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Barriers to Innovation in Urban Wastewater Utilities: Attitudes of Managers in California

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Abstract In many regions of the world, urban water systems will need to transition into fundamentally different forms to address current stressors and meet impending challenges—faster innovation will need to be part of these transitions. To assess the innovation deficit in urban water organizations and to identify means for supporting innovation, we surveyed wastewater utility managers in California. Our results reveal insights about the attitudes towards innovation among decision makers, and how perceptions at the level of individual managers might create disincentives for experimentation. Although managers reported feeling relatively unhindered organizationally, they also spend less time on innovation than they feel they should. The most frequently reported barriers to innovation included cost and financing; risk and risk aversion; and regulatory compliance. Considering these results in the context of prior research on innovation systems, we conclude that collective action may be required to address underinvestment in innovation.

Keywords Innovation · Wastewater · Decision-making · Risk · Technology

Introduction

The municipal wastewater industry plays a crucial role for the sustainability and livability of cities. However, in spite of dramatic progress in the US wastewater sector's effectiveness and efficiency in protecting water quality over the past century (Stoddard et al. 2003), the sector will need to evolve to meet changing conditions in coming years. Growing populations, beleaguered ecosystems, climate change, land use change, urbanization, and changing regulatory requirements have pushed urban water systems to, or in many cases past, the limits of their capacity. This should not be surprising, given that the backbone of most modern urban water systems remains a collection of

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decades- or century-old technologies (Sedlak 2014). Satisfying the wide variety water supply, water quality, environmental protection, and other demands that are placed on these systems under changing conditions will require innovations in all aspects of the enterprise, the ultimate expression of which will be a complete reinvention at a system level (Luthy and Sedlak 2015). The development and diffusion of new technologies (Rogers 1962) will be necessary elements, but technical challenges are not the only bottlenecks to reinvention of urban water systems. Arguably, they may not even be the most important barriers—institutional factors are critical determinants of pathways to more sustainable water systems (Bakker and Cook 2011; Conca 2006; Kiparsky et al. 2013).

Innovation can be defined generally as the development, application, diffusion, and utilization of new knowledge (Carlsson and Stankiewicz 1991; Hekkert et al. 2007). Innovation always operates within broader social and technical contexts, and urban water systems are no exception. Notably, the institutions that influence decision-making by actors such as wastewater system managers play a crucial role in determining how innovation does and does not proceed. We define *institutions* as the rules, norms, and conventions that govern decision-making. Formal components, such as regulations and laws, fit within this definition, but it also acknowledges the many other factors that shape water systems, such as capabilities, cultural factors, and governance structures (Kiparsky et al. 2013; Scott 2001). Note that by our definition, institutions complement and influence *organizations*, collectively oriented groups that pursue goals linked to an external environment. Crucially, institutional factors can overwhelm analytical metrics such as physical performance or financial cost in actual decision-making, and stand in the way of the adoption and diffusion of technology.

Building on our previous conceptualization of the institutional challenges to innovation in the urban water sector (Kiparsky et al. 2013), this research further elaborates on the observation that there is an innovation deficit in urban water management (Thomas and Ford 2005; London Economics 2009; Potts 2009; Ajami et al. 2014). Specifically, the research asks how decision makers recognize the need for, and are able and willing to promote, innovative solutions. Wastewater utility managers are central to the future development of the water sector because they must develop, evaluate, and implement innovative solutions to prepare utilities for future challenges. By assessing how decision makers in wastewater utilities perceive opportunities for innovation, how they engage with innovative ideas, how they interpret institutional conditions for implementing their strategies, and whether and where they perceive these institutions as barriers for proactive engagement with innovations, this work provides insights into future actions and policy changes. To address these questions, we administered an online survey to high-level managers within wastewater and multi-service utilities in California. The goal of the survey was to characterize challenges for innovation in the wastewater sector, with a focus on individual decision makers and their attitudes towards innovation.

Background

Innovation (or its absence where standard methods are adopted) helps to determine how utilities will go about meeting their regulatory goals as well as their interests in providing service to customers at minimum costs. However, infrastructure systems such as water and sanitation are widely characterized as less innovative than other economic sectors (Markard 2011). A number of structural characteristics impede innovativeness in water and wastewater: asset durability, capital intensity, regulatory intensity, systemization, public organizations, competition intensity, and environmental impacts (Markard 2011). These characteristics impede innovation, resulting in slow, incremental change and path dependency.

Institutional factors can exacerbate these challenges in a variety of ways (Kiparsky et al. 2013). One crucial example is that much, although not all, of the urban water sector in the US resides in the public sector (see, e.g., Baumert and Bloodgood 2004). A number of differences have been noted in the challenges of innovation between the public and private sectors (Bekkers et al. 2011; Dominguez et al. 2009; Hartley 2005; Lieberherr and Truffer 2015; Potts and Kastelle 2010). Unlike in the private sector, where incentives arising from competition, profit motive, and focused decision-making motivate innovation, innovation in the public sector is challenged by the absence of such incentives, or even by counter-incentives to innovation (Tidd and Bessant 2013). Furthermore, the public sector is also fundamentally different because private sector incentives generally work to restrict sharing of innovation, and public sector innovations are usually public goods (Hartley 2005). Other barriers include short-term planning and budget horizons; scant innovation management skills; few incentives to innovate; organizational constraints; hesitance to close down failing programs; and administrative burdens (Albury 2005).

Finally, risk and risk aversion (Chavas 2004) among decision makers (Lach et al. 2005; O'Connor et al. 2005; Rayner et al. 2005) can significantly influence innovation and deserves to be highlighted as one of the key effects resulting from the incentive structures in place in public organizations generally, and in water and wastewater in

particular. In the public sector, decision makers typically face a set of incentives that encourage risk aversion. These incentives relate closely to disincentives for innovation. Probing the perceptions of risk (Dobbie and Brown 2014) and the incentives for risk aversion is a first step towards developing broader institutional change to speed the evolution of urban water services.

