A hydro-electric installation at China's Three Gorges Dam: urbanization can increase a country's productivity and improve living conditions, but these same benefits often translate into enormous demands on water and energy

Managing urban water utilization: A delicate balance

By Lvxiang Deng and Bryan W. Karney, PhD, P. Eng.

EXECUTIVE SUMMARY

Serious water problems—from issues of scarcity and security to poor quality—now affect a large proportion of the world's population. These challenges are particularly intense in regions with high population density, low average precipitation and weak economies. Given the current state of technology and necessarily limited water sources, administering and using water reasonably and efficiently is crucially important now and in the years ahead.

This article considers the relationships among water supply stakeholders and several water management strategies including the "5E-principle" related to economic, environmental, equity, efficiency and energy factors. We advance a water management system and framework for meeting urban socio-economic growth challenges while maintaining water utilization sustainability, based on a notable Beijing experience.

GLOBAL WATER CHALLENGES

All effective policy decisions and strategies must take into account key physical, social, economic and ecological realities. This is a daunting enough task for conventional subjects, but when a policy inquiry is directed to something of undisputed intrinsic value, and when that subject enters into a complex mix of other interdependent relationships, the challenge can be almost overwhelming. Such is the case with managing urban water supplies.

Indeed, water is a crucial resource for almost every human and natural activity, and ensuring its reliable supply has become a key factor limiting development in many places, not surprisingly in arid regions but even in some historically water-rich areas. Throughout Asia, Africa and the Americas, water scarcity, quality deterioration and security issues have become so severe as to become potential sources of conflict, even violence. Population growth, climate variability, uncertain and overlapping temporal and spatial scales as well as social and environmental considerations all contribute to the complexity of water-resource problems (Alcamo et al., 1997; Arnell, 2004; Biswas, 1991; Shiklomanov, 1991; Simonovic, 2000). To say that there is a looming water crisis is no exaggeration (Johnston Foundation, 2010).

Almost everywhere, the relationships among water resource utilization and preservation strategies, urban socio-economic development and the options for future deployment are imprecise and controversial. Indeed, although there are common threads to water issues worldwide, each region has unique challenges, varying in complexity, intensity and character due to differences in the local economy, in the aquatic environment, in development history, in culture and religion as well as many other factors.

Engineers need to remember that water problems are seldom merely technological, but also social, political and administrative. This reality is gradually impressing itself on the consciousness of the profession as well as upon policy-makers and researchers.

EXPERIENCES FROM LEADING DEVELOPED COUNTRIES

Many countries and jurisdictions—including Canada, the United States, Germany, the Netherlands, Singapore, Israel and Japan—have had natural incentives to foster the growth of water-related industries. For example, water-stressed Singapore has historically relied heavily on imported water from Malaysia, at times for 40 per cent to 50 per cent of its supply. To decrease the vulnerability that this degree of water import implies, Singapore has focused on developing multiple sources including rainwater and the re-use of treated water. As a result, it now has some of the highest water re-use rates in the world (World Bank, 2006). For its part, Israel, with its high level of water scarcity and insecurity, has become a world leader in the development of efficient water technologies such as desalination, reuse, drip irrigation and rainwater use. Indeed, 98 per cent of all Israeli rainwater is put to practical use.

In western countries, such as the United Kingdom, France, the Netherlands and Germany, water treatment and re-use ratios are also very high. There are about 10,000 water treatment plants in each country, or almost one plant per 10,000 people. The ratio of waste water treatment to the total water supply exceeds 90 per cent (Deng, 2009).

At the same time, the water leakage rates during treatment, transmission and distribution are relatively low in most developed nations. In Canada, for example, Toronto estimates its losses at only eight per cent (City of Toronto, 2002).

URBAN DEVELOPMENT AND THE AQUATIC ENVIRONMENT

Effective urban water management rests on understanding the interrelation between the urban economy and the aquatic environment. Normally, there are two key elements to this interaction: (a) the usually negative influence of city growth on the aquatic environment and (b) the key constraints that the aquatic system imposes on urban growth. Clearly, rapid economic development can negatively affect surrounding aquatic environments, whether through hydrologic, geomorphologic, water quality or habitat changes (Stormwater Manager's Resource Center, 2000). Specific negative impacts include disruption of the natural water balance such as changes to the partition of rainfall between runoff and infiltration, an increased likelihood of (or vulnerability to) natural disasters such as flooding and drought, decreased ecological diversity through the dominance of particular (often invasive) species and a general degradation of habitat coupled with local climate change (such as urban heat islands and local changes to wind and precipitation patterns).

