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FEATURED COLLECTION INTRODUCTION: WATER FOR MEGACITIES — CHALLENGES AND SOLUTIONS[1]

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BACKGROUND

The Earth has entered into Anthropocene, a new epoch dominated by people. The world's urban population has grown more than four times during the past 60 years to 3.9 billion. Today, more people are living in the cities than in the countryside in most nations. Cities are growing bigger and faster than ever before (United Nations, 2014). Cities that have a population >10 million are commonly considered as megacities as defined by UN-HABITAT (Li *et al.*, 2015b). Globally, there are about 28 megacities with approximately 13% of the world's urban population (United Nations, 2014). Most of these megacities are found in Asia. By 2030 the world is projected to have 41 megacities with cities in Africa and Asia growing the fastest (United Nations, 2014).

Megacities face many emerging challenges, from economic development and social stability to environmental changes in the 21st Century. Obviously, many of the water resource challenges in megacities are rooted in the rapid rise in competing water demands by people for multiple uses. Water problems arise when water demand cannot be met by water supply due to either natural (e.g., surface or groundwater exhaustion), socioeconomic (e.g., financial and governance), water quality, or environmental constraints. Meeting rapidly growing water demand in megacities often means sacrificing the environment such as water quality degradation, ecosystem damage, and/or unsustainable water use such as groundwater depletion and salt water intrusion. Competing water use by irrigated agriculture, thermoelectric power generation, and industrial and residential water use are common causes of water shortages for megacities, especially in arid or semiarid regions or during extreme drought years.

Water pollution alone from megacities can turn a "water rich" city into a "water poor" one as demonstrated by megacities in many developing countries. Climate change affects water availability everywhere, but megacities are most vulnerable simply because of the large water demand by people (Li *et al.*, 2015a, b). Growing extreme weather events (e.g., hurricane, droughts, and floods) associated with climate change and variability pose some of the biggest challenges to water supply infrastructures in megacities. It is

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important to increase resilience to protect megacities from extreme climate change in both droughts and floods (de Sherbinin *et al.*, 2007).

The complex water challenges of megacities can only be understood holistically recognizing historical, economic, cultural, social, regulatory, and institutional contexts. Water resource issues for megacities cannot be adequately solved in isolation, an integrated, multidisciplinary, and multi-jurisdictional approach, Integrated Water Resources Management (IWRM) is required for efficient and sustainable solutions (AWRA, 2011, 2012). IWRM is defined by Global Water Partnership Technical Advisory Committee (2000) as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." IWRM approaches have been accepted internationally for efficient, equitable, and sustainable management and use of the world's limited water resources and for solving conflicting demands (Michelsen and Brelle, 2012). There have also been many theoretical and technical advances in integrating hydrologic, institutional (laws, regulations, and operations), environmental, and economic factors in water resources management and policy analysis (Booker *et al.*, 2012). In addition, much can be learned from similarities and differences in water resources planning and management in different cities and cultures (Sheng *et al.*, 2015). Managing water resources requires concerted efforts from multiple institutions, technology innovation, and nontraditional approaches (e.g., green infrastructure) toward integrated watershed management. For example, the importance of wetlands and forests for water supply ecosystem services "Natural Capital" is increasingly recognized (Brauman *et al.*, 2007), and preserving and enhancing these services is a cost effective way to address municipal water supplies. Improvements in water use efficiency, conservation, water reuse, managed aquifer recharge and desalination, and water pricing to reflect the true values of water are some of the emerging strategies to achieve water sustainability. Long-term water demands and demand management must be considered in urban planning, while water resource development planning should also be an essential part of the urban planning processes. Advanced technology such as integrated computer modeling, decision support systems (DSS), and smart water grids (i.e., water network linking water sources and end users) are being used in water resource management for megacities.

Peer-reviewed journal publications addressing modern megacity water issues are limited. A Web of Science search with the keywords of "Megacities" and "Water" results in less than 100 citations that focus on water resources in megacities. The seven papers collected in this volume represent samples of ongoing research activities on water for megacities in Asia and North America. These papers reflect recent advances in understanding water sciences and management related to megacities. The central objective of this collection is to share real-world experiences in addressing water management challenges under changing environments, and most importantly with an ultimate goal of developing guidelines and techniques to address important water issues in megacities. It is our hope this collection will help promote international dialog among scientists, managers, engineers, stakeholders, and policy- and decision makers on emerging water resources management challenges surrounding megacities.

OVERVIEW OF FEATURED COLLECTION

This featured collection starts with a synthesis study by Li *et al*. (2015a) who provide a global overview of the diverse characteristics and water challenges for 28 megacities. The authors find megacity water challenges can be best understood from the perspectives of geographic contexts, historical development trajectories, growth rates, forms of urban expansion, and climate change. In addition, urban fragmentation and contradictions between historical and cultural legacies and the rise of globalization of engineering and technology for solving water problems, contribute to modern water challenges as well. The study concludes megacities are increasingly more vulnerable to climate change and other stressors, and the authors further suggest a holistic, cooperative, dispersed engineering approach such as "green infrastructure" that mimics the natural water cycles and fits in local conditions is promising to reduce risks and increase resilience in an urbanizing environment.

