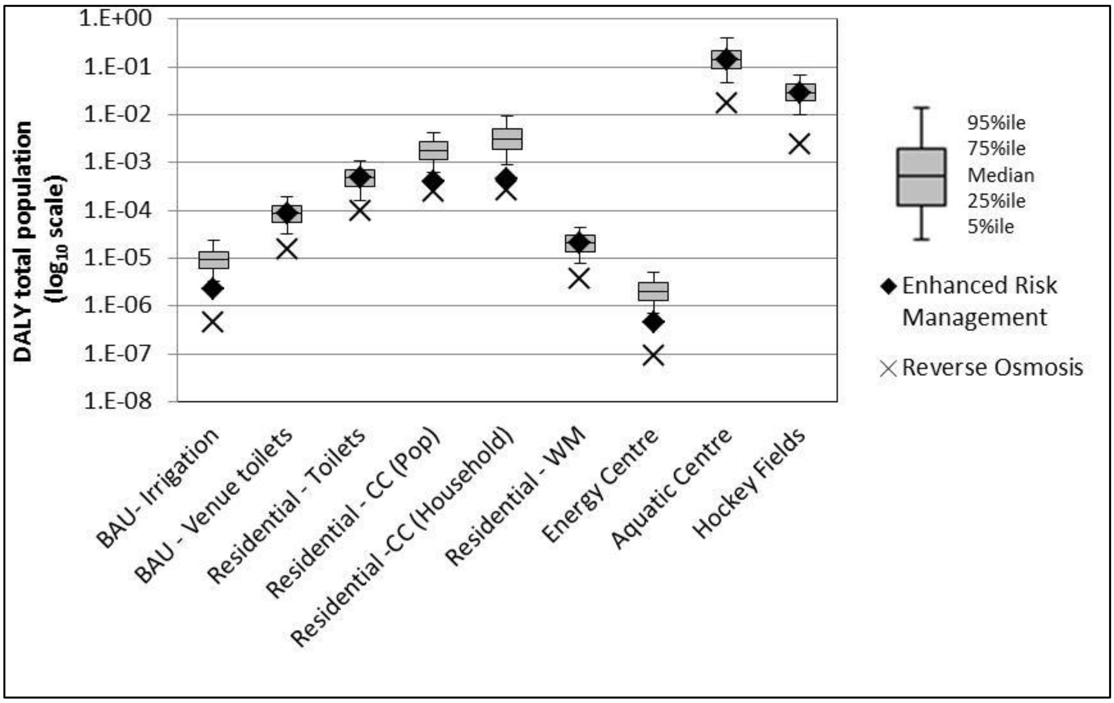


Figure E-4 Health risk assessment - total population burden box and whisker graph showing percentile values. Risk interventions show median values only.

Previous studies documenting total disease burden estimates include: an annual DALY of 0.2 to 9 (for a range of pathogens) for a population of 28,600 exposed to treated wastewater and sludge applied to land (Harder et al., 2014), and a total DALY of 5.7 per year (for *Campylobacter* spp., *Cryptosporidium* spp. and rotavirus) for a hypothetical population of 200,000 exposed to unplanned indirect potable reuse (with upstream wastewater treatment) (Aramaki et al., 2006). Thus, these studies put into context the highest total population burden for this study for the aquatic centre with a total DALY of $4.62x10^{-2}$ – $3.99x10^{-1}$ for a population range of 50,000 - 150,000. For residential toilet flushing, Fewtrell & Kay (2007) estimated a total disease burden for flushing toilets with rainwater of $7.14x10^{-5}$ DALY (*Campylobacter* spp. and *Salmonella* spp.) for a residential population of 4,483 people. This puts the results for the residential (toilets) option into context, with a higher total DALY of $1.63x10^{-4}$ – $1.09x10^{-3}$ but also a larger population of 5,000 - 11,000 (noting that the different pathogens considered mean the results are not directly comparable).

