

## Evaluation innovation prioritizing to use new technology in urban management (Case study: water and wastewater organization)

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**Abstract:** This paper is concerned with the ability of water and wastewater organization to innovate and successfully achieve technological and organizational change. Interaction between institutional change and technological change poses important constraints on transitions of urban water systems to a state that can meet future needs. It recognizes the complexity of the issues that contribute to the management of such change and the role of the learning organization. Research on urban water and other technology-dependent systems provides insights that are valuable to technology researchers interested in assuring that their efforts will have an impact. In the context of research on institutional change, innovation is the development, application, diffusion, and utilization of new knowledge and technology. To solve current urban water infrastructure challenges, technology-focused researchers need to recognize the intertwined nature of technologies and institutions and the social systems that control change. Given the technical and institutional challenges facing urban water, design of future urban water institutions needs to consider innovation. Doing so is nontrivial because of the nature of innovation, which is by definition impossible to predict. While institutional reforms will be critical to fostering future innovation in urban water, a successful, generalizable model has yet to emerge.

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### 1. Introduction

Using new technology based on internet or computer (IT & ICT) is a new enhancement for developing countries. All managers need to use the latest innovation and created technology to manage costs and saving time to get proper results. One of the main organizations is water and waste water management which is really important. All society knows that urban water management is a priority for all nations to continue their life in hometown. So in this paper, our main purpose is considering latest information systems and evaluation their use in water and waste water organization. Also, we want to evaluate challenges to reach this goal. Over the past three decades, the engineering community has begun to recognize the need to embrace a suite of new technologies to improve the performance and resiliency of urban water systems. While compelling visions of reinvented water systems exist, progress has been slow in practice. In this review article, we explore one reason for slow progress: innovation is often conceived in narrow terms that emphasize technological change.

Considering scholarly research on sociotechnical innovation (i.e., the interrelated change in technologies, firm strategies, and institutional structures) in water and related systems can help ensure that efforts to develop new technologies can be properly targeted to address potential barriers to adoption. The challenge of innovation is sharpened by

inertia in the water industry. There have been modern examples of large-scale, sweeping changes in urban water systems, but such instances have been rare.

Soft path solutions rely on the decoupling of the productivity and use of water from the amount of water used, and on changes in the technical and institutional methods used to manage water for human and environmental needs. Responding to these stresses will require substantial technological and management changes for which major changes in regulations or funding for operation and maintenance may not be available. Forces including climate change, increasing urbanization, and the decay of existing infrastructure are already stressing the ability of urban water systems to meet their expectations for performance. Simultaneously, increasing awareness of the environmental impacts of water use is increasing pressure to do more with less. Novel concepts have been proposed to enable radical changes in urban water systems. In response to these forces, for example, advocates of “soft path” solutions propose a conceptual shift toward a focus on water-related services, rather than absolute quantity of water deliveries, and are conceptually compelling as redefinitions of the technological challenges faced by existing urban water systems. Gleick suggests that a “transition is under way to a ‘soft path’ that complements centralized physical infrastructure with lower cost community-scale systems, decentralized and open decision-making, water markets and

equitable pricing, application of efficient technology, and environmental protection.”

However, wholesale soft path solutions have been slow to manifest in practice (Brooks and Holtz, 2009), and arguably most or all of the soft path elements remain the exception rather than the new norm. Consideration of water institutions and the way that they respond to innovation helps explain the challenge of implementing soft path solutions. Two concepts are crucial to the development of a deeper understanding of the ways in which change can come to urban water systems: innovation and institutions. Innovation can be defined generally as the development, application, diffusion, and utilization of new knowledge. In urban water systems, innovation takes several key forms, including (1) new technologies (e.g., desalination, energy recovery from wastewater); (2) new approaches to management (e.g., regional coordination, rate structures, new business models); and (3) techniques that increase the efficiency of existing systems (e.g., sensors and controls, application of understanding from more precise models). Institutions can be broadly defined as the rules, norms, and practices that govern decision-making.

