A formal model concerning policy strategies for building public acceptance of water reuse

Kris Hartley[1], Asit Biswas[2], Cecilia Tortajada[3]

Abstract

Water stress is an increasing burden in regions with arid climates, aquifer vulnerability, and erratic rainfall. Population growth and competing domestic, industrial and agricultural uses are also stretching the capacity of water supply systems. Such threats are prompting governments to explore alternatives beyond usual sources like groundwater extraction, surface catchments, and inter-basin transfers. These alternatives include desalination, greywater recycling, and reclaimed or recycled wastewater. The latter, also known as water reuse with differing qualities, has been used for a variety of purposes including irrigation, street cleaning, industrial processes, and groundwater recharge. However, reused water for potable purposes has been limited, due in part to lack of public acceptance. This article examines the dynamics of public acceptance for water reuse. A formal mathematical model is introduced to conceptualize how water utilities and the public interact to facilitate or hinder acceptance of systems to reuse water for potable purposes. The article's theoretical contribution is a systematic and broadly applicable framework for understanding public acceptance of alternative water source technologies.

Keywords: wastewater reuse; environmental policy; sustainability

1. Introduction

Scarcity of access to safe and affordable potable water threatens human health and economic development, particularly in developing countries. An estimated 780 million people around the world lack such access, 2.5 billion lack access to adequate sanitation, and millions are afflicted with preventable waterborne diseases (CDC, 2016). With challenges such as erratic weather and competition over scarce supply further exacerbating the problem, governments must mediate economic development needs with limitations to institutional, managerial, and fiscal capacity. Moreover, water challenges are not isolated to developing countries. While most developed countries have built systems to support high standards of water quality and supply reliability, maintaining this standard is increasingly costly and fraught with risk given the uncertainty of climate-change impacts and the resistance of water consumers to change their behavior.

[1] The Education University of Hong Kong, Department of Asian and Policy Studies
[2] National University of Singapore, Lee Kuan Yew School of Public Policy
[3] National University of Singapore, Institute of Water Policy

Water reuse has been used to address water scarcity, with measurable results. By providing an additional source and enhancing supply redundancy and stability, it has the potential to help improve public health outcomes and reduce the negative environmental impacts of over-extraction from natural sources (e.g. aquifers and rivers). While various forms of reuse technology have existed for decades, advancements in the science of purification have reduced both the complications and costs of treatment. Water reuse is thus a potential source of clean, safe, and reliable water for residential, industrial, and agricultural purposes.

Despite these benefits, there remain social and political barriers to adopting reuse systems for potable use, including significant image problems borne of concerns about health and environmental risks, and even social propriety and stigma. This article introduces a formal mathematical model to theoretically illustrate policy strategies to build public acceptance of water reuse for potable use, with particular reference to the role of information and communication. To understand how public acceptance has been conceptually treated in the academic literature, the article first provides a brief review of literature addressing the cognitive dynamics of public acceptance and their relationship to knowledge dissemination. The article then introduces a model that conceptualizes the relationship between government and the public, and how this relationship influences acceptance and adoption of reuse. In the conclusion, the findings of the model are applied to policy recommendations concerning information and communication for increasing public acceptance. The conclusion also issues a call for further research about the mechanisms through which public perceptions of water reuse are shaped.

2. Literature review

This review focuses on findings about government-circulated information and the relationship between the public and governments and water utilities. The cognitive and contextual determinants of public acceptance of and opposition to water reuse have already been robustly explored and are outside the scope of this review. The current state of the literature is summarized usefully by Fielding et al. (2018) in a review that finds, among other things, a consistently positive relationship between acceptance and dissemination of information (e.g. about recycling processes, safety, and benefits). The authors observe this pattern across methodologies, including studies based on case analysis and experiments. Structural equation modeling (SEM) has also been employed to examine such relationships, producing findings that are relevant to the analysis in this article. For example, Hurlimann et al. (2008) find communication by and public trust in water utilities to be a positive determinant of consumer satisfaction with water reuse programs, while Ross et al. (2014) determine that a community's shared identity with water utilities regarding recycled water schemes was dependent on consultative exchange and information-sharing, ultimately improving trust in a way that lowers perceptions of risk and raises acceptance levels. Trust in government was found to exert influence on attitudes, and thereby intended consumption behavior, in a structural equation model-based study of water reuse in Australia (Leviston et al. 2006). Trust (in both science and government) was likewise identified as a determinant of public acceptance of various water sources, including water reuse, stormwater, and desalination, in an Australian survey-based study (Fielding et al. 2015). There is less consensus about the role of information. De Franca Doria et al. (2005) find that external information is a relatively weak determinant of public acceptance, a finding later confirmed by Leviston et al. (2016). However, a South Africa-based study conducted by Adewumi et al. (2014) found that knowledge about the advantages of water reuse and trust in suppliers (utilities) predicted respondents' intention to accept water reuse for both domestic and non-domestic purposes, with knowledge having the highest path coefficient of all determinants among domestic-use respondents. By using SEM, studies such as those above have been able to identify the types of latent variables that are often difficult to measure in socio-political contexts. Their findings largely confirm those of studies using other methodologies.

Experimental research has also been valuable in identifying determinants of public acceptance, particularly with reference to information and communication. According to Fielding et al. (2018, p. 18), "experimental or field studies comparing informed and non-informed participants conclude that providing factual information about recycled water increases knowledge about, and acceptance of, recycled water." The authors argue that further experimental research is needed to identify causal relationships between knowledge and acceptance, and to understand varying dynamics across user group types. Examples of experiment-based research are numerous, but a comprehensive review is beyond the scope of this study (see Fielding et al. 2018 for additional summaries). Nevertheless, two studies are directly relevant to this article and deserve mention. In an experiment involving 1,000 Australian citizens, Dolnicar et al. (2010) found a positive association between information provision and likelihood of use for both desalinated and recycled water; the authors argue that factual information should be prioritized by governments over campaigns based on persuasion. This is of particular importance when considering the role of information and the competition over narratives between government and utilities on one hand and interest groups or water reuse skeptics on the other. In a survey-based study, Dolnicar and Schäfer (2006) found varying public perceptions about determinants of quality, health, and risk between desalinated and recycled water, with higher cognitive reservations about the safety of recycled water. The study is useful in identifying trends among dimensions of knowledge as measured by a series of science-related statements; statements about which respondents exhibited lower levels of understanding (e.g. those addressing environmental impacts, energy consumption, and contribution to systemic resilience) provide guidance about which topics public officials should consider when crafting a communications and knowledge-sharing strategy.