Based on these considerations, we formulated a survey to identify and assess capabilities of managers for innovation management as well as the perceived barriers to successfully implementing these innovations. From our earlier research, we derived a number of questions for managers around the following topics: future prospects for innovation; effort and investment in innovative activities; perceived barriers to innovation; and dynamic capabilities for fostering innovation.

Methods

To analyze potential institutional barriers and drivers of innovation in California's wastewater sector, we conducted an online survey of senior managers of utilities represented by the California Association of Sanitation Agencies (CASA), an industry group whose members service over 90 % of California's sewered population. Email invitations were followed by reminder emails and phone calls to increase response rate.

The survey sample was purposeful (Coyne 1997) targeting a specific, small population—those managers with primary authority for technology and management decisions in the municipal wastewater sector in California. Survey recipients were mostly General Managers, but in some cases Engineering Director or similar titles were also included on the invitation list. We received a response rate of 55 % (63/115), which is above typical response rates for internet surveys (Cook et al. 2000), and a relatively high rate for a survey of high-level decision makers.

The survey consisted of approximately 23 questions, depending on logic that eliminated redundant questions in some cases. Median survey response time was approximately 16 min. The survey addressed topics including services provided, experience with selected technologies and management practices, governance structure, size, budget, perceptions of innovation, and major challenges in technology adoption. We also used survey data to generate an "innovation index" (*Ii*) for each responding utility, detailed in Supplemental Material, as a data-driven, objective measure of the innovative activity exhibited by each utility.

Recognizing that "innovation" is a broad concept with many definitions (Osborne and Brown 2011), we included the following intentionally inclusive definition in all questions where the term was used in the question text itself: "*Innovation* involves the identification, development, and implementation of new products, processes, and ideas, including original approaches to technology and/or management." Note that the definition we used to communicate the concept within the survey was different than the operational definition for our research as stated in the "Introduction" section, above. The survey definition was consistent with our more general definition, but we developed this more concrete wording to be more readily understandable to the practitioners who comprised our target audience. Further, while the both general definitions used here include technical and administrative innovations, we acknowledge frameworks that usefully distinguish between the two (e.g., Damanpour 1991), and focused on technical innovation in some of our analysis.

In our survey, we used the word innovation only in questions bearing directly on our specific conception of innovation. In other questions, such as those focusing on technology adoption more generally, we did not reference the word innovation.

We report our results in two sections. The first addresses the notion of an innovation deficit in wastewater management both by querying technology adoption as a proxy for innovativeness, and by reflecting managers' perceptions of their own innovativeness. The second results section queries the reason for the innovation deficit, drawing on a framework including key variables such as cost and financing (asset durability, capital intensity, systemization); governance form (public organization); regulatory compliance (regulation intensity); and risk and risk aversion (systematization), motivated by frameworks presented in the innovation systems literature (Lieberherr and Truffer 2015; Markard 2011).

Results

Current State of Innovation Management Among California Wastewater Utilities

In a first set of survey questions, we examined the state of innovation-related capabilities, including involvement in different forms of innovative activities and effort spent for innovation. We also probed whether and which formal structures had been implemented to foster innovation.

Range of Technology and Management Practice

Respondents reported providing a range of services (Fig. 1), and managers reported various levels of

