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An integrative regional resilience framework for the changing urban water paradigm

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ABSTRACT

The water sector is going through a paradigm shift. Many communities are incorporating decentralized solutions such as water reuse and recycling, stormwater capture, and demand-side management in order to address both short-term and long-term water resources challenges due to population increase, economic growth, intensified climate variability, as well as environmental concerns. For these projects to be sustainable, local characteristics including social and institutional contexts must be incorporated in the planning process. This paper presents a flexible and bottom-up framework that facilitates integration of such characteristics in evaluation of various water resource management strategies. It incorporates various locally-driven factors such as water use efficiency, stress on existing supplies, and adaptation capacity potential, to identify how various local and regional solutions affect resiliency at the utility and regional levels. Rather than defining top-down resilience standards, this framework incorporates quantitative and qualitative assessments that can help decision-makers tailor adaptation measures to the needs and opportunities of a given location or community. A case study application of the framework in the San Francisco Bay Area highlights how community-level characteristics can be used to identify opportunities and adaptation strategies in order to enhance both local and collective water resource resiliency.

1. Introduction

The past few decades have seen changes in the scope and focus of urban water management in many parts of the world (Hering, Waite, Luthy, Drewes, & Sedlak, 2013). Traditional urban water systems were built as a combination of independent components and managed by multiple governing agencies, typically comprising extensive distribution pipelines to bring water into cities, centralized treatment plants, and disposal systems for moving wastewater and stormwater away from urban centers. In many urban areas, where climate variability, growing populations, and degrading ecosystems are prominent, it is now evident that this traditional paradigm will not be suitable to meet future challenges (Chartres & Williams, 2006; Hering et al., 2013; Padowski & Gorelick, 2014; Viviroli et al., 2011). There is increasing awareness that over-reliance on imported supplies places undue stress on supply sources that are themselves sensitive to seasonal precipitation changes, periodic droughts and infrastructure degradation (Brozovic, Sunding, & Zilberman, 2007; Cayan et al., 2010; Diffenbaugh, Swain, & Touma, 2015; Viviroli et al., 2011). Furthermore, the fragmented nature of today's water management institutions translates into a disconnect between local priorities, environmental concerns, and regional water resources that know no political boundaries (Graymore, Sipe, & Rickson, 2010; Hering et al., 2013; Hughes & Pincetl, 2014; Kauffman, 2002; Padowski & Jawitz, 2009). In response to the growing water insecurity, especially in arid and semi-arid regions such as Australia, Israel, and the Western United States, there has been increasing interest in alternative practices including water recycling and reuse (Arlosoroff, 2007), stormwater capture, desalination, water efficiency and conservation measures (Hornberger, Hess, & Gilligan, 2015; Mini, Hogue, & Pincetl, 2015), and combinations of these options (Beh, Dandy, Maier, & Paton, 2014; Luthy & Sedlak, 2015; Newman, Dandy, & Maier, 2014; Srinivasan, Lambin, Gorelick, Thompson, & Rozelle, 2012; Tarroja et al., 2014). The adoption of these alternative supplies has been accompanied by innovative and adaptive governance configurations in the search for more reliable and resilient systems that can withstand variable and uncertain condi-

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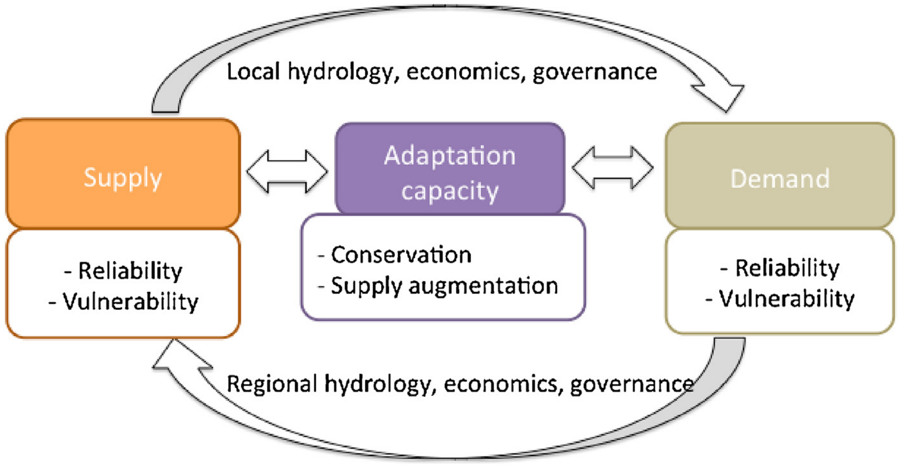

Fig. 1. Resilience framework for urban water systems, based on the assessment of supply, demand, and adaptation capacity.