The importance of information and communication specifically is confirmed in numerous theoretical and empirical studies about public perception and the legitimacy of water reuse programs (see: Hui and Cain, 2018; Harris-Lovett et al. 2015; Fielding and Roiko 2014; Hartley 2006; Christen 2005). The focus on communication as a catalyst for public acceptance emerges from what Fielding et al. (2018) describe as the "information-deficit approach" (p. 17); the authors find that the literature on water reuse shows a broad consensus that knowledge and acceptance have a positive relationship. Nevertheless, Kemp et al. (2012) find that effective communication does not necessarily inoculate the public against the support-dampening effects of "scare" campaigns, with a strong recency effect observed for the process of influencing perceptions. Lack of knowledge about the sources of water, implying a weak communication effort, has been shown to negatively affect levels of acceptance of *de facto* water reuse (Rice et al. 2016). Examples of knowledge-sharing from the government-to-public perspective are numerous, but those from the opposite perspective (public-to-government) are scarcer. Beecher et al. (2005) employ risk communication theory in emphasizing the importance of two-way communication between the public and water authorities, recognizing that the public possesses useful knowledge regarding waste management in general; the authors argue, "Sharing control of the research process with diverse stakeholders can make research more focused, relevant, and widely understood" (p. 122). The importance of public-to-government communication for water reuse programs is likewise underscored in a study by Gibson and Burton (2014) of governments' information gathering approaches, stated-preference questions, and the influence of latent attitudes on interpreting both. Indeed, such two-way exchange of information is acknowledged in the literature as a means to build public trust of government institutions (Gil-Garcia et al. 2017; Hong 2013; Torres 2007; Hartley 2006).

A search for literature employing formal theoretical or mathematical modeling returned no studies that focused specifically on establishing a conceptual basis for understanding the relationship between public policy and public acceptance of water reuse. The literature gap filled by this article is the absence of such a theoretical model. The model in this article aims to generate a novel platform for more rigorous empirical studies by focusing on government actions to improve communication and knowledge dissemination, both of which have been shown by the literature to be crucial in building public trust and acceptance. Policy implications emerging from the model build on research by Tortajada and Nambiar (2019) about public communications strategies addressing both technological innovations and the governance dimensions of water reuse. According to the authors, "public communications through the media play a central role in the development of public policies and their acceptance by the population" (p. 25). The model is introduced in the following section, which describes how equilibrium levels of acceptance can be manipulated through changes in variables such as investment, communication, and credibility. In particular, the model provides guidance on the degree to which policymakers' efforts to influence public mindset can raise acceptance of water reuse. The conclusion translates these theoretical propositions into actionable policy options.

3. A model for water supply source acceptance

3.1. Background and conceptual framing

The model introduced in this section is based on the following assumptions. In a given water management setting, societal or public benefit results from investment by water utility companies or agencies (hereafter "WU") in the water supply portfolio and the sustainability of that portfolio. This model conceptualizes the behavior of WUs rather than that of "government," as the latter is multidimensional and often internally contradictory regarding policies. WUs are assumed to be increasingly interested in water reuse due to its reliability and lower cost relative to other source options, including water transfers and desalination. This assumption is based on observed trends; regulatory standards regarding the quality of discharged treated wastewater are increasingly stringent, including in the United States (Sanchez-Flores et al. 2016) and other industrialized countries (Morris et al. 2017). To remain compliant, utilities must invest more resources to treat wastewater for discharge, but this burden is compelling some to treat up to reusable standard to by-pass the discharge process altogether. In the long-run, this strategy is potentially more financially sustainable than adjusting to constantly mutable regulatory targets.

An increasing number of WUs are pushing for water reuse not only because it provides a reliable source of clean water, but also because it saves money in the long-run and because WUs understand the supporting science. Elected governments (as democratically beholden to public sentiment) may be often less supportive of water reuse due to lack of sufficient understanding of the risks and the tendency to submit to the stigmatization effect. Thus, there is a tension internal to WUs regarding the mediation of public and agency interests. On one hand, the monopoly supply status of WUs gives them more freedom to pursue desired water reuse options; the public, as customers, can turn to no alternative supplier. Additionally, WUs are not directly democratically accountable to the public because, like many administrative agencies, their officials and employees are rarely elected. On the other hand, WUs are concerned about the direct and indirect impacts of public acceptance because political sentiment impacts the behavior of elected governments and by extension influences resource allocation decisions. water reuse projects can be stalled due to opposition from the public and government authorities, and WUs know that they will not be able to distribute recycled water if the public does not accept it. This underscores the importance of communication and awareness campaigns (for cases from Singapore, Australia, and the United States, see Tortajada and Nambiar 2019).

The public is assumed to be better off if water is supplied safely, reliably, and efficiently, and without compromising future ability to do so. This benefit can be modeled as a function of the behavior of two actors – the public (with interests expressed by government positions and public policy) and WUs – for a given water supply method (WS; examples being water reuse, groundwater extraction, rainfall capture, desalination, and other methods as they may arise). The public exhibits a given level of support for a WS among multiple supply options, and WUs exhibit a given level of support through their role as water suppliers and implementers of policy. Support by the public and WUs, in some combination, is assumed to lead to an optimal supply portfolio balance and thereby to enhanced public benefit. A given WS can enhance benefit by providing redundant or contingent capacity, reducing pressure on other water supply sources, and in the case of water reuse, strengthening supply security by closing the supply loop. According to the same logic, lack of support from either actor could compromise development of a given WS and thereby decrease benefit.

The model presented in this section, including equations and graphs, is an adaptation of a similar model introduced by Vu (2009) to conceptualize foreign aid and development management. This model examines support for a given WS as negotiated between the public and WUs. It is parameterized through variables shown by the literature to impact water reuse development, including public acceptance, investment, and the cost of WS project failure. To existing studies, the model adds a theoretical basis for how government can encourage public acceptance of a given WS, including water reuse.