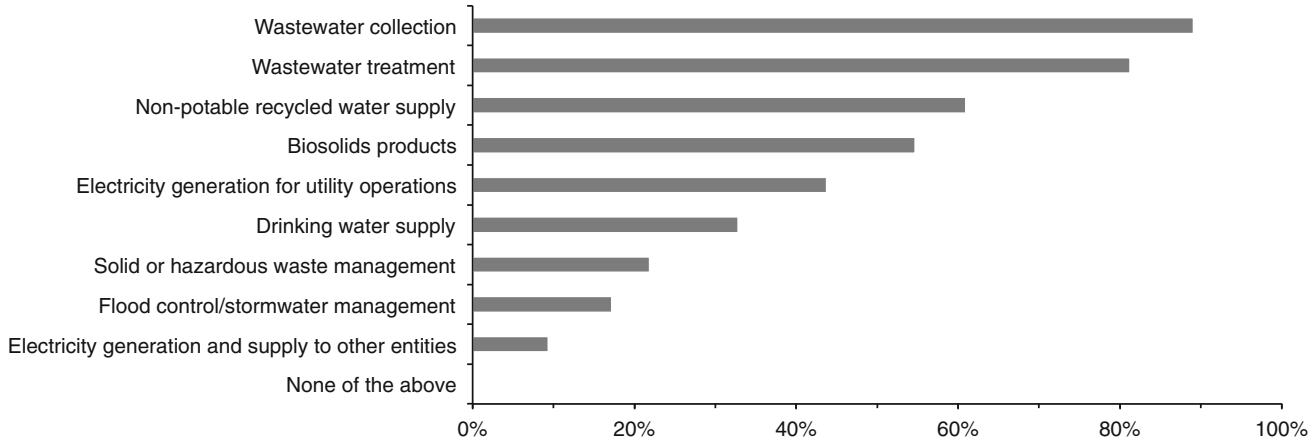

Fig. 1 Services provided by utilities responding to survey

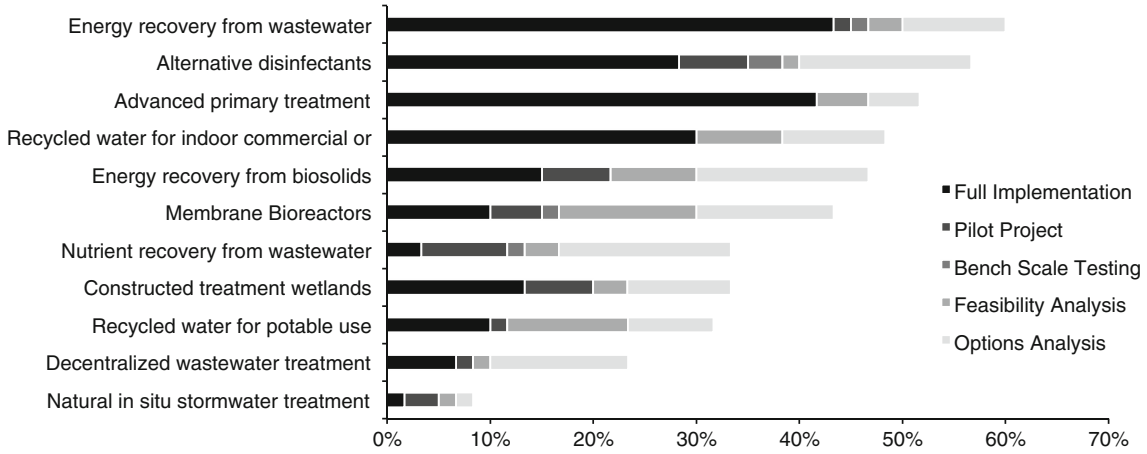

Fig. 2 Reported levels of technology implementation

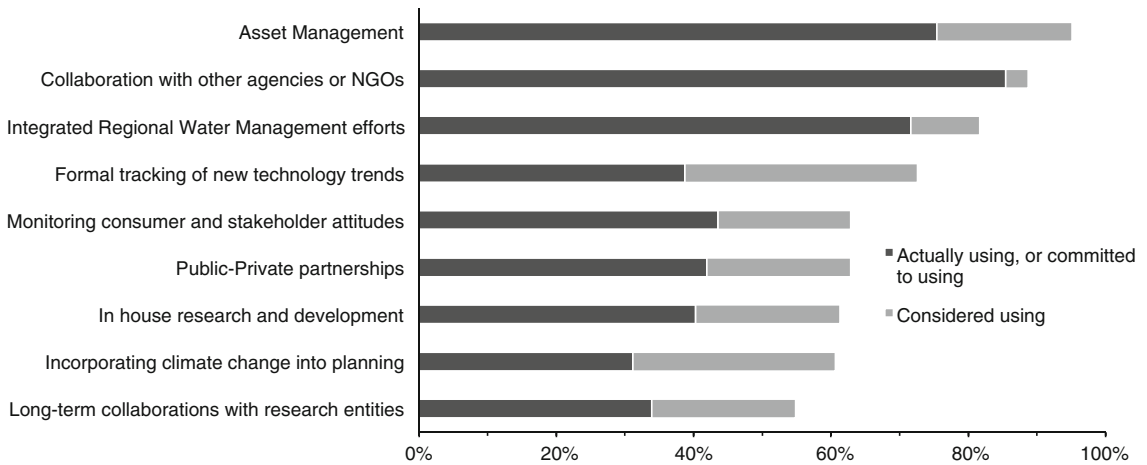

Fig. 3 Reported levels of experience with management practices

experience with a range of technologies and management practices (Figs. 2, 3). A transition within the industry to resource recovery is reflected in these data. Reported technology use among some utilities is consistent with actively approaching wastewater as a resource from which water, energy, and nutrients can be extracted (Grant et al.

2012; Water Environment Federation 2013). Many sanitation agencies report implementation of energy recovery, which could include a broad range of technologies, ranging from biogas capture to in-line micro-turbines. Also consistent with this theme, the degree of reported non-potable reuse of water was high. Reported implementation of recycled water for potable use is smaller, but consistent with the growing number of potable reuse projects in California.

Motivations for Innovation

Respondents expect that innovation will advance the ability of technology to meet water quality goals. While they expect innovation might lead to lower costs in the long run, they were less sanguine about the potential to see short-term cost reductions.

Managers generally expect that innovation will help the industry meet regulatory requirements for clean water, and do so at reasonable cost (Fig. 4). However, they tend to be more optimistic about prospects for innovation in the long term than in the short term. Almost all (93 %) agree or strongly agree that innovation will lead to better water quality in the long term, with the majority (58 %) strongly agreeing. Further, most (73 %) agree or strongly agree that innovation will lead to lower costs in the long term. While this is a strong majority, managers are more optimistic about technology's long-term ability to deliver on water quality than on lower costs. In the short run, respondents were less optimistic. Fewer respondents (67 %) agree or strongly agree that water quality improvements will result from innovation in the short term as compared to in the long term. A similar pattern can be seen for the prospect of short-term reductions in costs as compared to long term (33 vs. 73 % agree or strongly agree, respectively). We acknowledge that "short term" change is imprecise and is likely interpreted differently by each respondent. Regardless, it is natural that short-term prospects are likely more relevant to the bulk of the decisions made by a manager.

These data suggest that managers implicitly understand the importance of innovation for the wastewater sector, with potential for improving two of the most important technological parameters for their industry: system performance and cost. Note that reliability could be considered on par with these two elements in importance, as reflected by the discussion of risk and risk aversion below.

An Effort Deficit for Innovation?

Recognizing the importance of future innovations for their organizations, most managers think they should spend more time than they do on work related to innovation. The distribution of the responses related to the amount of working time respondents reported spending "investigating and implementing novel technology or management practices" compared to what they thought they should spend (Fig. 5) support the idea of an effort deficit. Most respondents (73 %) spend less than 20 % (mean 15 %) of their time on innovative projects, with a significant cluster reporting that less than 10 % of their time was spent on innovation. This is consistent with expectations, as innovation is a rare activity by definition. Nevertheless, it indicates relatively low effort on just the type of activity most needed to move the industry as a whole move forward.