This definition can include formal institutions, such as regulations and laws, but also acknowledges the multiplicity of factors that shape water systems, such as behavior and cultural factors.

In this article, we focus on examples from water-stressed regions, recognizing that the lessons learned may inform other water management situations. The overarching goals of this review are to (1) characterize literature on innovation and illustrate the degree to which both technological and management innovations are nested within broader institutional context, and (2) present selected examples that highlight the importance of institutions as key hindrances (and potential drivers) of innovation in urban water systems. Thus, water quality regulations, which are designed to protect public health and the environment, career incentives that reward conservative choices within a water utility, and trends toward increasing environmental awareness are all examples of institutional factors that can influence whether a particular technology or practice is implemented. Most importantly, these factors can often outweigh analytical metrics, such as physical or financial efficiency, in actual decision-making. Even where technology with demonstrated potential for improving urban water management is available, institutions may stand in the way of technological diffusion and utilization. Organizations are collectively oriented groups that pursue goals linked to an external environment, and are intimately related to institutions.

Institutional and technological aspects of water systems have co-evolved in areas where water stress is the dominant concern to create challenges and opportunities for innovation that merit a distinct analysis. The importance of the former lies in the insights that emerge from formal conceptualization of innovation systems.

### **Literature review**

In contrast, innovation systems focus on different, but equally important aspects of innovation, namely, the actors, networks, and institutions that develop new products and technologies. The distinction between the two and the resulting analysis of the importance of context for technological innovation underlie a key concept: technological inventions are necessary, but not sufficient, for innovation, and the success of each is strongly influenced by context. The articles in this special issue of Environmental Engineering Science and the field of environmental engineering in general, rightly focus on technological aspects of innovation. Such hardware technology systems comprise the material core of urban water services provision, such as sewers, toilets, and water treatment facilities. This example illustrates the distinction between invention and innovation, but also suggests that defining, measuring, tracking, and characterizing innovation can be a long-term process. Note that in water resources, both inventors of new technologies and the utilities that adopt them could be considered innovators. That is, adopting a new technology can be an innovative act in itself, as it is a key enabler of diffusion.

In some cases, the distinction can be made by subjective perception, but even extreme examples can present problems due to the existence of multiple simultaneously relevant continuums for most products, such as price, performance, potential for substitution, or functional elements along a value chain. For example, membrane bioreactors are radical technology in the sense of relying on fundamentally different physical and chemical principles from the filtration systems they can replace. A given technology can move in a trajectory from radical to incremental over time. For example, desalination was initially a radical invention as it opened possibilities for entirely new sources of drinking water. However, in practice, membrane bioreactors could be considered incremental if retrofitted into existing treatment plants to meet requirements for more effective filtration. Making even coarse comparisons of the importance of different innovations can be challenging. Various classification schemes for innovation have been proposed, but one often-used distinction is made between radical innovation and incremental innovation. Radical innovations can represent “clear departures from existing practice” as opposed to

“minor improvements or simple adjustments in current technology”.

Over the past decades, with its increasing acceptance as a potential part of water supply portfolios, desalination has benefitted from incremental technical improvements, to the point where it is a mature and commercially viable technology. Even in the absence of major technological shifts, most water systems are not static, as incremental change comes from production engineers, technicians, and others involved in day-to-day operation. Radical and incremental changes are each important to innovation, and cumulatively both have substantial roles in the evolution of technology over time. An additional distinction can be made between incremental innovation for specific technologies as described above, and broader transitions to new states. Transition management deals with co-evolution between technological and institutional aspects of new sociotechnical regimes, and often spans time frames of several decades. Both are important for urban water management: incremental technological change is ongoing, but the durable nature of water infrastructure makes other institutional timeframes such as electoral and business cycles less applicable to state changes as broad as those envisioned for holistic reinvention of urban water systems.

Empirical analyses of technological innovation on the scale of market sectors, such as agriculture or industry, suggest that diffusion of new technologies into widespread use follows a predictable conceptual pattern. In a classic technology diffusion framework, initial adoption happens slowly as early adopters risk unproven reliability for the promise of novel benefits.