3.2 Model details

Assume that the function takes the following form (Eq. 1):

$$U = M * \frac{R^{\alpha}}{(C_L / C_H)^{\pi}} + (1 - M) * \lambda * \frac{I^{\beta}}{(1 + F)} \tag{1}$$

Where:

- *M* is a dummy variable for the success of a given WS project: $M = 1$ if the project is successful; $M = 0$ if the project is a failure. For modeling simplicity, it is assumed that a given WS cannot be a partial failure or partial success.
- C_L and C_H ($0 < C_L, C_H \leq 1$) are, respectively, the low and high levels of public support for a given WS. Both variables are operationalized as resources to mobilize advocacy and generate evidence of public sentiment that informs government policy and by extension the efforts of WUs. If support is low ($C = C_L$), there is assumed to be relatively weak political pressure for implementation of a given WS. If support is high ($C = C_H$), there is assumed to be relatively strong political pressure for implementation.
- π ($\pi \geq 1$) is the mechanism by which public sentiment impacts the importance assigned to a given WS by a WU. The variable can be seen as a proxy for the responsiveness of WUs to public sentiment (see the literature on democratizing public administration, including Denhardt and Denhardt's (2015) *new public service* and Frederickson's (1980) *new public administration*). The variable's placement as an exponent to a fractional term implies that its numerical value and the strength of its influence are positively related.
- R ($0 \leq R \leq 1$) is the importance level given by a WU to a given WS.
- λ ($\lambda \geq 1$) is the benefit of WS project failure. This variable is present only if the public shows low support for a WS.

- I ($I \geq 0$) is the amount of investment in a given WS by a WU.
- F ($F > 0$) is the credibility loss of a WS failure that accrues to a WU, particularly with reference to the sentiments of supportive citizens, interest groups, and the global knowledge community.
- α ($\alpha \geq 1$) and β ($\beta \geq 1$) are terms that respectively capture the nonlinear relationship between R and U, and I and U. U is increasing $(\partial U / \partial X > 0)$ and has a concave function $(\partial^2 U / \partial^2 X < 0)$ on X, where $X \in \{R, I\}$.

While the outcome variable of the model represents overall public benefit, the public can be disaggregated to subgroups whose perception of a WS sorts them into three types: progressive (type I), indifferent (type II), and regressive (type III). A group is said to be progressive if it accepts a given WS, indifferent if it exhibits no acceptance, and regressive if it opposes a given WS. The benefit function of the group, depending on its type, can take the following form:

- If the subgroup is progressive, $U = M$; the group is happy if a WS is successful and unhappy otherwise.
- If the subgroup is indifferent, $U = 1$; the group's benefit is unchanged regardless of whether a WS is successful.
- If the subgroup is regressive, $U = 1 - M$; the group is happy if a WS is not successful and unhappy otherwise.

Given the function in Eq. (1), the public, as a rational decision maker, accepts a WS only if:

$$U \,|_{C=C_H} > U \,|_{C=C_L} \tag{2}$$

Note that

$$U \,|_{C=C_H} = \frac{R^\alpha}{(C_L / C_H)^\pi} \quad \text{and} \quad U \,|_{C=C_L} = \frac{\lambda I^\beta}{(1+F)}$$

The condition (Eq. 2) is equivalent to:

$$\Leftrightarrow \frac{R^{\alpha}}{(C_L / C_H)^{\pi}} > \frac{\lambda I^{\beta}}{(1+F)}$$

$$\Leftrightarrow R > R_C \quad \text{, where } R_C \equiv \left[\frac{\lambda}{(1+F)} (C_L / C_H)^{\pi} \right]^{1/\alpha} * I^{\beta/\alpha} \qquad (3)$$

For simplicity, it is assumed that $\alpha = \beta$, therefore Eq. (3) can be rewritten as:

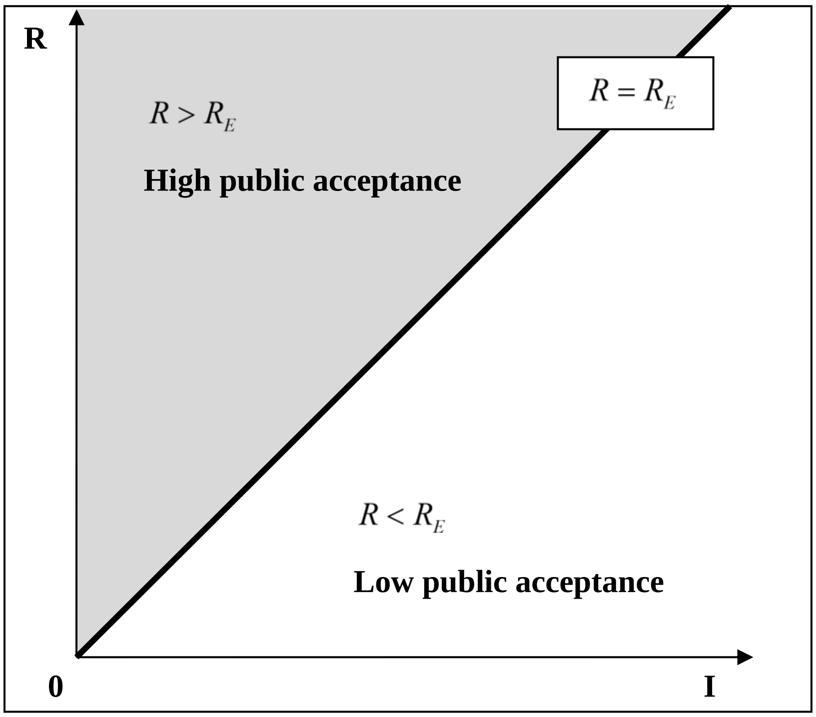
$$R_C \equiv \left[\frac{\lambda}{(1+F)} (C_L / C_H)^{\pi} \right]^{1/\alpha} * I \qquad (4)$$

or

$$R_C \equiv k * I \text{ ; where } k = \left[\frac{\lambda}{(1+F)} (C_L / C_H)^{\pi} \right]^{1/\alpha} \qquad (5)$$

As a summary of Equations (2), (3) and (5), benefit is increased when $R > R_C$ and weakened when $R < R_C$. The relationship between a WS investment (*I*) and that WS's importance level (*R*) is graphically depicted with *I* on the horizontal axis and *R* on the vertical axis (Figure 1). Line $R = R_E$ divides the space into two areas. In the upper area, the WS importance level is relatively high ($R > R_E$), a result of a high level of public acceptance. In the lower area ($R < R_E$), WS importance level is relatively low, a result of a low level of public acceptance.