Beijing, the capital city of China, is under an extreme water scarcity status and reflects most megacity water problems. Beijing became a megacity in 2000 and its population has doubled in 15 years and exceeds 21 million today. Each year Beijing adds half a million residents, equivalent to the population of Atlanta, Georgia, United States. Wang *et al.* (2015a) provide an overview of the challenges and solutions to provide adequate water supply to support Beijing's continued population growth, sustain its economic development, and improve the living environment. Beijing is challenged by water demands from a large population and economic growth and also water supply decline in precipitation and depletion of groundwater over the last several decades. Based on

Beijing's experience addressing these challenges, in cooperation with the Beijing Municipality Government and the Chinese Central Government, the authors present a host of potential solutions from both the supply and demand sides of the equation. These solutions include inter-basin water transfer, reuse of wastewater, rainwater harvesting, market-based water pricing, and institutional changes in water management in the City and surrounding areas.

Computer simulation models and DSS have become an essential tool to understand hydrological processes, identify water resource problems, and optimize solutions of coupled human-nature systems. Four papers in this collection provide diverse case studies for megacities across China and Jakarta, Indonesia. Water pollution is one of the major threats to megacities' water supplies even in "water rich" regions. This is especially true for coastal cities that rely on drawing surface water during extreme droughts (Sun *et al.*, 2013). Using an Environmental Fluid Dynamic Code (EFDC) modeling framework, Yang *et al.* (2015) examine the effect of drought on pollutant transport in the Yangtze River Estuary, where Shanghai, the largest megacity in China with a population of over 24 million, obtains its drinking water. The authors conclude prolonged residence time coupled with tidal influence during drought-induced low discharge in the river could introduce saltwater intrusion and pollutant accumulation in the estuary, potentially threatening the water supply to the cities around the estuary. The second paper by Xiao *et al.* (2015) describes a DSS framework that is built on hydrodynamic and water quality models (EFDC and WASP, respectively) and a Web-GIS interface. The DSS is designed to allow decision makers access to and control of the highly technical water quality simulation models for managing drinking water security. The study area, the North Pearl River Delta, is a densely populated urban cluster located on the south China coast. It has a combined population of 31.7 million that relies on a tidal river network for drinking water supply. The DSS framework is used to determine pollutant load reductions necessary to achieve water quality goals as well as emergency responses (e.g., flow augmentation) needed to counter sudden water quality degradation during incidental pollution events. The third modeling paper by Hao *et al.* (2015) focuses on water supply and demand balances for Chifeng City, located in the Farming-Pastoral Ecotone in northern China, a region that has experienced tremendous land use changes, overgrazing, and groundwater overuse by the mining industry. Using the Soil and Water Assessment Tool and Water Evaluation and Planning models, the authors examine the effects of adaptive management options such as adding reservoirs, adjusting cropping structure, and improving water use efficiency on water supply and demand relations. The authors conclude combining measures of reducing water demand with measures of increasing supply is the most effective and practical solution to the water shortage problems in Chifeng City. The fourth modeling paper by Vollmer *et al.* (2015) focuses on river rehabilitation strategies and implementation measures targeted at addressing issues related to water scarcity, climate change, and environmental health risks in the megacity of Jakarta, Indonesia. The authors propose a multidisciplinary framework that links riparian landscape change to human well-being and that facilitates stakeholder involvement in decision making. The framework attempts to solve the complex water problems through an iterative, participatory approach based on conceptualization and mathematical modeling that involve nested hydrologic, hydrodynamic, and water quality models operating at catchment, corridor, and local site scales. The study intends to demonstrate a change in paradigm in river rehabilitation is possible, and also provides future scenarios that balance concerns over flooding, water quality, and ecology for a rapidly growing megacity.

As noted above, solving water supply problems requires holistic IWRM approaches that consider interactions between upstream and downstream water uses, between water and land use, between water quantity and quality, and between aquatic communities and other watershed ecosystem services. Forest lands are often found in headwaters and thus are the sources of water supply in many municipal watersheds. Healthy forests sustain healthy watersheds and stable freshwater supplies. There is a close relationship between forests and water resources since forests both produce and consume large amounts of water when producing other ecosystem services. Therefore, water and forest management are inherently coupled. The last paper in this collection by Wang *et al.* (2015b) addresses issues related to tradeoffs between water yield and growing plantation forests in the mountainous areas in arid northern China. The authors design an "ideal" stand structure for multifunctional forests (MFF) and determine its key parameters by integrating existing forest hydrology knowledge and experience. The authors offer a 5-step decision process for MFF stand management so that the water yield function of forests can be improved while promoting other forest functions.

CONCLUSIONS

The number of megacities on Earth is on the rise in the 21st Century and we are living in an increasingly urbanized world. Findings from this collection clearly show that megacities are facing profound challenges to achieve sustainable development under the ongoing rapid global change. Climate change, urbanization, population and economic growth, and social welfare development are common key stresses on the ever-changing urban environments — water resources in particular. Securing adequate and reliable water resources has become one of the top priorities for policy makers, city planners, and land managers in many developing countries as well as developed countries. Process-based understanding of the sources and stressors on water supply and demand, water quality, ecosystems, society, and culture in megacities is essential for designing adaptive integrated water resource management practices, a major tool to solve modern water problems. It has become more imperative than ever that water managers, engineers, scientists, and policy makers work together to develop and implement effective long-term innovative solutions to water issues facing megacities.

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