Moreover, deterioration of the water environment can retard urbanization, cause regression of local economies and contribute to frequent and destructive natural calamities. The consequences of both insufficient water availability and lower-quality water can degrade human and ecosystem health, reduce agricultural and industrial output, as well as increase the potential for social and political conflict (Postel et al., 1996).

THE CO-ORDINATED DEVELOPMENT CHALLENGE

Despite the importance of water resources, the prevailing urban development model is too often dependent on the ineffectively constrained consumption of renewable and nonrenewable resources, especially water. All countries must directly face the conflict between economic growth with intended improvement of human living conditions on the one hand and natural limitations to that growth with the possible exhaustion of resources. If improperly resolved, this tension can result in deeply unsustainable development.

Moreover, as the water crisis intensifies, so will its inevitable connection to, and interdependence with, energy demands and stressors due to the inevitably heavy energy costs associated with the treatment, supply, and pumping of clean water along with the treatment of used water. The key question related to water management is almost invariably this: can we learn to co-ordinate long-term economic development and water-resources consumption? More specifically, is it possible for the effects of water consumption on the aquatic environment to be ameliorated through a better understanding and use of natural and societal processes?

STAKEHOLDER RELATIONSHIPS

By almost any measure, water management is as important as it is complex. Taking into account relationships among stakeholders, Rowan et al. (2006) studied how water allocation can result in lower economic growth and environmental damage. Stacey (2008) outlines how to progress from a water-management policy review to a regional action plan for the Middle East and North Africa despite its diversity and complex water-related issues. Maynard (1997) illustrates the general relationships among the water resource system, the human system that depends on it and the entity responsible for water-resources management. In all jurisdictions, various relationships must be considered to co-ordinate water-utilization development and urban economic growth.

Urbanization is one way to quickly increase gross domestic product (GDP) and average living conditions. But these same benefits often translate into enormous water and energy demands. Sometimes, they are indirectly related to huge production and conservation projects such as China's Three Gorges Dam, which is motivated primarily by the quest for energy but also has upstream and downstream implications for water use.

Sometimes, urbanization in one area has direct implications for the availability of water serving surrounding cities, since development in one location has impacts on another, and one change can necessitate a sequence of new adjustments. For example, urbanization in one region might cause not only local flooding, but may also have implications for upstream and downstream water levels and flood risks, forcing neighbouring communities to make their own adjustments which then impact their neighbours, and so on. The image of a dog chasing its tail is inescapable.

Rather than the typical reactive response, a more proactive plan for urbanization would be for cities to balance development and water-use goals. Cities need to assess carefully the characteristics and health of the urban ecological system in order to manage industrial and residential water demands from the outset.

Water is also one of the most important and fundamental resources for many industries. If water could be more flexibly deployed, by adjusting the water quality to meet only local industrial requirements rather than broad general standards, for example, it might be possible in some cases to supply water more economically and to effectively reduce water demand. For example, sea water might sometimes be used for sanitary purposes (as in Hong Kong) or rainwater for garden use. Such flexibility has clear positive implications not only for easing water supply, but also for the cost and technical challenges of water treatment and re-use.

Continuing environmental degradation eventually leads to water scarcity and waste. Overall, if a city's demand for water can be limited, so too will be the consequences of the withdrawal of that water from the natural environment. Water resources can be saved by building a smaller and less costly infrastructure for water's supply, treatment and delivery. As a result, there will be more options available for environmental protection, and often more time to explore them since the pace of expansion can also be slowed. Clearly, if any environmental system is less stressed, then its natural resiliency and recovery systems are left more intact for whatever unplanned events ultimately arise.

Another way to position or frame these interacting elements is through what we coin here as the "5E- principle."

'5E-PRINCIPLE'