Figure 1: Importance level and government investment for a given WS



3.3. Public acceptance at equilibrium

Assume *R** denotes the importance level of a WS, and assume that the public's demand function is defined as:

$$R = R^*$$

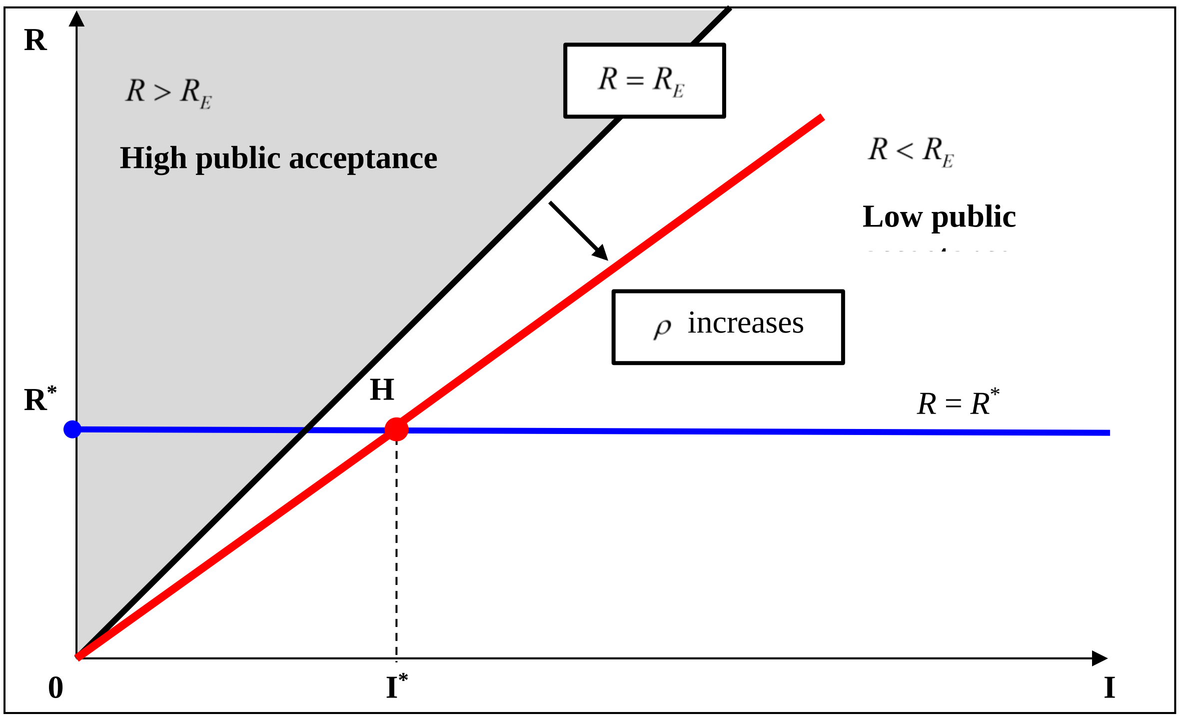
At a WS importance level *R**, the public's demand for the WS ranges between 0 and $+\infty$, with WS investment decided by the WU. In Figure 2, the public demand curve is a horizontal line crossing the vertical axis at *R**. Regarding the supply curve, assume that a WS investment amount takes the following functional form:

$$I = \rho R, \qquad (\rho > 0) \tag{6}$$

The coefficient ρ and its magnitude are determined by the WU's interest in a given WS (resulting from government and public pressure, scientific evidence, etc.) and by the peripherals of the case context (whether observable or otherwise). For a given value of *I*, the larger the coefficient ρ, the larger the WS importance level *R*.

Equation (5) can be transformed to $R = \frac{1}{\rho} I$, indicating that the public demand curve rotates clockwise (becomes flatter) as ρ increases, and rotates counter-clockwise (becomes steeper) as ρ is reduced. The public demand curve $R = R^*$ and the WS supply curve $I = \rho R$ cross at equilibrium point *H*, where $I = I^* = \rho R^*$ (Figure 2). Point *H* can be in the lower area (low-acceptance) as shown in Figure 2, or in the upper area (high-acceptance), depending on the relative values of ρ, *I**, and *R**.

Figure 2: Public demand at equilibrium



4. Policy insights

4.1. Changing the equation

In Figure 2, the equilibrium point *H* falls in the low-acceptance range (below line $R = R_E$) when the WS investment remains at *I**. Due to low public acceptance, investment in a WS is low and benefit is limited. This is illustrated through the following expressions:

$$R^* < R_E |_{I=I^*}$$

$$\Leftrightarrow \frac{1}{\rho} I^* < \left[\frac{\lambda}{(1+F)} (C_L / C_H)^{\pi} \right]^{1/\alpha} I^*$$

$$\Leftrightarrow (C_L / C_H)^{\pi} > \frac{1}{\lambda} . \frac{(1+F)}{\rho^{\alpha}} \tag{7}$$

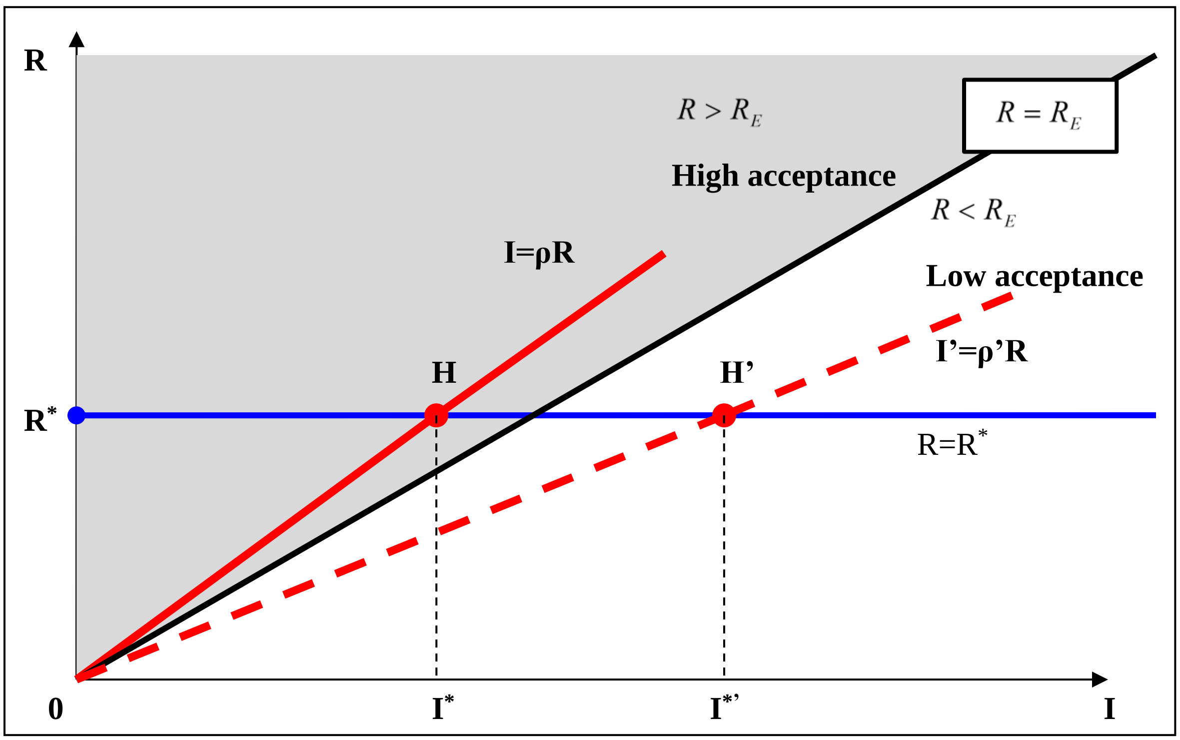
Inequality (7) illustrates that factors determining a WS's importance level include level of public support C_L / C_H, the costs F of WS failure, and the coefficient ρ. The assumed implication is that low support for a given alternative WS is an equilibrium choice made by the public based on comfort with the *status-quo* of a given water supply mix. Further, this choice is reinforced if there are changes that increase the left-hand side or decrease the right-hand side of the inequality. Changes that reinforce the equilibrium level of low support can be illustrated through two scenarios. First, the left-hand side of the inequality is increased, with $(C_L / C_H)^{\pi}$ becoming higher; that is, reasons for the public to oppose a WS are higher than those to support another one, or the justification for public opposition is more convincing than that for support. One example is a case in which risk concerns, and commercial or ideological interest groups opposing a WS stoke public antipathy through information campaigns and press engagement. This can be done by leveraging a focusing event such as the failure of a WS project or a cautionary example of a WS project that experienced budgetary over-runs. The value of the left-hand side of the inequality can also be altered through π, the exponential lever by which public sentiment impacts the importance assigned to a given WS by a WU. When democratic mechanisms allow public sentiment to influence WU investment behavior, an anti-support frame ($C_L > C_H$) increases the value of the left-hand side of the inequality while a pro-support frame ($C_L < C_H$) decreases it.