Although determining appropriate indicators for assessment of innovation is not always straightforward, diffusion has been measured using total installed capacity, market share, or proxies such as patents, bibliometric indicators, or revealed preferences (Markard and Truffer, 2008).

For example, global desalination capacity has grown exponentially since the 1990s. As technology improves and becomes more energy-efficient and cost-effective, desalination capacity is projected to double over the period from 2008 to 2016 (The Economist, 2008). From the perspective of market share, existing desalination plants in operation account for only 0.5% total global water use as of 2008. However, such metrics are sensitive to how a market is defined. If the market for desalination were segmented further, such as geographically into coastal areas or those with ready sources of brackish groundwater, or by sector, such as for industries requiring high-quality water, such metrics might appear different. Later, the rate of adoption increases

as solutions to initial issues arise and acceptance is gained among early and late majority adopters. The rate of adoption then tapers as the sector reaches saturation.

The innovation system literature emphasizes the interplay of different actors (firms, but also research institutes, regulators, associations and other intermediaries, civil society and end users) in diverse network structures (Markard and Truffer, 2008), which is useful for looking both at management of incremental innovation or sectoral transitions. However, they did so within existing frameworks, such as mainframe or microcomputer manufacturers. Entrant companies did not contribute to cutting edge engineering. Rather their success as disruptive innovators was based on developing new paradigms for use of disk drives—creating new markets that eventually developed to take over incumbent mainframe and microcomputer business. In particular, the approach of technological innovation systems enables the identification of necessary conditions for radical innovations to succeed by overcoming barriers stemming from deficiencies in firm capabilities or mismatch in institutional structures between new technologies and incumbent systems (Jacobsson and Bergek, 2011). A technological innovation system can be thought of as “a network of agents interacting in the economic/industrial area under a particular institutional infrastructure [...] and involved in the generation, diffusion, and utilization of technology”. It is important to note that the emphasis here is on the actors, networks, and institutions that enable innovation, and not on the nuts and bolts of the hardware itself. This emphasis reflects the importance of these nontechnical elements in the generation of innovation.

A potential lesson here for urban water innovators is that entry points for innovation may be found not only through technological refinements of process efficiencies, but also through conceptual disruption of established ways of operating. For example, community or building-scale water and wastewater treatment many create opportunities for new entities, such as private water service providers, to operate under different business models from that of centralized utilities. Similarly, disruptive institutional innovations have begun to shift centralized decision-making through more transparent decision-making and the incorporation of stakeholders in collaborative processes. The impact of an innovation depends heavily on how much it disrupts existing modes of operation. The key to their disruptive nature was that in each case they enabled new markets and ways of using the products, such as when they reduced in size to enable the development of desktop or laptop computers. Established

companies were aggressive and innovative in developing technological advances. The core question is whether established capabilities in a firm are suited to support a technological novelty or whether entirely new capabilities and routines will have to be built up. Disruptiveness can be independent from technological advancement. For example, Christensen drew a distinction between sustaining and disrupting innovations, using a case study of the computer disk drive industry. Sustaining innovations continue existing trajectories of product development. For disk drives, sustaining innovations refined performance within an existing format. Disruptive innovations, in contrast, generate new standards and trajectories for performance, perhaps adding additional metrics, enabling new and different uses and creating new markets. Perhaps surprisingly, in the case study of the disk drive industry, disruptive technologies were actually minor technological advances that initially generated quantitatively inferior performance on accepted metrics such as total storage capacity.

To address the problem of a large scale sectoral transformation toward more sustainable future service provision, a whole set of radical technological innovations would have to take place causing disruptive innovations within an industry, or even the entry of new industry actors and associated new institutional frameworks. Large-scale, long-term transformation processes (for example, a shift toward an electricity system based largely on renewables) have been analyzed in the recent literature on sustainability transitions (Smith et al., 2010; Van Den Bergh et al., 2011; Markard et al., 2012). One core element of transitions research considers the emergence of new industry structures that provide new products and services, becoming important drivers of the transition processes.