As an absolute measure, there are obvious limitations in self-reported activity data. These include uncertainty in perception of time spent, ambiguity in what might be considered time spent, and value bias towards the term innovation that could manifest in either positive or negative direction. However, the important point revealed by the data in Fig. 5 is that managers believe they do not spend

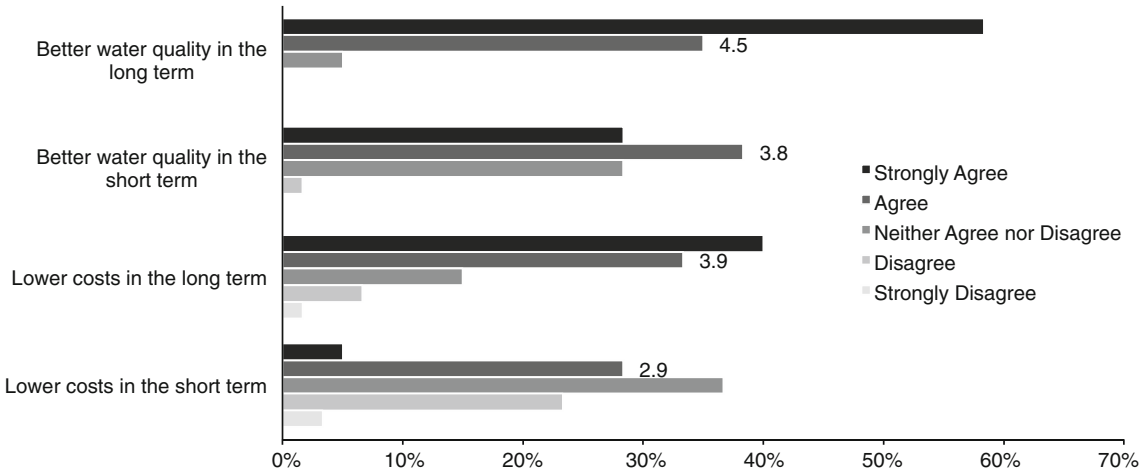

Fig. 4 Reported perceptions of the short- and long-term value of innovation (scale based on Tummers et al. 2012)

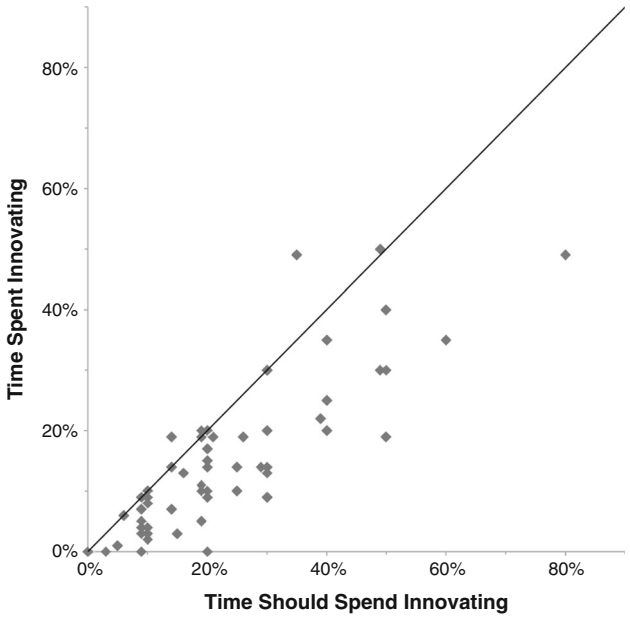

Fig. 5 Plot of reported time spent on innovation, versus amount of time respondent reports they *should* spend on activities related to innovation given the pressures facing their utility. The 1:1 line indicates answers where respondents report spending as much time as they think they should spend. *Survey Text*: How much of your own working time do you [believe you *should*] spend investigating and implementing novel technology or management practices (as opposed to managing existing processes and systems, or implementing industry standard technology) to meet the challenges your organization faces?

enough time on innovation. Seventy five percentage of respondents reported that the amount of time they should spend on innovative projects is less than the amount they do spend. Note that these data are consistent with the prospects for innovation discussed above (Fig. 4), which suggest that managers recognize the potential of innovation as well as its importance. If managers did not recognize the importance of innovation, they would not express the normative preferences implied by Fig. 5.

As discussed above, managers overwhelmingly indicate that innovations will lead to better water quality and lower costs in the long term (Fig. 4), but they do not see innovation as having as much short-term impact. Coupled with the need to attend to short-term pressures, this may explain the apparent disconnect in how managers spend their time on innovation.

Note that the survey questions were framed around individual organizations, not around the industry as a whole. Incentives for collective action are scant in this sector. This suggests respondents weighted the perceived importance of doing things differently for the future *for their own utility*. One might expect that posing these questions in a broader context would produce similar or even stronger patterns of this sort.

Innovation Management

Innovation management refers to a set of strategies and tactics aimed at capturing the benefits of innovation within an organization (Tidd and Bessant 2013). Innovation management is a subset of dynamic capabilities—organizational routines that enable organizations to create, evolve, and recombine resources ranging from physical assets to specific skills (Lieberherr and Truffer 2015). Dynamic capabilities can be used as core indicators of organizational innovativeness, in part because they can be related to the ability to innovate (Lieberherr and Truffer 2015).

One such dynamic capability relates to budgeting. Only 10 % of respondents indicated that their organizations have a policy related to research and development or new technology expenditures. This suggests that strategies to manage innovation are likely not explicitly in place at most utilities, a notion further supported by responses showing minorities of respondents with in-house research and development, formal tracking of new technology trends, or other such strategies (Fig. 3). Thirty nine percentage of respondents indicated that novel technology is accounted for in the forward (future year) budgeting process at the organization they represent. Since it could serve as a catalyst for experimentation, the nature of existing forward budgeting bears more in-depth exploration.

Institutional Barriers to Innovation

A second set of questions examined institutional factors serving as barriers to innovation-related activities. We probed for systematic bias in the self-perception of innovativeness among managers, and evaluated typical institutional conditions reported as barriers to innovation activities, revealing cognitive biases and systematic misrepresentation of the needs for innovation.

Skewed Perception of Innovativeness

Wastewater utility managers may have a skewed perception of their own innovativeness. As Garrison Keillor describes the fictional Lake Wobegon, "where all the children are above average," wastewater managers also believe they are more innovative than available evidence would indicate. When asked to self-assess how innovative the organization they represent is, 87 % of managers reported that their organizations have average or greater innovativeness relative to other utilities (Fig. 6). Only 13 % of managers report less innovativeness. None ranked themselves among the least innovative.