The implications of these findings are to support the previously identified benefits of using total population disease burden to compare wastewater treatment and exposure options (Westrell et al., 2004).It is also worth noting that there are many limitations to the accuracies of the DALY method, for example, compared with epidemiological methods (Barker, 2014). Moreover, there are limitations around variable susceptibilities of different individuals (Derry et al., 2006), the selection of reference pathogens and fitting parameters to different norovirus genogroups (Sales-Ortells and Medema, 2014). However, the method provides a useful approach for comparing health risks of different exposures for therefore aiding decision-making.

The impacts of risk reduction measures

The technology risk reduction intervention (i.e. RO) increased the costs for all connection options and also reduces the potential health risk (assuming normal operating conditions). An enhanced risk management intervention had a similar impact on cost-benefits as the RO intervention, however, the health risk reductions were more variable. This is because for many of the options (e.g. aquatic centre) there were no assumptions made about practical ways to reduce exposure. The result did show potential benefits of enhanced risk management for managing cross-connections in new residential developments. Improving the response time for detecting a cross-connection from six months to one month had a similar risk reduction impact as the RO intervention, both in terms of per person and total population exposed. This highlights the challenges with managing the risk of cross-connections in residential development, particularly for hazardous events (such as membrane or RO failure where the risk control would be compromised). As recommended by related studies (e.g. Westrell et al., 2004), worst-case scenarios need further analysis to help evaluate the appropriate risk controls.

The most favourable results for both CBA and QMRA calculation were for the energy centre. This had no initial investment required (as infrastructure is already in place), reliable annual demand and low exposure potential (both per person and total population disease burden). The health risk to be managed was assumed to be a small number of staff working at the facility, as this connection option would be unlikely to affect the health of the wider community. Nonetheless, despite the potential cost-benefits, any new connection would increase the health-risk over BAU (without any further risk reductions or cessation of existing uses), as more individuals would be exposed to the non-potable water. Therefore, for a new connection to the energy centre, future analysis is recommended to consider the magnitude of the increased risk for that particular option. For example, an assessment of the risk from exposure to *Legionella* – a problem for cooling towers irrespective of recycled water use – would be necessary (Hamilton and Haas, 2016). However, there are suitable disinfection and risk controls available for managing *Legionella* risk in cooling tower systems using recycled water (Jjemba et al., 2015), thus inferring the collaborative role different stakeholders may need to play in risk management.

Whilst this study has considered adding an RO process as the technology intervention, other water treatment steps such as UV or advanced oxidation could also be considered for targeting pathogens, including viruses (Liga et al., 2011). This would, to a degree, be dependent on any key water quality criteria that were identified as needing to be reduced. In the case of targeting health-risks associated with connecting the energy centre and sports fields (both originally intended to be connected and with the top two CBA results), an additional treatment barrier may help placate previously expressed customer concerns. However, an RO intervention would be required if, for example, there are concerns about impacts from total dissolved solids on cooling tower operations – noting that this should be more cost-effective if installed on the customer's site (Institute for Sustainable Futures, 2013c). For enhanced risk management, this study draws attention to difficulties in estimating both the costs and health risk impacts. This is due to inherent difficulties in estimating the effects of behaviour change or new management practices. For example, whilst it may be appropriate to assume reduced exposures are achievable (WHO, 2006), these may be harder to validate. Therefore, it is not unreasonable to suggest that beneficial risk management practices may be constrained by a lack of incentives, poor enforcement or inadequate sharing of management responsibilities (Qadir et al., 2010).

Stakeholder decisions about non-potable reuse

Related studies highlight the important role stakeholder expectations and risk perceptions play in determining the economic viability of non-potable water schemes (Turner et al., 2016; West et al., 2016). This study showed how the economic performance of the scheme under consideration could potentially be improved with careful selection of new customers. Furthermore, this brief study also identified a number of areas where there could be potential benefits to sharing risk management (and cost) responsibilities. A useful extension of this study would be to investigate how different stakeholders deliberate and assign importance to evaluation criteria associated with recycled water decisions. This would help to build on existing knowledge regarding the inter-relationship of different criteria involved in selecting new recycled water uses (Chen et al., 2014a) and, furthermore, develop understandings of stakeholders' willingness to share risk management responsibilities, costs and benefits as part of a risk management process.