Urban water systems are linked to deteriorating environmental quality within cities as well as upstream and downstream of them. Increasing societal recognition of the benefits of aquatic ecosystem services puts corresponding pressure for restoring and reducing impacts to aquatic systems. The inexorable deterioration of even long-lived Green infrastructure, distributed water reuse, recovery of energy and nutrients from wastewater (Guest et al., 2009), potable water reuse (NRC, 2012), source separation of wastewater components (Larsen et al., 2009), and other concepts all have potential to change the physical structure and financial outlook for urban water systems. Many of these technologies are the subject of intensive research, and some are reviewed in companion articles in this issue. Infrastructure suggests impending challenges even absent these stressors (American Society of Civil Engineers [ASCE], 2011). On top of all of these pressures,

funding investment and maintenance in urban water systems is increasingly challenged with tightening budgets at all governmental levels (OECD, UNESCO/World Water Assessment Program, 2006; Urban Land Institute and Ernst and Young, 2007), and recurring debates about organizational reform in utilities complicate efforts for future planning. In coming decades, increasing stresses on urban systems will influence supply, demand, quality, and cost, environmental, economic, and distributive elements of urban water. The perennial challenges of climate variability will grow in importance for urban water as it is exacerbated by climate change. Historical expectations for surface water and groundwater supplies and flooding can no longer be relied upon, leading to unanswered questions about future water and storm water management. Existing practices will need to change in ways not yet anticipated, and simply doing more of the same will not be economically efficient or societally acceptable. New ways of doing things—innovation—will be critical to the future of urban water systems. Population growth and urbanization trends promise to increase the spatial extent of urban areas as well as their population density, putting pressure on sources of water supply. The energy and greenhouse gas intensity of water and wastewater systems (will need to be addressed with both new technologies and decision-making strategies as costs and regulations for emissions increase. Emerging contaminants, such as endocrine disruptors and pharmaceuticals and personal care products, threaten ecological and public health and promise to complicate water treatment.

The primary unifying theme of this nonexhaustive list is that of change and uncertainty—the only thing we can say for sure about the future of urban water is that it will look quite different from the past. Water crises are increasingly viewed by the business (World Economic Forum, 2012) and national security (Clapper, 2012) communities as among the greatest social risks of coming years, and urban water systems will be called on to ameliorate these risks.

However, in spite of much promise, radical technological advances have not been implemented at large scale. While technological inventions are necessary to the future of urban water systems, they are not in and of themselves sufficient. Rather, the potential for innovation depends on a blend of technological and institutional factors that operate in concert.

Can technology promise solutions commensurate to the impending stresses on urban water systems? To some extent it can. Much theoretical room remains for futuristic advances in the efficiency of water-related technologies (Shannon et al., 2008; Elimelech and Phillip, 2011). However, paradigm-shifting concepts

promise innovation in all aspects of the urban water cycle (Daigger, 2011).

### **Processes behind technological innovation**

A progenitor of current models, the “chain linked model” serves to illustrate the paradigmatic shift. It presents innovation as not a single process driven by scientific discovery, but a chain of innovation activities including market identification, detailed design and testing, production, and so forth.

Whether innovation is driven more by the supply of new technological options (“technology-push”) or by market demand for solutions to known problems (“demand-pull”) has not been explored in depth for water resources, although the question has been explored with some nuance in areas such as renewable energy (Taylor, 2008). Freeman suggests that the answer depends in part on the stage and type of innovation. For example, there is unlikely to be preexisting market demand for a given radical, early-stage innovation. Some innovators understand this intuitively, as illustrated by the way Steve Jobs eschewed market research while creating a new market category with the Apple iPad, saying, “It’s not the consumers’ job to know what they want” (Markoff, 2011). The key point emerging from the chain linked model is that a view of innovation that places science as its central driving force is not only simplistic, but potentially misleading. Research is crucial to innovation, but exists only within a larger set of processes.