Self-perception was often inaccurate, as revealed by comparison with the innovativeness index (*Ii*). About half

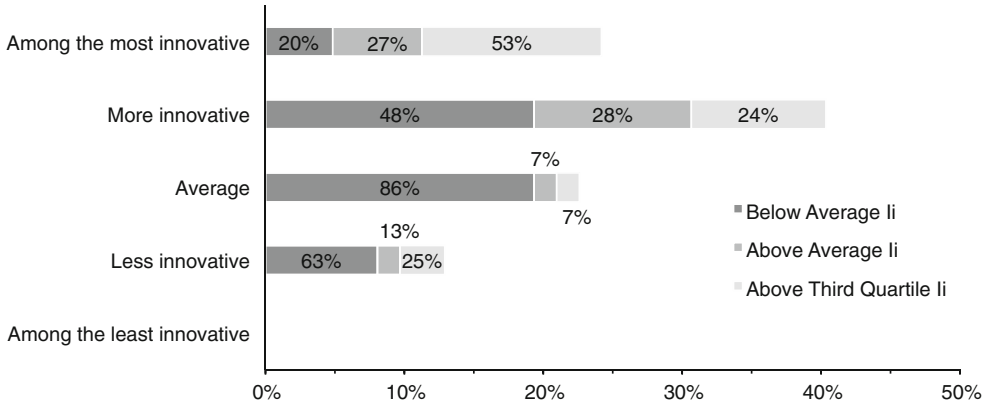

Fig. 6 The Lake Wobegon effect and innovativeness. The total length of each *bar* shows the proportion of respondents self-identifying in each category on the vertical axis. With each *bar*, the makeup of each group in terms of its *Ii* is shown by the other groupings. The data suggest that high confidence in innovativeness is often warranted, but in other categories self-perception was often inaccurate

of those self-reporting as above average have above average *Ii*, and only a small fraction of those self-reporting as average have above average *Ii*. One exception was that high confidence in innovativeness is often warranted. Among those self-reporting as "among the most innovative" (24 %), 80 % represented organizations with above average *Ii*. However, only 53 % of the total respondents in this most innovative category were actually ranked in the top quartile of *Ii* (Fig. 6).

Overestimates of innovativeness are consistent with superiority biases (Hoorens 1993) evident in self-rating in other contexts, where people consistently overestimate their own performance. For example, job performance self-ratings are consistently inflated or lenient relative to ratings from supervisors (Heidemeier and Moser 2009), and large majorities of people have been shown to rank themselves above average in attributes ranging from driving ability (McCormick et al. 1986; Svenson 1981) to popularity (Zuckerman and Jost 2001).

The implications of the Lake Wobegon effect among individual managers are most significant when considering the need for a sector-wide transition to a reinvented urban water sector as described in the "Introduction" section. If individual managers generally think they are doing a lot, but are actually under-investing in innovation, the collective result will be slower progress than expected. One implication is that reducing the Lake Wobegon effect could be beneficial for the sector, for example through better information exchange about the activities of peers within the sector.

Perceived Barriers to Innovation

An open-ended question in the survey asked respondents to identify the three most important barriers to innovation in their organizations. Figure 7 summarizes the responses, which we coded into a number of important categories. Perhaps most revealing about these data is the paucity of responses related to technological or technical barriers to innovation. The dominant barriers reported for innovation are institutional in nature. The most important barriers are summarized below.

Seventy four percentage of the respondents who answered this question (N = 47) cited cost or financing as a barrier to innovation at their utility. These answers included references to the absolute cost of innovative technology, and to financing and available funding. It was not possible to reliably parse out the distinction between those who viewed one or the other as the key barrier (for example, "economics" or "money" is ambiguous in this respect). Nonetheless, the prevalence of financial themes is unsurprising (Ajami et al. 2015), but also revealing as a measure of the perception of the importance of innovation.

All wastewater utilities are likely to be attuned to the cost of their service. Institutionally, this manifests itself directly through board members' sensitivity to constituents' concerns about increasing fees, or indirectly in places where wastewater more directly impacts the broader budget of a municipality. In California, as elsewhere, political and legal pressures on financing are currently acute (Hanak et al. 2014). Thus, managers understandably feel squeezed between the need to meet increasingly stringent regulatory requirements and their inability to increase per capita or per household revenue to do so. However, managers generally state an expectation that innovations in the wastewater sector will eventually lead to lower costs, albeit not as strongly as the expectations for better water quality from innovation (Fig. 4). This expectation is consistent with experience in other sectors, perhaps most famously evidenced by learning curve effects such as Moore's Law in the semiconductor industry (Moore 1965; Schaller 1997), but also in the water sector by steady improvements in efficiency of desalination technology (Kiparsky et al. 2013). An important nuance might be found in the distinction between short-term (e.g., investment and capital) costs versus life-cycle costs for a

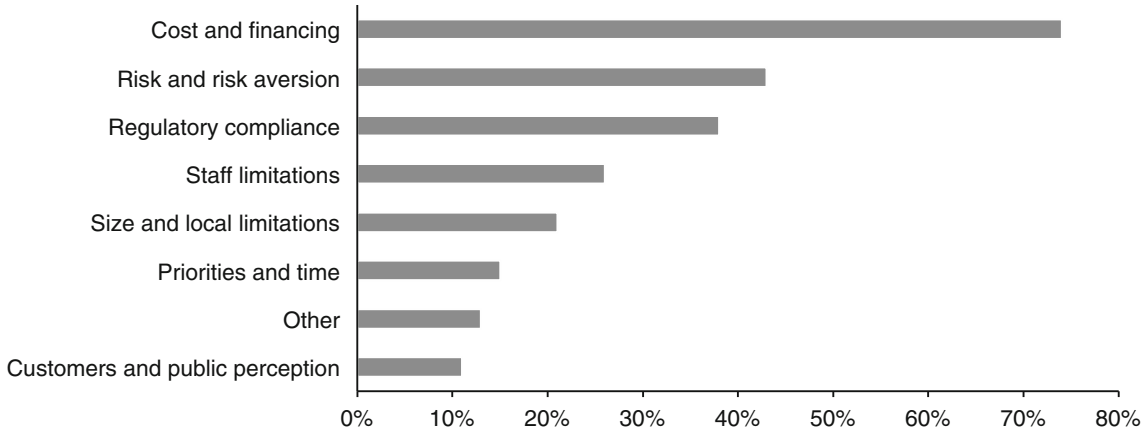

Fig. 7 Barriers to innovation, coded from open-ended question with three response fields. Percentage of respondents (N = 47) reporting each category

given technology. For example, where access to capital is a key hurdle for a local utility, infrastructure investment can be challenging even where long-term rate reductions may result. Thus, utility financing models may be a key cost barrier, rather than either kind of measure of absolute cost.