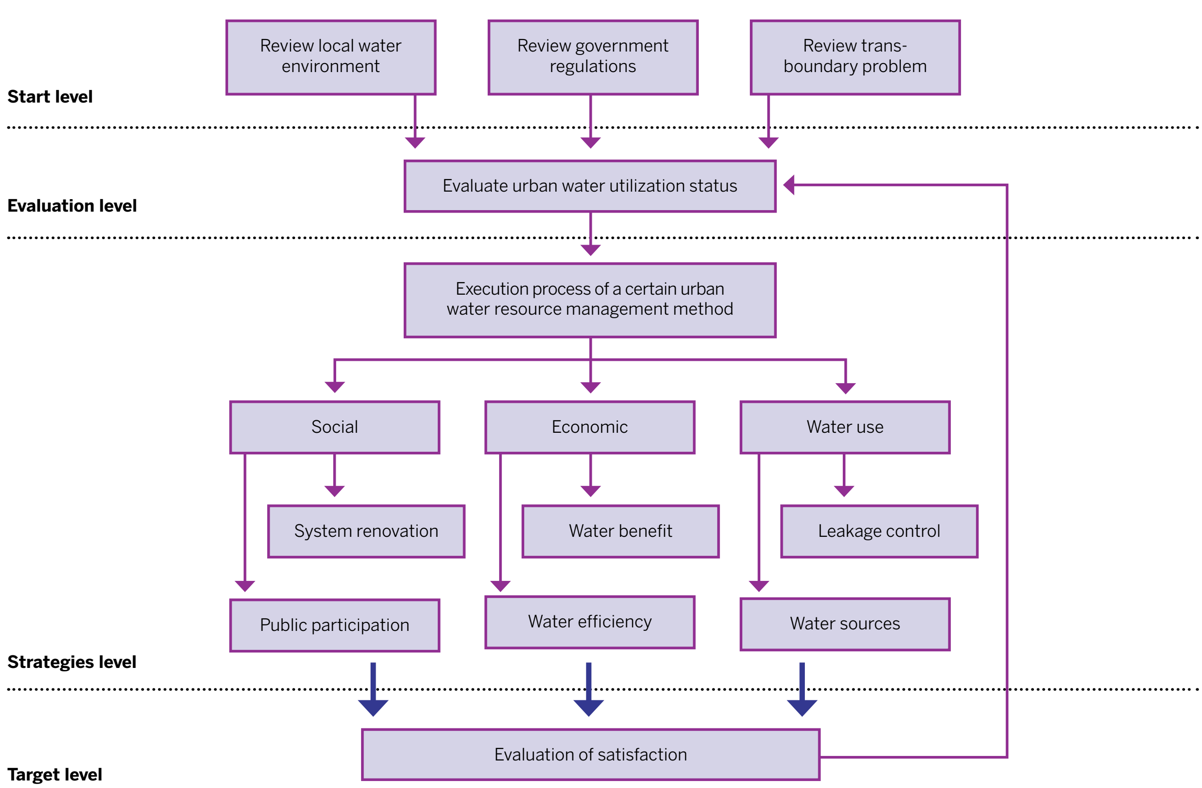
Issues related to water utilization and deployment such as population growth, urbanization, industrial expansion, climate change (whether local or global), as well as deteriorating and insufficient water infrastructure inevitably involve social and political aspects as well as conventional technological challenges. At least five principles should be considered in the complexity of water management, organized loosely here under 5Es. They are: (i) Economic growth which must take into account both (ii) environmental protection and recovery and (iii) equity consider-ations. However, to better constrain and manage the demand for natural resources, consideration must be given also to (iv) efficiency improvements in the technical supply, use and treatment of water and waste water as well as (v) explicit consideration of energy conservation.

In order to better resolve water problems, there are also 4Rs that form a convenient checklist of approaches worthy of serious consideration: reducing demand, reusing water where possible, recycling treated waste water and the renewal/remanufacture of both infrastructure and the systems that use water.

FRAMEWORK FOR WATER MANAGEMENT

Clearly, any framework for urban water management must reflect a country's water-resources policy. To ensure a relevant and sustainable water-management approach, we suggest a prior policy review that should include an examination of: (a) the importance of water from a national, social and economic perspective; (b) quantification of the pressures on water-resources development; (c) identification of

Figure 1: A framework for policy considerations



Source: Author's illustration

Avoiding desertification: balancing the huge and growing human demand for water with water's crucial role within the natural system will be one of the most pressing challenges of the 21st century

options for mitigation; and (d) preparation of a matrix of problems, critical issues and their potential solutions (World Bank/UNDP/FAO, 1995).

The framework proposed here differs from the well-known water-demand management approach used in many countries that is based on pricing and conservation measures to control or manage water demand. Specifically, our framework attempts to draw the attention of policy-makers and stakeholders to both water use and its socio-economic aspects in order to co-ordinate both kinds of development (see Figure 1). The key assumption of the 5E framework is that the world is dynamic and that water policies must be reviewed and executed both consistently and regularly. In Figure 1, the pivotal parts are the "Evaluation level" and "Target level." Both raise obvious questions of evaluation, which require a still-challenging analysis as part of the assessment under the "5E-principle."