Conversely, demand for improvement of existing technologies is more likely to spur incremental innovations. The development of desalination illustrates both points. The initial commercialization of cellulose acetate membranes can be classified as a technology push. Since then, innovations in water permeability and salt rejection of reverse osmosis membranes have resulted in gradual improvements in the efficiency of desalination technology (Lee et al., 2011). Over time, a demand for better performing membranes has led to a pull that motivates efforts to increase economic viability of desalination plants.

Distinguishing between technology-push and demand-pull models of innovation may often be a false choice over the lifetime of a technology. Such formulations imply linear models with smooth, one-way flows of information from research to development to product marketing. Such linear models have been roundly criticized not only as simplistic, but as simply wrong, and replaced by more sophisticated views of innovation process. Each element of the chain is connected to the others via feedback loops, and also directly or indirectly to research and knowledge production.

“Hard” functions, such as basic and applied research, development and testing of prototypes and

products, and the provision of technical services, all of which are core elements of engineering training and practice, are directly involved in development of new technology. However, while technological advances are central to innovation, innovation also includes “soft” functions such as information exchange, policies, financial methods, management strategies, or ways of doing business. Such functions provide essential complements to the “hard” ones more directly related to technology development.

### **Innovation in context**

For example, a collaborative group of firms may combine their offerings into an interrelated package, forming an innovation ecosystem that can offer otherwise untenable products, but creating a new set of risks for the now interdependent enterprises. An example would be separate firms making hardware and software for mobile phones. Factors such as this can complicate understanding or forecasting of technological change. They can also lead to insights about what a specific invention needs to consider in order becoming a successful innovation. Scholarship on innovation studies takes as its starting point the premise that innovation is determined not only within a given firm or research group, but also by the context in which they are embedded. Myriad elements, including but not limited to technical ones that influence the potential for successful innovation. A novel technological development alone is not sufficient to disrupt an existing technological regime, nor can it be developed in isolation from the institutional and social context in which its entrepreneurial researchers operate. Innovation results from complex interactions among people and organizations.

Knowledge development can include “learning by doing” and “learning by searching.” For example, East Bay Municipal Utilities District (EBMUD) has attempted both approaches to attaining its goal of an energy-positive wastewater treatment facility. Motivated by California’s energy crisis in 2000–2001 as well as the adoption of a Renewable Portfolio Standard by the state, but lacking an accepted set of best management practices for a new goal, EBMUD has had to mix engineering analysis with experimentation to further its efforts in innovative energy management.

Knowledge diffusion often occurs through social and business networks, through learning by interacting or learning by using. Trade organizations such as International Water Association provide forums where industry representatives and public agency representatives can engage through conferences to build networks of knowledge and practice. Regional forums or groups for those with

more specialized needs or specific goals provide more targeted opportunities for knowledge diffusion.

Similarly, water organizations have been slow to adopt promising emerging approaches such as in-line energy recovery (Klein et al., 2005; House, 2010) or leak detection and reduction that promise to plug into existing systems, reducing existing inefficiencies to deliver potentially rapid return on investment. The explanation may stem in part from an inability of the new technology to overcome the advantages of existing technology, or from institutional context, such as lack of familiarity, embedded best management practices, or risk aversion among decision-makers faced with unproven options. Technological merits alone cannot explain the ultimate fate of new technologies. A superior but unfamiliar technology needs to overcome the advantages of the ecosystem that develops around an incumbent technology. Existing technologies benefit from knowledge accumulated by users, capital outlays and infrastructure, available skills, and other aspects that collectively support an inertial dominance. For example, in considering whether to change from sand filtration to membrane filtration, a water system operator could not simply evaluate the decreased risk to public health and space efficiency. In addition, they would need to weigh the potential costs of retraining its workforce and developing a new supply chain. Often, broader effects on interconnected systems would have to be evaluated.