In the second scenario, the right-hand side of the inequality is decreased, which can occur for three reasons. The first is an increase in λ, the benefit of a WS project failure. This could result from the public's aforementioned comfort with the *status-quo*. Second, the credibility loss of WS failure F decreases. This could occur in situations where the given WU undertakes a WS project with weak technical, management, or local political accountability (e.g. in response to standards imposed by a national-level environmental agency) or the given WU sub-contracts a WS project to a private entity. In effect, this decouples WU image from project outcomes. Finally, the right-hand side of the inequality is decreased when the coefficient ρ in WS supply Equation (6) increases. This could result from the WU's heightened interest in a given WS, as motivated by regulatory inducements, political pressure, or scientific evidence.

4.2. Credibility pitfalls of increased investment

Assuming the importance level R^* remains the same, an increase in WU resources committed to a given WS rotates the WS supply curve clockwise, from $I=\rho R$ to $I=\rho' R$ ($\rho'<\rho$) (Table 3). The WS supply curve passes $R=R_E$ and the equilibrium point H moves from the high-acceptance area ($R > R_E$) to the low-acceptance area ($R < R_E$) (both areas remaining stationary relative to one another). In practical terms, committing additional resources to a project whose relative importance has not proportionally increased may erode public support, as illustrated by the movement of equilibrium towards point H'. The policy implication is that additional funds appropriated to a WS must be justified by accompanying communications and information dissemination strategies regarding evidence that the given WS improve public outcomes (e.g. increase in benefit).

Figure 3: Consequences of additional investment in WS

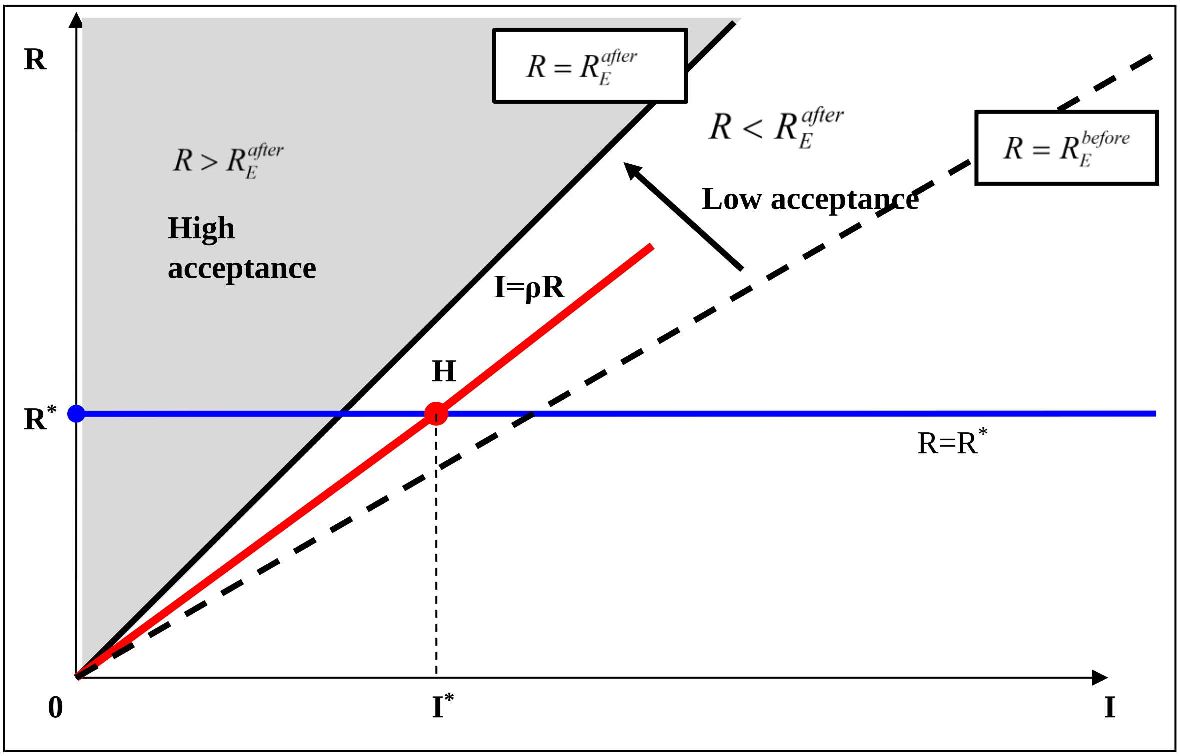


4.3. Feasibility and legitimacy of WS

Given that adopting WS methods such as water reuse and desalination often involve significant capital outlays, it is crucial to strengthen fiscal feasibility and legitimacy by building public support. However, a government may choose to maintain a WS investment despite deterioration of public support. This scenario would cause a rise in coefficient $k = \left[\frac{\lambda}{(1+F)}(C_L/C_H)^{\pi}\right]^{1/\alpha}$ in

Equation (5). For example, increasing public support only for the existing water supply portfolio increases λ, while a decline in accountability for a given WS reduces the credibility loss for the WU of failure F, and deteriorating feasibility or legitimacy of that WS raises the relative public opposition level C_L / C_H. As these dynamics increase coefficient *k*, curve $R = R_E$ rotates counterclockwise, shrinking the area of high public acceptance and enlarging the area of low public acceptance (Figure 4). As a result, the equilibrium point *H* defaults into the low-acceptance area without a corresponding shift in the supply curve. This resulting shift of public support from high to low decreases the benefit associated with the success of a given WS.