The wastewater sector also has examples of innovations that reduce cost of service. In particular, the paradigm shift from framing of wastewater to resource recovery illustrates this concept (Grant et al. 2012). For example, East Bay Municipal Utilities District (EBMUD) in California has pioneered the development of its biogas digestion and capture program not only as an energy cost reduction measure, but as a revenue generation mechanism (Ben Horenstein, EBMUD, personal communication). To do so, it made its treatment facility the first electricity-positive treatment plant in the country through innovative measures including trucked waste program to augment biogas production and expansion into new markets such as biomass and energy. The major benefit for ratepayers has been to reduce or eliminate energy costs at the facility, which account for the single largest O&M cost throughout the industry. This is an example of a cost-driven and rate-favorable innovation. Similarly, regulatory requirements for reduction of phosphorus in effluent streams coupled with within-plant struvite problems, have motivated the development of cost-effective resource recovery technology (Baur et al. 2008; Britton et al. 2009). When it precipitates, unchecked as a byproduct of a treatment process, struvite can damage infrastructure. However, when struvite is recovered from the waste stream and sold as premium fertilizer, the net result can be a lower-cost way to meet regulatory requirements while improving overall plant performance. In sum, innovation may not be inherently expensive, although the structural issues related to sunk costs of existing infrastructure, and difficulty in financing, may be important regardless of absolute life-cycle cost.

Risk and risk aversion comprised the second-highest category of barriers to innovation volunteered by respondents: Fourty three percentage of managers cited barriers related to these concepts. Because innovation and risk are intimately related concepts, this survey result is consistent with expectations, but its prevalence in the answers is striking. Many responses related to the potential for failure of an innovative technology. A number of respondents explicitly (e.g., "Our agency is very risk averse"), or implicitly ("the need for close to 100 % reliability") identified risk aversion as one of the barriers. Risk aversion has been discussed as a driver of conservative (non-innovative) decision-making (e.g., Parker 2011), and our results are consistent with such reports.

The water sector in general has been characterized as risk averse, which relates to tendencies to forego new technologies. However, risk aversion by no means stands alone as a determinant of such conservative decision-making. As discussed above, the incentives faced by water and wastewater managers, and the nature of water-related services and the water industry, encourage conservative decision-making. Risk aversion as an overarching driver characterizes managers' behavior.

The survey data do not reflect a threshold or bottleneck in willingness to adopt technology (Parker 2011), such as where managers would only consider technology with commercial-scale demonstration or greater experience, although there is an increasing stated preference for greater levels of demonstration (Fig. 10). Interestingly, many state openness to use less than standard technologies.

Most respondents (65 %) say they require at least a demonstration project to even consider a technology, and almost 25 % will only consider industry standard technology (Fig. 10). However, a substantial portion (35 %) of respondents state an openness to employing technologies with lower levels of proven success, or even acknowledge

the value of experimentation. The latter is borne out by the existence of pilot projects throughout the industry. If 10 % of respondents are willing to engage with new technologies, implying in essence hosting pilot studies, it is encouraging, and important because of the implications for the industry as a whole. This is how variation is generated in practice.

Another major category of responses (38 %) cited barriers related to regulatory compliance. Some were adamant on this point (e.g., one responded to the open-ended question in its entirety with the following three barriers, "California Regional Water Quality Control Boards; EPA; State of California"). Regulations are indisputably central drivers of managers' decision-making. The U.S. wastewater sector has been driven by regulatory requirements for most of its history, certainly since its major expansion in the passage of the Safe Drinking Water Act of 1974 (Dowd 1984) and the Clean Water Act of 1977 (Andreen 2003). Anecdotally, regulators are a common target of complaints among the regulated community, but the reality is that a diverse set of regulations govern a heterogeneous industry. Thus, it is likely that attempts to generalize about the blanket effects of regulation will fail without greater qualitative nuance.

Indeed, regulations were not universally perceived as barriers. A companion question (Fig. 8) shows that while 32 % of respondents disagree or strongly disagree that regulations encourage innovation, 38 % agree or strongly agree, and almost one third (30 %) neither agree nor disagree. This suggests that regulations might serve a dual role (e.g., encouraging incremental innovation to a point, but discouraging radical innovation), or perhaps a context-specific role (e.g., encouraging certain types of innovation, and discouraging others). This suggests that the dominant effects of regulations on innovation are likely to be ambiguous or situation-specific.

Regulators need to examine ways in which they can enable and incentivize innovation, fostering development of the sector as a whole while still maintaining individual system reliability. This subject warrants more detailed investigation, as regulatory changes could constitute a potentially significant lever for increasing innovation, but such changes may be constrained by political considerations.

Managers Feel They Have Freedom in Innovation

Given evidence of risk aversion supported by this survey, a reasonable expectation is that governance may play a role in fostering conservative decision-making. For example, in many US public water and wastewater utilities, elected boards of directors are answerable to constituents, who may respond more to promises to reduce the rate of increases in wastewater bills than to the ancillary goals promised by the potential for sustainability transitions in wastewater. Our data, although indirect and preliminary on this front, do not support the contention of a chilling effect of governance on innovation by managers. Final decisions on project development, particularly those involving significant expenditures, are almost certainly subject to approval by governing bodies. However, the stated responses do not support the idea that governance has a restrictive effect on innovation activities. Seventy one percentage of managers agree or strongly agree that they have freedom to decide how to develop innovations in the systems they manage (Fig. 8). Similarly, there is no strong indication that managers need to adhere to tight procedures when working on innovative methods, suggesting that tight oversight that might reduce freedom for experimentation is not present among the managers surveyed (Fig. 8). Similarly, a majority (62 %) indicate that they are free to make their own judgments when working on innovative projects.

