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KEY POINTS

- Beijing, the second-largest city in the world, ranks high among the most water-stressed cities.
- This brief presents several methodologies, high-level technologies, and policies that can help the People's Republic of China, particularly Beijing, accelerate and enhance water conservation planning. These include several measures: technical (water-saving features, urban forest); financial (tariffs, carbon tax); and social (public awareness, education).
- Managed aquifer recharge with treated effluent reuse is one of the most cost-effective water conservation measures for Beijing Capital Region, with high potential in other water-stressed cities to restore both quantity and quality of groundwater.

Water Conservation Strategies for Beijing Capital Region

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ABSTRACT

Beijing is the world's second-largest city after Shanghai and one of the most water-challenged cities. Faced with limited options, Beijing can only sustainably meet the additional water demand by 2030 through enhanced water conservation. Specific water conservation measures being reviewed include tariffs, nonrevenue water, increased water quality, water reuse, groundwater recharge, and residential water saving. One innovative approach for conserving water resources while increasing growth of urban forests to reduce urban heat and develop carbon sinks involves the use of sludge from septic tanks for its water content, instead of the freshwater now used for the city's landscaping. A project under consideration is recharging Beijing's declining aquifers with treated effluent through various techniques. Another water conservation measure consists of structuring a revolving fund to provide partial water tariff rebates for the purchase of low-water fixtures. This brief describes the current situation in Beijing and the proposed way forward for water conservation, including principles for groundwater recharge, wastewater reuse, carbon storage, and water tariff rebates.

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INTRODUCTION

Beijing Capital Region (BCR) is home to over 23 million people (2017) at the heart of the water–food–energy nexus with competitive use of water between agriculture (the largest user), industries, and cities. Water, as a limiting factor for growth in the BCR, is compounded by climate change impacts that could result to a much hotter and drier weather. According to the World Health Organization, acute water scarcity occurs when water resources fall below 500 cubic meters (m^3) per person per year; Beijing qualifies as a water-stressed city with water resources approximately 200 m^3 per person per year. Over 44% of the population of the People's Republic of China (PRC) resides in the country's north, with 58% of the total cultivated land, but only 15% of total water resources, mostly used for agriculture. With expanding urban population and local economic development, domestic and industrial water demand is growing at a faster rate than agricultural water use; this results in additional pressure on already dwindling water resources, threatening water and food security. In 2016, the total annual water consumption in the BCR, including agricultural use, was 4 billion m^3 with renewable freshwater resources estimated within 3 billion to 5 billion m^3 per year. With a water demand forecast of 4.5 billion m^3 by 2020, the BCR faces water shortage within the next decade.

Currently, about 55% of Beijing's water demand is met from groundwater and 45% from surface water. With groundwater levels retreating and limited water resources availability, one of the best options to sustainably meet the 2030 water demand is through water conservation. In addition, the Government of the PRC initiated the "national sponge city program" to plan climate change adaptation investments to store water in flood-prone areas through low-impact development urban planning and groundwater recharge. This brief explores additional water conservation measures for the BCR from international best practices case studies that can be upscaled to other water-stressed cities. These include vastly expanding the urban wetlands and groundwater recharge amounts; recycling treated effluent; and implementing mandatory water conservation methods, including low-flow fixtures, building water audits, drought-resistant landscaping, and labeling water appliances. Water conservation deals with the demand side of water resources is critical for water-stressed cities such as Beijing, to ensure adequate water supply to the population and partly address the competitive use of water within the water–food–energy nexus in the BCR.

METHODS

Review: ADB's Beijing Water Conservation Plan Review and Supporting Cases Studies

The Asian Development Bank (ADB) is assisting the Beijing Municipal Government (BMG) to meet its future water demand in an enhanced water conservation plan (WCP) by reviewing and assessing specific water conservation measures: tariffs; nonrevenue water (NRW); improved water quality; water reuse (wastewater; stormwater; industrial water); groundwater recharge (sponge city); water-saving fixtures; sustainable urban forestry and landscaping; and water conservation education.