Figure 4: Consequences of continued investment amidst lower public support



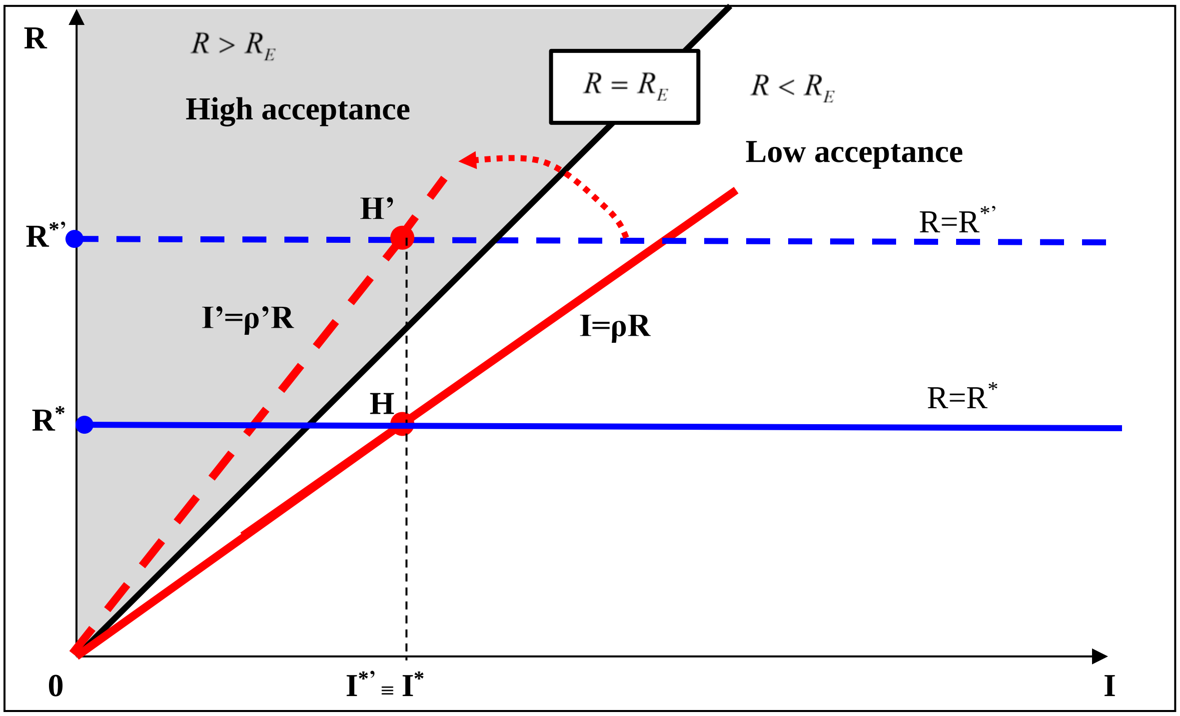
4.4. Influencing public acceptance

Assuming that the government is interested in the success of a WS, the model indicates that the public's acceptance level can be shifted from low to high. To realize this outcome, the government must consider strategic approaches that ensure that the area encompassing equilibrium *H* shifts from low- to high-acceptance.

In this scenario, the government maintains the existing investment level ($A^{*\prime} = \rho' M^{*\prime} = A^* = \rho M^*$) while raising the WS project's importance R^* to $R^{*\prime}$ ($R^* > R^{*\prime}$). This forces the supply curve to shift counter-clockwise, moving the public's equilibrium choice from *H* (area of low-acceptance) to *H'* (area of high-acceptance) (Figure 5). This shift requires the government to understand and communicate how the WS project improves outcomes, for example through systemic reliability, efficiency, and sustainability.

Figure 5: Consequences of changing importance level

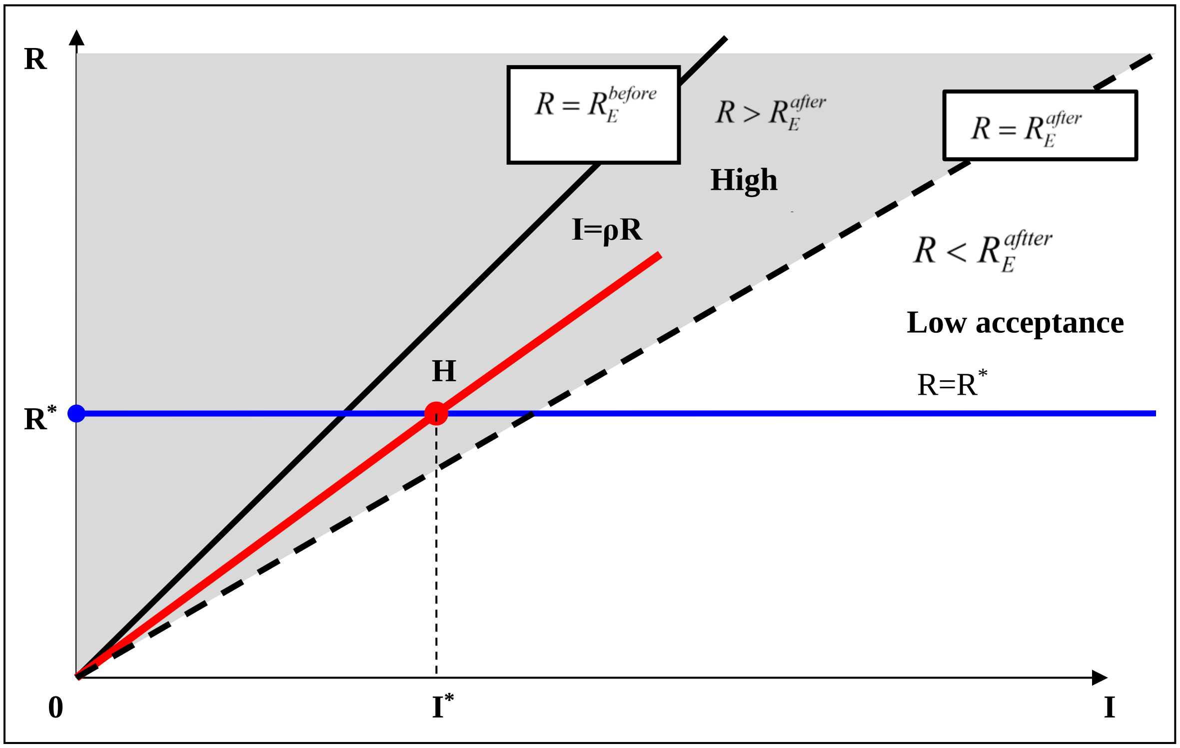
Government raises WS importance level while maintaining investment level