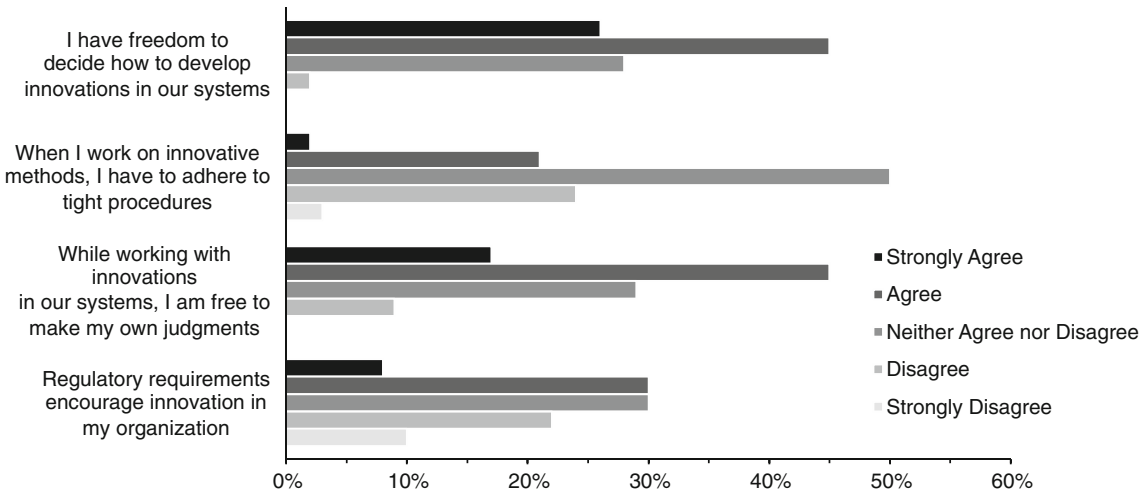

Fig. 8 Likert scale responses to statements about autonomy regarding innovation (scale based on Tummers 2012)

Taken together, these suggest that managers do not feel highly controlled, and therefore are unlikely to feel highly constrained, by their board members.

Managers characterized their decision-making environments as anything but conservative. Very few respondents indicated they perceived resistance to change from the people who would be most expected to influence their decision-making. Within their organizations, almost all (85 %) indicated that their superiors (e.g., boards of directors) were very open or somewhat open to change, a similar result when looking at those they managed (staff, 85 %) (Fig. 9). However, in each case, a greater proportion were "somewhat open" than "very open."

Customers/ratepayers were perceived as less open to change, largely because of a high (47 %) proportion rating customers as neutral to change. This might reflect a perception that customers are indifferent to *how* wastewater collection and treatment is accomplished, as long as it is done effectively and cheaply. Interestingly, only 3 % characterized their customers/ratepayers as resistant or very resistant to change, perhaps emphasizing the lack of perception of constraints from an important constituency. It is possible that this is particular to California, which has historically been a progressive leader on environmental issues in the US. If this were the case, it may have implications for geographic targeting of innovation-supporting activities.

That managers report feeling relatively unhindered in their innovative activities is an interesting result. Mangers often (67 %) serve at the pleasure of elected governance bodies. A priori expectations suggest that elected officials would be sensitive to their electorate, and that the ratepayers who elect the board will often be sensitive to the trajectory of fees. If short-term cost and financing is perceived as challenging for innovation, one would expect elected boards to be hesitant to support innovation. Questions related to board structure were inconclusive, but managers' attitudes intriguingly suggest this is not the case, nor is it the case with the staff members who report to them (Fig. 9).

Survey data support the notion that it is not staff openness to change that is lacking. There is some concern, however, that staff skills and capacity may keep managers from embarking on new technical or management solutions that would require additional operational capacity (Fig. 7).

Questioning the implicit assumptions about staff willingness and interest and ability to develop new skills, and researching the real costs of retraining or re-staffing, could be an important priority for regulators seeking to encourage innovation, and for vendors seeking to enable faster diffusion of new solutions.

Discussion

Our survey of wastewater managers in California reveals insights about how innovation has manifested in this sector, how decision makers in utilities perceive the existing innovation deficit, the attitudes of managers towards innovation, and how various actual and perceived disincentives might hinder experimentation (Farrelly and Brown 2011), exacerbating the innovation deficit in urban water.

Managers recognize the importance of innovation for their wastewater systems, but feel they could be doing more to foster it—most managers report spending little time on innovation, and feel they should spend more time than they actually do. Managers are optimistic about the prospects for innovation to improve water quality and reduce costs, but more so over the long run than in the near term. The implication is that managers believe that in spite of its importance, innovation has limited short-term relevance. This perception may combine with and exacerbate factors impeding public sector innovation. In particular, if innovation is seen as a long-term concern and the charge of the next generation, it could reduce motivation to act now. In an industry where durable infrastructure investments

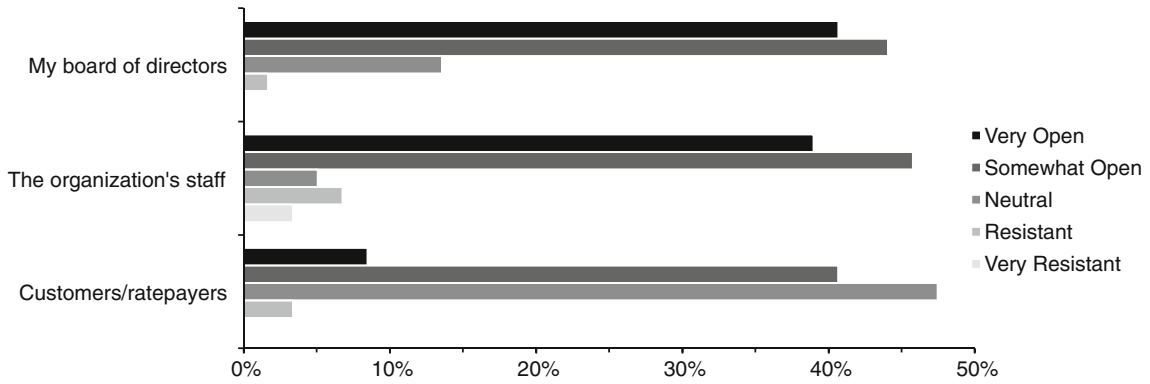

Fig. 9 Perceived openness of stakeholders to innovation (scale based on Metselaar 1997;see also Tummers et al. 2012)