E.4 Conclusions

CBA and QMRA are useful tools for comparing potential non-potable water reuse connection options. Furthermore, considering per person and total population disease burden for the different options contributes to evaluating different dimensions of risk. Understanding the trade-offs involved in these evaluations can then lead to more detailed assessments of specific options. The results showed that cost estimates and risk reductions for a technology risk reduction intervention may be easier to estimate than management-based interventions. However, the benefits of any risk reduction should account for hazardous events and methods of validating the effectiveness of management-based initiatives. This work contributes to understanding the inter-relationships between different evaluation criteria for comparing recycled water uses and can help build more robust methods for improving scheme design and governance decisions.

E.5 Acknowledgements

This research was co-funded by the UK's Engineering and Physical Science Research Council (EPSRC) grant number EP/G037094/1 and Thames Water through the STREAM Industrial Doctorate Centre.

E.6 References

AECOM 2015. Spon's Civil Engineering and Highway Works Price. CRC Press, Abingdon, UK.

Aramaki, T., Galal, M. & Hanaki, K. 2006. Estimation of reduced and increasing health risks by installation of urban wastewater systems. Water Science and Technology. 53 (9). pp. 247–252.

Barker, S.F. 2014. Risk of norovirus gastroenteritis from consumption of vegetables irrigated with highly treated municipal wastewater-evaluation of methods to estimate sewage quality. Risk Analysis. 34 (5). pp. 803–817.

CfSL 2012. Breaking the tape: pre-Games review. Commission for a Sustainable London. London.

Chaudhry, R.M., Nelson, K.L. & Drewes, J.E. 2015. Mechanisms of pathogenic virus removal in a full-scale membrane bioreactor. Environmental Science and Technology. 49 (5). pp. 2815–2822.

Chen, Z., Ngo, H.H., Guo, W., Lim, R., Wang, X.C., O'Halloran, K., Listowski, A., Corby, N. & Miechel, C. 2014. A comprehensive framework for the assessment of new end uses in recycled water schemes. The Science of the total environment. 470–471. pp. 44–52.

Chen, Z., Ngo, H.H., Guo, W.S., Listowski, A., O'Halloran, K., Thompson, M. & Muthukaruppan, M. 2012. Multi-criteria analysis towards the new end use of recycled water for household laundry: A case study in Sydney. Science of the Total Environment. 438. pp. 59–65.

Derry, C., Attwater, R. & Booth, S. 2006. Rapid health-risk assessment of effluent irrigation on an Australian university campus. International Journal of Hygiene and Environmental Health. 209 (2). pp. 159–71.

DOEE 2013. Stormwater management rule and guidebook - Appendix A. Department of Energy and Environment. Washington D.C.

Dufour, A.P., Evans, O., Behymer, T.D. & Cantú, R. 2006. Water ingestion during swimming activities in a pool: A pilot study. Journal of Water and Health. 4 (4). pp. 425–430.

Epstein, D., Knight, H., Sykes, J. & Carris, J. 2011. The Olympic Park Water Strategy. Olympic Delivery Authority. London, UK.

Fewtrell, L. & Kay, D. 2007. Quantitative microbial risk assessment with respect to Campylobacter spp. in toilets flushed with harvested rainwater. Water and Environment Journal. 21 (4). pp. 275–280.

Fisher-Jeffes, Ll.N. 2015. The viability of rainwater and stormwater harvesting in the residential areas of the Liesbeek River Catchment, Cape Town. University of Cape Town.

Fritzmann, C., Löwenberg, J., Wintgens, T. & Melin, T. 2007. State-of-the-art of reverse osmosis desalination. Desalination. 216 (1–3). pp. 1–76.

GLL 2015. London Aquatics Centre. Greenwich Leisure Limited. London, UK.

Hamilton, K.A. & Haas, C.N. 2016. Critical review of mathematical approaches for quantitative microbial risk assessment (QMRA) of Legionella in engineered water systems: research gaps and a new framework. Environ. Sci.: Water Res. Technol. 2. pp. 599–613.

Harder, R., Heimersson, S., Svanström, M. & Peters, G.M. 2014. Including Pathogen Risk in Life Cycle Assessment of Wastewater Management. 1. Quantitative Comparison of Pathogen Risk to Other Impacts on Human Health. Environmental science & technology. 48. pp. 9438–9445.