Promoting a change in public mindset alters factors underlying Inequality (7) and can shift equilibrium acceptance from the low- to the high-level. In this approach, the government does not change the level of investment in the WS but instead focuses on factors that reduce the left-hand side and increase the right-hand side of Inequality (7). The purpose is to rotate curve $R = R_E$ clockwise to enlarge the public's high-acceptance area such that it encompasses equilibrium point *H* (Figure 6). This approach requires a general mindset that is more receptive to the given WS, something that could be fostered mutually by government and the public.

The following are strategies the government can employ towards this end. First, the government can increase the relative public acceptance level C_L / C_H. This requires the government to take a direct role in communications and the circulation of scientific evidence about the effectiveness and benefit of the WS. Regarding variable π, which is treated in the model as an exponential variable and the mechanism by which public sentiment impacts the importance level of a given WS, the government can also strengthen public sentiment monitoring mechanisms and reform institutions to magnify the influence of public sentiment on WU policy; this potentially includes the adoption of more direct feedback mechanisms between the public and WUs. Second, the WU can lower the benefit of the failure of WS λ through similar means, by circulating evidence about the lack of reliability, effectiveness, and sustainability of an overall water supply portfolio that excludes that WS specifically and capacity redundancies and source diversity more generally. Finally, the WU can raise the disbenefit F associated with WS project failure by forecasting the costs and broader strategic setbacks of failure and by committing to robust monitoring and evaluation of WS project performance based on benchmark cases.

Figure 6: Consequences of promoting changes in public mindset



5. Policy implications and conclusion

In an era of increasing global water stress, governments are exploring new options for water supply. The improvement of purification technologies has reduced the cost and increased the reliability of wastewater treatment, generating new opportunities to introduce water reuse into existing supply portfolios. However, public acceptance of water reuse has hindered wider adoption of these technologies and remains a substantial hobgoblin for policymakers and WUs. The academic literature has examined this phenomenon through a variety of case studies and empirical research. To the scholarly discourse, this article contributes a formal mathematical model that conceptualizes the relationship between government and the public in regard to water reuse investment and public acceptance. The model provides theoretical support for policy initiatives to cultivate support for water reuse.

The model indicates that public support for a given (new) WS settles at an equilibrium level of support that can be considered relatively low. This can be explained in a variety of ways, including the general public's aversion to new water supply and purification methods and a preference for stability and predictability in the pricing and reliability of a crucial good. Entrenched interests, such as private firms or administrative units involved in operating the supply mix as it currently exists, may have something to lose if the supply *status-quo* is disrupted; thus, information campaigns focusing on high risk and cost have been deployed to threaten the political feasibility of new WSs (as conceptually illustrated in Inequality (7) above). Thus, the model in this article provides a theoretical illustration of the importance of communication strategies in building public acceptance of WS, as illustrated in Figure 6. By circulating information to the public, the government can demystify WS processes that the public may originally find difficult to understand or trust. The model also illustrates another potential point of emphasis for communication: the importance of a diversified supply portfolio with redundancies, and the role of a given WS within it. The model indicates that this can be achieved by deploying either a benefit- or risk-focused narrative. Establishing monitoring systems also ensures the supply of reliable data by which WS projects can be evaluated, thus focusing debates on fact rather than assumption and thereby strengthening the quality of communication between the public and WUs.

Communications are especially crucial in the early stages of WS adoption. Regarding water reuse in particular, an increasingly popular option for water supply, Tortajada and Nambiar state, "Water utilities' timely information on potable reused water to the media and the population are likely to improve communication and understanding of the messages provided" (p. 22). Thus, information "priming" provides the public with the understanding to interpret messages about supply safety. There are numerous strategies for such information priming, including engagement and education outreach programs, framing of public relations and media narratives around the science of water reuse and its contribution to sustainability and self-sufficiency, the fiscal and operational benefits of water reuse technologies, and the emphasis on end-product aspects of water as clean and reliable. Singapore's NEWater provides a useful case to explore how such information campaigns can build public support for water reuse (Joo and Heng 2017; Mainali et al. 2012; Tortajada and Pobre 2011; Guan and Toh 2011). As indicated by this article's model, WUs must consider communications as an *ex-ante* strategy to build legitimacy for a WS. In the event of WS failure risk, this strategy lowers the failure benefit and increases the potential credibility loss for the WU, compelling the WU to commit sufficient resources to ensure WS success.

While the adoption of new WS projects can involve technical, financial, and managerial challenges, the model in this article illustrates the importance of public acceptance as a determinant of WS success and the crucial role of communication in shaping a debate environment informed by facts rather than emotion. WS is a process improved over time by improved management and planning as well as refinement of technology. Ostensibly, it could be assumed that technology is a trustworthy alternative, particularly with respect to health and environmental factors. Such a narrative would hold that the more sophisticated a technology is, the cleaner the water will be and the fewer health risks there would be. WUs often argue that technology has developed to such a point that the health and environmental risks of water reuse are minimal. Nevertheless, it is clear from the literature that, in many cases, water reuse continues to be stigmatized by the public perception that recycled wastewater should not be used for potable purposes. This article advances the discussion of how governments can overcome this challenge.

Rapidly evolving developments in water supply technology, along with increasing supply urgency, mandate further research on several fronts. First, there is a need for better understanding about methods to improve the reach and effectiveness of public engagement efforts for water reuse. More specifically, further studies should examine the extent to which indirect contact with water reuse raises comfort levels and encourages individuals to embrace direct contact with water reuse. Second, further research should identify proven strategies for improving institutional trust among constituents and levels of government, as this is a crucial factor in implementing successful public engagement efforts and minimizing conflicting policies. Such research might proceed by examining how public perceptions of recycled and desalinated water were originally formed, how transparency and accountability are built into water planning efforts, and how best practices can be incorporated to strengthen relationships between agencies and the public (e.g. how a given community responds to particular types of outreach). Finally, additional research should seek to better understand valid concerns and emotional responses to the framing of water reuse information, in order to identify types of messaging that overcome pathogen aversion.