One lens through which to view innovation systems is that of evolutionary theory and evolutionary economics. McKelvey describes the net processes of innovation systems as analogous to biological systems, where necessary elements of evolution include (1) retaining and transmitting information; (2) generation of novelty leading to diversity; and (3) selection among alternatives. Information sharing, policymaking, design and enforcement of patent laws and other related standards, and professional coordination are critical to the information functions. An example would be scientific and professional conferences geared toward highlighting new available technology. Generation of technological diversity happens through research and development, manufacturing, and also by end-use. In the context of urban water infrastructure, consulting engineers will often serve the role of information brokers who add value by understanding and presenting a range of technological options that may fit a given utility's needs. Selection among alternatives can happen through the search process where customers look for solutions to existing issues, through allocation of resources for research and development, through exchange of information and

vision, and through external facilitation of new market formation.

Other key functions of innovation systems have been enumerated by Hekkert et al. Entrepreneurial activities help develop new knowledge, networks, and markets into business opportunities. Presently, support for water entrepreneurs is limited. Water technology entrepreneurs have some access to attention and funding from a small number of environmentally focused venture capital firms, but the capital deployed under the cleantech/greentech umbrella for water resources pales in comparison to that for renewable energy. In 2011, venture capital investments in water technologies totaled about \$224 million in 40 deals, or about 5% of the \$4.3 billion invested in 323 deals in the cleantech sector overall (PwC/NVCA, 2012). Awards for innovative water products provide avenues for increasing entrepreneurial visibility, but there is much room for growth. In part, the lack of entrepreneurial activity is tied to limitations on direct profit potential from water. These include its provision by public agencies rather than for-profit entities, limitations on water markets, and the expense of and limited scope of facilities for bulk storage and conveyance of water that limit the geographic potential of water markets.

Guidance of search refers to defining and increasing the visibility of demands for new functions among users. In a pull model, innovation producers recognize the need to understand market demands. Goal setting by policymakers is one mechanism for such signaling. For example, recently passed California legislation sends clear signals by requiring 20% reduction in urban water use from year 2000 levels by the year 2020 (State Water Resources Control Board, 2008, 2009). Analysis and communication that incorporates stakeholders can also clarify market demands. Such boundary work (Guston, 2001; Cash et al., 2003) recognizes the gaps between producers of and potential consumers of knowledge. Empirical and theoretical studies have shown that the use of knowledge in decision-making in policy contexts is made more effective through early, active, and ongoing collaboration between both groups, and such concepts likely transfer to innovation systems as well. Boundary work can be carried out by boundary organizations that have a defined mission to serve as a bridge between different sectors, and may be most effective when multiple stakeholders are involved in ongoing processes (Jacobs et al., 2010). Research foundations can also serve a boundary role as part of their mission. For example, the Water Research Foundation, the Water Environment Research Federation, and the Water Reuse Foundation not only fund primary research, but also conduct outreach to bridge technology development and

science communication. The role of boundary organizations and boundary work is implicit in innovation studies, but new research formally joining the two areas of inquiry could yield useful insights (Taylor, 2008).

The need for market formation recognizes that incubation of potentially disruptive new technologies in protected spaces or niche markets can enable them to mature to a point where they have a greater chance of being competitive. In niche markets, actors are willing to accept such teething problems as higher costs and will invest in improvements in a new technology, in order to work toward specific functionalities (Markard and Truffer, 2008). Protected spaces can be developed through policies such as tax regimes and minimal consumption levels. This model has helped enable development of increasingly efficient and cost-competitive renewable energy sources. For example, Germany has become a market leader in photovoltaics over the past two decades (Dewald and Truffer, 2012). The proximate enablers were subsidies in the form of a feed-in tariff providing a protected space. However, the ultimate origin of support for these subsidies can be traced to an evolving range of actors, starting with local pro-solar initiatives and moving across a range including local and state governments and corporations, illustrating the importance of a broad range of actors in a technical innovation system. Closely related to this example, mobilization of resources through industry or government funded R&D programs can enable high-risk, early stage actions that would be difficult to fund through market-based means alone.

Creation of legitimacy is also necessary to put a new technology on a policy agenda and break down resistance to disruptive change. One could argue that potable water reuse in the United States appears to be in the midst of a process of legitimacy creation, as technical understanding of its performance grows, and political and social resistance breaks down as nonpotable reuse and potable reuse projects operate for extended periods without adverse health effects (NRC, 2012). Ultimately, all of these functions described by Hekkert et al. (2007) are most effective when part of an iterative process.