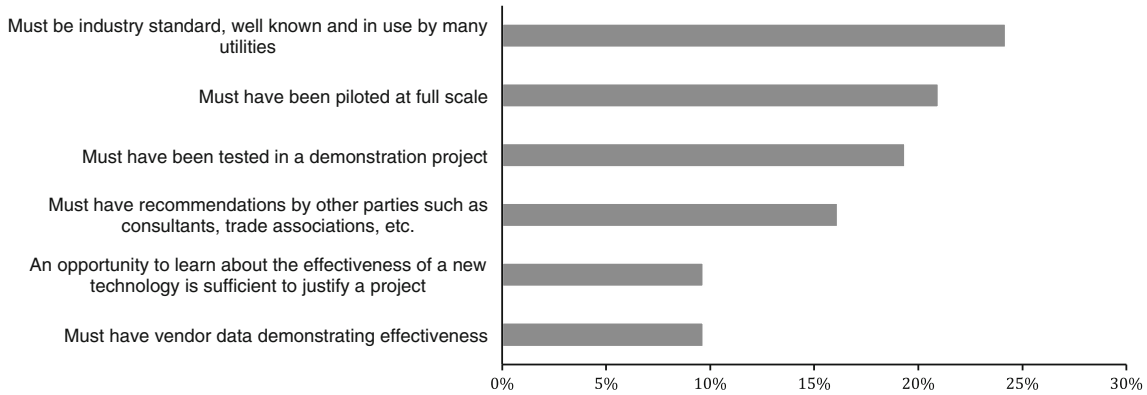

Fig. 10 Minimum previous demonstration necessary to consider adoption

may easily outlast individual careers, reduced impetus to experiment with long-term solutions new things could in aggregate result in a drag on the rate of innovation.

Managers overall report feeling they have freedom to innovate within their organizations—in spite of governance structures that at least anecdotally can sometimes hinder new approaches to doing things, managers characterized their decision-making environments as supportive and open to change. Nonetheless, consistent with superiority biases evident in other contexts, managers have a skewed perception of their own innovativeness—the vast majority believe they are more innovative than average, and most self-report as more innovative than justified by their actual technology adoption. If individual managers think they are more effective in their innovation activities than they actually are, it could exacerbate slow progress towards the technological system transitions that will be necessary for sustainability of urban water.

If the results here are reflective of broader realities in the municipal wastewater sector, they may reflect a systemic underinvestment that cannot be resolved at the level of the individual utility in isolation. In an evolutionary model of innovation, the generation of variation is one of the key parameters in the overall pace of innovation in a system (Kiparsky et al. 2013). That is, the greater the frequency and more diverse the individual attempts at innovation in a system are, the faster the overall system can be expected to evolve. This implies that the level of risk taking by individual managers is an important determinant of the course of the industry as a whole towards transition to new paradigms for urban water systems (Fig. 10).

Correspondingly, the study of innovation at the level of the decision makers who are ultimately responsible for technology adoption decisions is important. Recognizing the many challenges that exist for effective management of innovation within organizations (Tidd and Bessant 2013), the potential to learn from innovation management in other sectors (Miller et al. 2012) as a way to better harness internal and external innovations in wastewater utilities warrants more exploration. Most individual utilities tend not to possess the necessary internal structures for innovation management, like dedicated job profiles, ongoing collaborations with universities and research organizations, co-operation among different utilities in specific piloting and other activities, and research to learn from the experience in other areas could help unlock innovation at the level of individual utilities.

Conclusion

For innovation in the urban water sector, the importance of individual decision-making may lie in its influence on the sector-wide generation of variation. That is, attempts to execute a larger variety of new technologies that individually may or may not ultimately contribute as successful innovations, but collectively will increase the probability of transformative developments, is critical for the industry as a whole. Interestingly, the most frequently reported barriers to innovation included cost and financing; risk and risk aversion; and regulatory compliance. If the wastewater industry is to move forward quickly enough to meet next-generation challenges, incentives are needed to encourage individual decisions consistent with a collective action framing for technology development.

One way that individual decisions can be nested within a broader context is through networks. Therefore, closer attention to network effects within the water and wastewater sector is warranted. In particular, there are many ways in which formal networks (e.g., trade associations) can provide system resources (e.g., by correcting for coordination failures) (Musiolik et al. 2012). Operationally, this supports the notion that organizations such as the Water Environment Federation are well positioned to take on the strategic task of increasing the innovation activity across utilities, as they have begun to do (see, for example, http://

www.werf.org/lift). Similarly, an expanding role for universities is important. Where universities broaden their role beyond traditional basic science and engineering research to increasingly emphasize technology application, they can foster innovation when such efforts result in potentially viable new technology options (Scherson and Criddle 2014). Regardless, that cost is a perceived barrier implies efforts to reduce financial barriers to innovation will be important for the industry as a whole. Reducing the perceptions discussed above is one way. Increasing the financing targeted specifically for innovative technology and management is another. Regulators can encourage all of these types of actions, as exemplified by the current interest of US EPA's Office of Water in innovation (U.S. Environmental Protection Agency 2014).

Innovation is difficult and risky, but crucial. Understanding, and then changing, the motivations and hindrances for managers' innovation activities will ultimately be necessary, if the sector is to progress towards a sustainable reinvention.

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