References

Adewumi, J.R., Ilemobade, A.A. and Van Zyl, J.E., 2014. Factors predicting the intention to accept treated wastewater reuse for non-potable uses amongst domestic and non-domestic respondents. *Journal of the South African Institution of Civil Engineering*, 56(1), pp.11-19.

Beecher, N., Harrison, E., Goldstein, N., McDaniel, M., Field, P. and Susskind, L., 2005. Risk perception, risk communication, and stakeholder involvement for biosolids management and research. *Journal of Environmental Quality*, 34(1), pp.122-128.

CDC (Centers for Disease Control and Prevention) 2016. *Global WASH Fast Facts*. Atlanta, GA: Centers for Disease Control and Prevention. <https://www.cdc.gov/healthywater/global/wash_statistics.html> accessed 13 January, 2019.

Christen, K. (2005). Water reuse: Getting past the ‘yuck factor’. *Water Environment & Technology*, 17, 11–15.

de Franca Doria, M., Pidgeon, N. and Hunter, P., 2005. Perception of tap water risks and quality: a structural equation model approach. *Water Science and Technology*, 52(8), pp.143-149.

Denhardt, J.V. and Denhardt, R.B., 2015. *The new public service: Serving, not steering*. Routledge.

Dolnicar, S., Hurlimann, A. and Nghiem, L.D., 2010. The effect of information on public acceptance–the case of water from alternative sources. *Journal of Environmental Management*, 91(6), pp.1288-1293.

Dolnicar, S. and Schäfer, A.I., 2006. Public perception of desalinated versus recycled water in Australia. CD Proceedings of the AWWA Desalination Symposium 2006.

Fielding, K.S., Dolnicar, S. and Schultz, T., 2018. Public acceptance of recycled water. *International Journal of Water Resources Development*, pp.1-36.

Fielding, K.S., Gardner, J., Leviston, Z. and Price, J., 2015. Comparing public perceptions of alternative water sources for potable use: The case of rainwater, stormwater, desalinated water, and recycled water. *Water Resources Management*, 29(12), pp.4501-4518.

Fielding, K.S. and Roiko, A.H., 2014. Providing information promotes greater public support for potable recycled water. *Water Research*, 61, pp.86-96.

Frederickson, H.G., 1980. *New public administration*. University, Ala.: University of Alabama Press.

Gibson, F.L. and Burton, M., 2014. Salt or sludge? Exploring preferences for potable water sources. *Environmental and Resource Economics*, 57(3), pp.453-476.

Gil-Garcia, J.R., Helbig, N. and Ojo, A., 2014. Being smart: Emerging technologies and innovation in the public sector. *Government Information Quarterly*, 31, pp.I1-I8.

Guan, Y.K. and Toh, S., 2011. From zero to hero: NEWater wins public confidence in Singapore. *Water Sensitive Cities*, p.139.

Harris-Lovett, S. R., 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.

Hartley, T. W. (2006). Public perception and participation in water reuse. *Desalination*, 187(1), 115–126.

Hills, S., Birks, R., & McKenzie, B. 2002. The Millennium Dome “Watercycle” experiment: To evaluate water efficiency and customer perception at a recycling scheme for 6 million visitors. *Water Science and Technology*, 46(6–7), 233–240.

Hong, H., 2013. Government websites and social media's influence on government-public relationships. *Public Relations Review*, 39(4), pp.346-356.

Hui, I. and Cain, B.E., 2018. Overcoming psychological resistance toward using recycled water in California. *Water and Environment Journal*, 32(1), pp.17-25.

Hurlimann, A., Hemphill, E., McKay, J. and Geursen, G., 2008. Establishing components of community satisfaction with recycled water use through a structural equation model. *Journal of Environmental Management*, 88(4), pp.1221-1232.

Joo, Y.M. and Heng, Y.K., 2017. Turning on the taps: Singapore’s new branding as a global hydrohub. *International Development Planning Review*, 39(2), pp.209-227.

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(4), 337–346.

Keremane, G.B., 2007. *Urban wastewater reuse for agriculture: governance paradigms and institutional arrangements in Australia and India* (Doctoral dissertation, University of South Australia).

Leviston, Z., Nancarrow, B.E., Tucker, D.I. and Porter, N.B., 2006. Predicting community behaviour: Indirect potable reuse of wastewater through Managed Aquifer Recharge. Land and Water Science Report, 2906(29), p.06.

Mainali, B., Ngo, H.H., Guo, W.S., Pham, T.T.N., Wang, X.C. and 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), pp.297-306.

Morris, L., Colombo, V., Hassell, K., Kellar, C., Leahy, P., Long, S.M., Myers, J.H. and Pettigrove, V., 2017. Municipal wastewater effluent licensing: A global perspective and recommendations for best practice. Science of The Total Environment, 580, pp.1327-1339.

Nancarrow et al. (2009). Measuring the predictors of communities' behavioural decisions for potable reuse of wastewater. *Water Science & Technology*, 60(12): 3199-3209.

Rice, J., Wutich, A., White, D.D. and Westerhoff, P., 2016. Comparing actual de facto wastewater reuse and its public acceptability: A three city case study. *Sustainable Cities and Society*, 27, pp.467-474.

Ross, V.L., Fielding, K.S. and Louis, W.R., 2014. Social trust, risk perceptions and public acceptance of recycled water: Testing a social-psychological model. *Journal of Environmental Management*, 137, pp.61-68.

Sanchez-Flores, R., Conner, A. and Kaiser, R.A., 2016. The regulatory framework of reclaimed wastewater for potable reuse in the United States. *International Journal of Water Resources Development*, 32(4), pp.536-558.

Torres, L.H., 2007. Citizen sourcing in the public interest. *Knowledge Management for Development Journal*, 3(1), pp.134-145.

Tortajada, C. and Nambiar, S., 2019. Communications on Technological Innovations: Potable Water Reuse. *Water*, 11(2), p.251.

Tortajada, C. and Pobre, K., 2011. The Singapore–Malaysia water relationship: an analysis of the media perspectives. *Hydrological Sciences Journal*, 56(4), pp.597-614.

Vu, K. 2009. "Enhancing the Effectiveness of Development Management with a Global Transparent Monitoring System," paper presented at the Development Studies Association (DSA) Annual Conference 2009, Belfast City, UK.