Hernández, F., Urkiaga, A., Fuentes, L. De, Bis, B. & Chiru, E. 2006. Feasibility studies for water reuse projects : an economical approach. Desalination. 187. pp. 253–261.

Hills, S. 2013. Applying a Water Safety Plan Approach for Reclaimed Water Use at the 2012 Olympic Park in London. In: IWA Reuse Conference Namibia. 2013.

Hills, S. & James, C. 2015. The Queen Elizabeth Olympic Park Water Recycling System, London. In: F. A. Memon & S. Ward (eds.). Alternative Water Supply Systems. IWA Publishing, London, pp. 309–328.

HM Treasury 2011. The Green Book: Appraisal and Evaluation in Central Government. London, UK.

Institute for Sustainable Futures 2013. Matching Treatment to Risk: Building Industry Capacity to make Recycled Water Investment Decisions. Institute of Sustainable Futures, Univeristy of Technology for the Australian Water Recycling Centre of Excellence. Sydney.

Jjemba, P.K., Johnson, W., Bukhari, Z. & LeChevallier, M.W. 2015. Occurrence and Control of Legionella in Recycled Water Systems. Pathogens. 4 (3). pp. 470–502.

Khan, S. 2013. Drinking Water Through Recycling - The benefits and costs of supplying direct to the distribution system. Australian Academy of Technical Science and Engineering. Melbourne, Australia.

Knight, H., Maybank, R., Hannan, P., King, D. & Rigley, R. 2012. Lessons learned from the London 2012 Games Construction Project – The Old Ford Water Recycling Plant and Non-Potable Water Distribution Network. Olympic Delivery Authority. London.

Leverenz, H.L., Tchobanoglous, G. & Asano, T. 2011. Direct potable reuse: a future imperative. Journal of Water Reuse and Desalination. 1 (1). p. 2.

Liga, M. V., Bryant, E.L., Colvin, V.L. & Li, Q. 2011. Virus inactivation by silver doped titanium dioxide nanoparticles for drinking water treatment. Water Research. 45 (2). pp. 535–544.

Lindhe, A., Rosén, L., Norberg, T., Bergstedt, O. & Pettersson, T.J.R. 2011. Cost-effectiveness analysis of risk-reduction measures to reach water safety targets. Water research. 45 (1). pp. 241–53.

LLDC 2014. Local Plan Background Paper: Housing. London Legacy Development Corporation. London, UK.

Mattheiss, V. & Zayas, I. 2016. Deliverable D4.4 Social and environmental benefits of water reuse schemes – Economic considerations for two case studies. DEMOWARE.

Mok, H., Barker, S.F. & Hamilton, A.J. 2014. A probabilistic quantitative microbial risk assessment model of norovirus disease burden from wastewater irrigation of vegetables in Shepparton Australia. Water Research. 54. pp. 347–362.

NRMMC EPHC & AHMC 2006. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1). Biotext Pty Ltd (ed.). Natural Resource Ministerial Management Council, Environment Protection and Heritage Council and Australian Health Ministers, Canberra.

Olympic Delivery Authority 2012. Learning Legacy - Reducing the Aquatics Centre's water consumption. London, UK.

Page, D., Miotliński, K., Toze, S. & Barron, O. 2013. Human health risks of untreated groundwater third pipe supplies for non-potable domestic applications. Urban Water Journal. (April 2014). pp. 1–6.

Pankratz, T. 2015. Reverse Osmosis Desalination. In: Energy Optimized Desalination Technology Development Workshop. 2015, San Francisco. Available from https://energy.gov/eere/amo/downloads/energy-optimized-desalination-technology-development-workshop-november-5-6-2015.

Parker, J.M. & Wilby, R.L. 2013. Quantifying Household Water Demand: A Review of Theory and Practice in the UK. Water Resources Management. 27 (4). pp. 981–1011.

Pickering, P. 2013. Economic viability of recycled water schemes. Australian Centre for Water Recycling Excellence, Brisbane.