Technological, behavioral, and institutional changes need to be explicitly situated within existing infrastructures and institutions. Recognizing innovation as the product of a multitude of influences and dissecting the different elements that influence innovation promises to help reveal bottlenecks and inform decision-making.

The scholarship discussed above helps peel away layers of complexity for better conceptual understanding of the ways in which context affects innovation. For example, Kotz and Hiessl use Agent

Based Modeling (ABM) to represent choices and decisions by water suppliers and water consumers within an urban water management system, although with coarsely parameterized and incomplete implementation. Translation of such insights into predictive models of innovation systems is in its infancy, and much room remains for further research toward this goal. Arguably, innovation is inherently unpredictable, but attempts have been made to quantitatively model diffusion of new water technologies within multifaceted innovation systems.

Institutional context can be a key hindrance or enabler for innovation in urban water systems. Defining institutions broadly as the rules, norms, and practices that govern decision-making enables inclusion of the multiplicity of factors that shape water systems. Such factors include public health regulations and laws, but also economic, social, cultural, and other nontechnical aspects. Even where technology with demonstrated potential for improving urban water systems is available, institutional challenges may prove to be the greatest hurdles to cross. Learning how institutional elements enable innovation in urban water will be a key enabler of transforming technological inventions into technological innovations.

In many cases institutions hinder possibilities for innovation, as Roy et al. (2008) discuss in the context of sustainable storm water management. Uncertainties in performance and cost relate provide challenges (Roy et al., 2008). This can be exacerbated by risk aversion and resistance of change by decision-makers who may prefer proven technologies to a potentially better one. Insufficient engineering standards and guidelines (Roy et al., 2008) may apply particularly to radical innovations. Fragmented responsibilities, lack of institutional capacity, and lack of legislative mandate (Roy et al., 2008) all provide challenges for decision-making in water systems that cross existing jurisdictions, and institutional design that can address such challenges presents opportunities for new research. Lack of funding and effective market incentives exacerbate water's dual status as a public and private good (Hanemann, 2006). With the possible exception of performance uncertainties, these are not technical impediments per se, but rather institutional challenges that affect the potential for implementation of existing technologies.

In the face of such challenges, there may be the potential to adapt institutions in support of innovation. Edquist and Johnson suggest that institutions can function in three ways to foster innovation. First, institutions can serve to reduce uncertainty by providing information. Information provision can be required by laws, such as the U.S. National Environmental Protection Act reporting requirements.

It can also function through informal means, such as networking among practitioners at industry conferences. Second, institutions can actively manage conflicts and foster cooperation, such as when stakeholder processes allow communities to engage with and develop more durable solutions that take multiple interests into account (Dominguez et al., 2009). Third, institutions can provide incentives for innovation. For example, patent laws generally protect new intellectual property such that entrepreneurs can profit from taking risk on technology development. More specific drivers can be provided by targeted research funding to encourage development in desired areas. Such funding exists from sources including government programs and venture capitalists, but has typically been small for water technologies relative to other natural resources, with U.S. government and private sector investment in water technology lagging renewable energy funding by orders of magnitude in recent years.

#### **Conclusion:**

Several avenues present promising possibilities or avenues for further research. This definition is intentionally inclusive: technological innovation will play a key role in reinvention of urban water systems, but is only part of what is necessary. Innovation usually depends on context, such that major changes to infrastructure include not only the technological inventions that drive greater efficiencies and physical transformations of water treatment and delivery systems, but also the political, cultural, social, and economic factors that hinder and enable such changes. Removing barriers and increasing incentives for more modular systems could increase the effective speed of the technology life cycle, enabling competition and iterative solutions and creating technology portfolios within urban jurisdictions. On the basis of past and present changes in urban water systems, institutional innovation will be of similar importance to technological innovation in urban water reinvention.