tions (Beh, Maier, & Dandy, 2015; Connell-Buck, Medellin-Azuara, Lund, & Madani, 2011; Ferguson, Brown, Frantzeskaki, de Haan, & Deletic, 2013; Hughes, Pincetl, & Boone, 2013; Nelson, Howden, & Smith, 2008; Paton, Dandy, & Maier, 2014; Rijke, Farrelly, Brown, & Zevenbergen, 2013; Tal, 2006). Despite emerging initiatives, there are still many financial, political, and institutional barriers to the widespread adoption of more reliable and resilient urban water supplies (Brown & Farrelly, 2009; Hughes, 2013; Moglia, Alexander, & Sharma, 2011; Winz, Trowsdale, & Brierley, 2014). As the water use cycle evolves, existing tools for the assessment, planning and management of urban water systems need to be re-designed to support a more holistic evaluation of the combination of supply diversification options, system-wide dynamics, and intra-regional collaboration called for by the current paradigm shift in urban water management.

Numerous metrics and assessments that have been developed in the past can provide a robust backbone to enable such a systems-level perspective (Brown et al., 2015; Juwana, Muttil, & Perera, 2012; Marlow, Moglia, Cook, & Beale, 2013; Padowski, Gorelick, Thompson, Rozelle, & Fendorf, 2015). For example, the popular metrics of reliability, resiliency, and vulnerability (Hashimoto, Stedinger, & Loucks, 1982; Loucks, 1997) provide an understanding of various components of our water supply systems at various scales, such as regional hydrologic flows (Ajami, Hornberger, & Sunding, 2008; Sandoval-Solis, McKinney, & Loucks, 2011), and local distribution systems (Aydin, Zeckzer, Hagen, & Schmitt, 2015; Li & Lence, 2007). These and other metrics have been applied in comprehensive assessments of the resilience of existing systems when faced with the uncertainties of a range of future scenarios (Milman & Short, 2008; Sullivan, Meigh, & Lawrence, 2006; Sandoval-Solis et al., 2011). However, these assessments typically focus on how robust the engineered or natural systems are with respect to pre-defined standards, rather than their capacity to be adapted in response to changing needs and priorities of multiple water actors and uses (Sivapalan, Savenije, & Bloeschl, 2012; Sivapalan et al., 2014). Overall, while previous approaches have developed useful tools for the analysis of their respective study goals, they have been tailored to the needs of the conventional water management perspective, focused on supply-side infrastructure and centralized top-down objectives. For example, despite the growing emphasis on supply diversification as a means to achieve increased reliability and resilience, there is currently no guidance on what constitutes a diverse water supply portfolio, or how this measure can be used as a guideline to enhance regional resiliency. There is a need for more flexible frameworks that can help identify bottom-up resiliency strategies based on local needs and opportunities, as well as the potential for collaborative approaches.

In this paper we present a novel resilience framework that builds upon previous assessments with two new and significant contributions designed for the emerging challenges in the urban water sector: (1) a focus on the added flexibility that decentralized approaches can provide to urban water systems; and (2) a bottom-up measure that integrates the local socio-hydrologic realities of water service providers and assesses their role on regional-scale resilience. Thus, rather than attempt to define top-down resilience standards for a region and arbitrary numerical goals to pursue, our systematic framework helps identify strategies that suit each community's needs and opportunities which can ultimately improve overall regional resiliency. We follow qualitative and quantitative indicators related to three pillars: supply, demand, and adaptation capacity. We demonstrate the application of this framework to a subset of water utilities in the San Francisco Bay Area of California, who have recently been under significant pressure to implement reliability and resilience measures in the face of a historical drought. The urban water service providers in this case study are interconnected not only by hydrologic systems, but also by a representative coordinating agent: the Bay Area Water Supply and Conservation Agency.

2. Methods

2.1. Conceptual framework

The resilience framework developed in this study integrates a qualitative and quantitative screening of an urban water system's capacity to prepare and adapt to potential stressors based on: the reliability of existing supply portfolios, the capacity to implement demand-side management, and the potential impacts of adaptation strategies on both supply and demand (Fig. 1). The framework consists of (1) defining indicators and metrics relevant to a given region's goals and realities, which are subsequently (2) aggregated into a single resilience index. This is followed by (3) an evaluation of the local and regional characteristics driving the performance metrics of water service providers. Finally, (4) we perform a comparative assessment of what these metrics tell us about urban water reliability and resilience at the local and regional scales. This systematic bottom-up approach provides a comparative platform for utilities to identify their relative strengths and weaknesses with respect to different metrics of interest, while highlighting opportunities for collaborative management in the implementation of adaptation strategies that are feasible and practical in context.