Note that water-related social strategies generally include public participation, water-management modelling, an approach to water use, water-use standards, water-efficiency planning and technical considerations raised by the engineering community. Economic strategies include water price adjustments and their variation over the period of use, water benefits, water subsidies, water rebates and other proposed measures. Water-use strategies include leakage control, water metering technology, rainwater use, water audits, water sources exploitation and technical improvements to household appliances and devices.

BEIJING'S EXPERIENCES

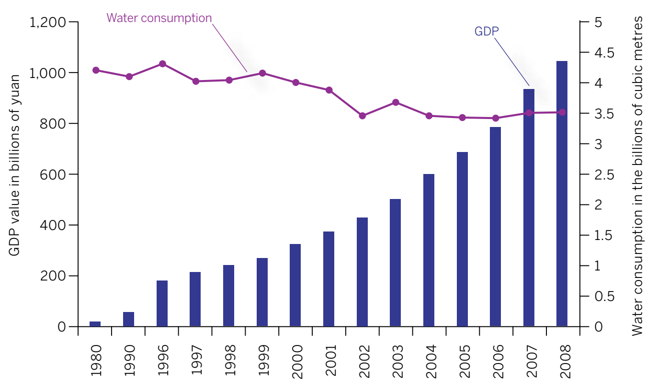
Beijing, with a per capita average water use of about of 300 cubic metres per year (Beijing Water Authority, 2008) in a water-scarce region, is in many ways a microcosm of China. Several factors might well make Beijing, with its population of some 20 million, one of the most seriously water-scarce metropolitan areas in the world (Huang and Wang, 2005). There is an acute conflict between supply and demand caused by rapid economic development, especially under conditions of recent and persistent drought. Increased water pollution, related to an inability of wastewater treatment to keep up with demand, has increased the ecological stress in the nearby aquatic environment. As a result, there has been a lowering of water levels and quality in both surface and subsurface systems.

To address these concerns, the Beijing authorities are enhancing water-use efficiency to maximize economic output while minimizing resource consumption. Among the measures employed are delivery-system efficiency improvements, preserving the water ecosystem by limiting water withdrawals during sensitive time periods (such as periods of low water levels, high water temperatures with their corresponding low concentrations of dissolved oxygen or during spawning seasons), reducing water demand through improvements to manufacturing processes and improving water-use and treatment technology.

Specifically, Beijing has restricted or relocated high water-consuming industries (such as power, iron and steel companies) to regions with water surpluses, developed tertiary less-water-consuming industries (such as high-tech and retail) and decreased water use for agriculture by reducing local areas under irrigation through better crop choices and applying a variety of water-saving technologies. As well, Beijing is looking elsewhere for water relief, such as through water supply diversions including the controversial proposed South-to-North Water Diversion

Captured rainwater can provide a viable supply of the often scarce resource. Among other sources, Singapore has developed rainwater diversion and re-uses treated water. Fully 98 per cent of all Israeli rainwater is put to practical use

Figure 2: Beijing GDP compared with water consumption



Source: Beijing Water Resources Bulletin 1980, 1990 and 1996-2008

Project. Finally, Beijing has moved to rely more on re-used water and rainwater.

The past several years' efforts have led to some successes. In 2008, Beijing's GDP was US$150 billion, more than triple the 2000 figure, even while total water consumption in 2008 decreased by 100,000 cubic metres, almost 15 per cent less than in 2000 (see Figure 2). However, this impressive record does not answer the ultimate question of whether sufficient sustainable water supplies exist to support the vast urban area and its industrial activities. Certainly, the concerted effort has demonstrated that high water demands can be at least partially limited, that local challenges can be effectively met and that actions make a difference.

CONCLUSION

The challenge of managing an urban water system efficiently and effectively is a long-standing and demanding one. There is a deepening and widespread recognition that the already huge but still growing human demand for water must be balanced with water's still-crucial role within the natural system. Given this tension, not to mention regional differences in water use and supply, it can easily be anticipated that the quest to create, maintain and revise effective water-management policies will be one of the most pressing challenges of the 21st century.

Certainly, as described here, there are many tools and options for addressing these issues, ranging from the quest for more efficient technologies to better economic incentives, to a better evaluation of the tradeoffs between different options. Where large cities have quickly expanded, particularly in areas of relative water scarcity like Beijing, only a range of co-ordinated strategies are likely to be effective.

What is clear overall is that water will continue to challenge us, to frustrate us, to enliven us and to fascinate us, perhaps particularly so as we move into a period where we can no longer presume its unlimited and inexpensive abundance.

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