Purnell, S., Ebdon, J., Buck, A., Tupper, M. & Taylor, H. 2016. Removal of phages and viral pathogens in a full-scale MBR: Implications for wastewater reuse and potable water. Water Research. 100. pp. 20–27.

Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P.G., Drechsel, P., Bahri, A. & Minhas, P.S. 2010. The challenges of wastewater irrigation in developing countries. Agricultural Water Management. 97 (4). pp. 561–568.

QEOP 2016. Olympic Park - facts and figures. Available from: http://www.queenelizabetholympicpark.co.uk/media/facts-and-figures (Accessed: 1 July 2016).

Rutter, P. 2013. Old Ford Water Recycling Plant. In: CIWEM Conference 2013. 2013, Chartered Institute of Water and Environmental Management.

Sales-Ortells, H. & Medema, G. 2014. Screening-level microbial risk assessment of urban water locations: A tool for prioritization. Environmental Science and Technology. 48 (16). pp. 9780–9789.

Schets, F.M., Schijven, J.F. & de Roda Husman, A.M. 2011. Exposure assessment for swimmers in bathing waters and swimming pools. Water Research. 45 (7). pp. 2392–2400.

Simmons, F.J. & Xagoraraki, I. 2011. Release of infectious human enteric viruses by full-scale wastewater utilities. Water Research. 45 (12). pp. 3590–3598.

Sinclair, M., Roddick, F., Nguyen, T., O'Toole, J. & Leder, K. 2016. Measuring water ingestion from spray exposures. Water Research. 99. pp. 1–6.

Singh, R.P. 2013. Water Desalination ' The Role of RO and MSF '. IOSR Journal Of Environmental Science, Toxicology And Food Technology. 6 (2). pp. 61–65.

Storey, M. V., Ashbolt, N.J. & Stenström, T.A. 2004. Biofilms, thermophilic amoebae and Legionella pneumophila - A quantitative risk assessment for distributed water. Water Science and Technology. 50 (1). pp. 77–82.

Storey, M. V, Deere, D., Davison, A., Tam, T. & Lovell, A.J. 2007. Risk Management and Cross-Connection Detection of a Dual Reticulation System. In: eds. S.J. Khan,R.M. Stuetz, andJ.M. Anderson (ed.). 3rd Australian Water Association Water Reuse and Recycling Conference (REUSE07). 2007, UNSW Publishing and Printing Services, Sydney, pp. 115–123.

Tam, C.C. & O'Brien, S.J. 2016. Economic cost of campylobacter, norovirus and rotavirus disease in the United Kingdom. PLoS ONE. 11 (2). pp. 1–12.

Teunis, P.F.M., Rutjes, S. a., Westrell, T. & de Roda Husman, a. M. 2009. Characterization of drinking water treatment for virus risk assessment. Water Research. 43 (2). pp. 395–404.

Turner, A., Mukheibir, P., Mitchell, C., Chong, J., Retamal, M., Murta, J., Carrard, N. & Delaney, C. 2016. Recycled water – Lessons from Australia on dealing with risk and uncertainty. Water Practice and Technology. 11 (1). pp. 127–138.

Verrecht, B., James, C., Germain, E., Birks, R., Barugh, A., Pearce, P. & Judd, S. 2012. Economical Evaluation and Operating Experiences of a Small-Scale MBR for Nonpotable Reuse. Journal of Environmental Engineering. pp. 594–601.

Verrecht, B., Maere, T., Nopens, I., Brepols, C. & Judd, S. 2010. The cost of a large-scale hollow fibre MBR. Water Research. 44 (18). pp. 5274–5283.

West, C., Kenway, S., Hassall, M. & Yuan, Z. 2016. Why do residential recycled water schemes fail? A comprehensive review of risk factors and impact on objectives. Water Research. 102. pp. 271–281.

Westrell, T., Schönning, C., Stenström, T.A. & Ashbolt, N.J. 2004. QMRA (quantitative microbial risk assessment) and HACCP (hazard analysis and critical points) for management of pathogens in wastewater and sewage sludge treatment and reuse. Water Science and Technology. 50 (2). pp. 23–30.

WHO 2006. Guidelines for the Safe Use of Wastewater, Excreta and Greywater. World Health Organisation, Geneva.