From a technological perspective, the observations about risk and risk aversion discussed above may provide additional arguments for the merits of distributed systems. Distributed, modular systems provide the promise of cost-effective ways for new approaches to water and wastewater treatment, but as described above this alone may not be enough to support their adoption and diffusion. However, modular systems could potentially be recognized as a series of experiments, each of which carries less risk to a jurisdiction than a corresponding system-wide change. Development using technology portfolios could spur learning by doing, and pooling such portfolios among multiple agencies could amplify this effect through learning by sharing. Novel

processes for decision support and decision-making hold promise. Building flexibility into decision-making through discursive approaches to planning including strategic planning (Dominguez et al., 2009, 2011) and collaborative processes are increasingly cited as a way to bring additional viewpoints and generate more durable solutions (Innes and Booher, 2010).

Regulatory changes, supported by data on public health risks and system performance, could favor such risk spreading and risk sharing, to increase the potential for decisions that reduce the magnitude of high-risk experiments. Such observations might change the perception of investing in this kind of technology development are currently perceived as too expensive or risky. The key would lie in the recognition that individual large-scale risk-taking is not necessarily prudent from the perspective of an individual decision maker, but increasing collective risk taking by the water industry as a whole has the potential to spur innovation, and thus should be encouraged (Potts, 2009). Frameworks have been proposed that explicitly incorporate multiple aspects of the urban water cycle. They include the soft path concept (Gleick, 2003), Integrated Water Resources Management, and anticipatory governance (Quay, 2010). In locations where water is clearly perceived as a priority, motivating such changes in thinking about water through novel planning processes may prove productive.

Increasing the capacity for strategic planning in order to improve consideration of multiple concerns, acknowledging that such capacity will take different forms depending on specific organizational needs and goals. Information transfer, in multiple directions, needs to be facilitated. The role of boundary organizations to help increase linkages between producers of knowledge and its potential consumers is expanding in some areas of water management, and we anticipate an acceleration of this concept in practice in coming years.

In some cases, indirect pathways have the potential to motivate for new ways of addressing water. Green building and green infrastructure often have water efficiency as components, suggesting possible avenues for leveraging the price premiums they command in the marketplace. However, a focus on water efficiency from such measures may involve generating new standards, or targeting existing ones more heavily toward water efficiency: while LEED certification for green building includes water efficiency, it is limited to five among 69 total possible points (Starr and Nicolow, 2007).

Another indirect lever could be found in the energy-water nexus. Increasing attention to the fact that it takes energy to manage water supplies, and



takes water to produce energy, has motivated an increase in attention to the interactions between the two resources. The potential to draw linkages between water (which arguably is undervalued and has low exposure to market forces) and energy (for which markets exist and future prices are projected to increase) may provide opportunities to gain additional leverage for water efficiency efforts, and to motivate further rethinking of energy resource opportunities that already exist in wastewater treatment. The potential to value greenhouse gas emissions reductions has related implications. Many challenges exist for integrating two regulatory sectors that are each fragmented already, and exploration of the technical and practical opportunities will require technical and policy focused research.

The perception of acute crisis can often be the key to rapid change. The creeping nature of the stressors projected to impact urban water systems makes it challenging to directly leverage such future projections. Drought, however, has effectively focused the public's attention on regional water issues, including in recent years. Most generally, technologists could increase their power to affect change by thinking more broadly about innovation. Not only will institutional innovation be of similar importance to technological innovation, achieving it will present similar levels of difficulty. Intertwined technological and institutional barriers will require joint consideration to enable development of viable solutions for the next generation of urban water management challenges. Achieve the sort of truly integrative solutions that may represent the ultimate in innovative reinvention for urban water, rethinking institutional forms at the same depth as rethinking the hydrological, biological, and infrastructure systems may be appropriate. Increasing the diversity of organizational forms in water providers to reflect the disparate sets of challenges faced by individual utilities is a first step. From the perspective of technologists, engaging or partnering early in the technology life cycle with stakeholders including business and investors may help to develop networks and target nascent technology more directly toward viable niches.

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