Groundwater recharge with recycled water, an important water conservation measure, is already identified as necessary for sustainable agricultural, residential, and industrial water resources in other parts of the PRC. The World Bank's Second Water Conservation Project focuses on agricultural water conservation, and one aspect is sustaining groundwater elevations.[1] A recent ADB study in Beijing concluded that managed aquifer recharge (MAR) is possible in the dry riverbeds of the Chaobai river in the BCR.[2] The river channel proposed for MAR is 12 kilometers (km) long and about 500 meters (m) wide, with a base consisting of gravel and cobblestones. The proposed channel depth is between 12 and 20 m with the underlying aquifer about 150 to 350 m thick and the water table at 60 m. The total MAR area is estimated at 3 square kilometers (km^2) and annual total MAR potential amounts to 290 million cubic meters (m^3), using an infiltration rate of 0.4 m^3 per day (m^3/d) with 240 days of operation. The proposal includes a river channel to be constructed as an ecological corridor for scenery, public recreation, dust prevention, and nature conservation. Potentially safe and treated effluent could enhance the MAR.

The Beijing Water Affairs Bureau (BWA) implements NRW reduction programs with leak detection, block tariffs, low-flow toilets, and regulated water restrictions for activities such as car washes, bathhouses, and golf courses. In 2012, an ADB study recommended investing in technology upgrades to both realize complete treated effluent reuse and to reduce wastewater's large energy and carbon footprint.[3] The study concluded that NRW could be improved through smart water management. Currently less than 1 million m^3/d wastewater is recycled in Beijing, with most of the recycled water used for cooling, and some for road cleaning and landscaping. Rainwater is not harvested in Beijing due to the low rainfall, but the government is studying options to collect

[1] World Bank. 2012. *Water Conservation Project II (PRC)*. Washington, DC.

[2] ADB, IHE Delft. 2018. *Guidelines and Good Practice for Managed Aquifer Recharge with Infiltration Basins: Demonstration Project on Artificial Groundwater Recharge in Beijing*. PRC.

[3] ADB. 2014. *Water Management: Water Metering, Sludge Management, and Nonrevenue Water – the PRC Experience (Support to Evaluation of Sludge Treatment Technologies for Beijing Drainage Group and Development of a Nonrevenue Water Action Plan for Beijing Water Affairs Bureau)*. Manila.

rainwater and is developing harvesting codes. Under the new plan, the Ministry of Housing and Urban–Rural Development will require rainwater collection systems constructed in all new buildings. BWA sources some of its water from the Yangtze River through the South-to-North Water Diversion Project, but expects to meet future water demand primarily through the implementation of an enhanced WCP.

Case Studies: Relevant International Examples and Lessons Learned

Case Study 1—Ho Chi Minh City, Viet Nam: implementing water conservation to meet water demand. Ho Chi Minh City has severe groundwater depletion, contamination, and saltwater intrusion causing similar issues experienced in northern PRC with a water–food–energy nexus under pressure. The Saigon Water Corporation (SAWACO), in charge of water supply in the city of 8.6 million people, completed in 2013 with the assistance of ADB, a WCP focused at practical and effective water conservation measures.[4] SAWACO's initial plan to meet this growing water demand was to develop an entirely new water resource at a cost of over $500 million; however, the cost ratio between the new water resource and the WCP is over 100 to 1. By implementing a third of the WCP, SAWACO is delaying the new water resource investment by more than 15 years, while improving water availability through demand management.

The Department of Natural Resources and Environment formulated and enforced a policy to restrict the amount of groundwater extraction to less than 440,000 m^3/d by 2016 and 100,000 m^3/d by 2025 from 660,000 m^3/d in 2013. Groundwater users need a water connection from SAWACO, thus, adding about 500,000 m^3/d to the water demand by 2025. This demand is expected to be met from both water conservation and restoration of groundwater resources to increase future water security.

Case Study 2—Southern California, United States (US): passive groundwater recharge, water-saving fixture programs, and public education. The Southern California region in California state, which includes Los Angeles and Orange counties, met water demand over the last 20 years largely through water conservation. In 1976, Orange County decided to reuse treated effluent and upgraded wastewater treatment processes to include microfiltration, reverse osmosis, and disinfection by ultraviolet combined with hydrogen peroxide. Approximately 200,000 m^3 of recycled water is now pumped daily into injection wells to maintain ground water elevations and prevent salt water intrusion. Another 200,000 m^3 is transferred to recharge basins lined with sand and gravel to help filter prior to discharge to the Santa Ana River, which recharges the groundwater for water supply and irrigation.

The Los Angeles Department of Water and Power (LADWP) WCP considers three levels of investment that includes passive program conservation potential least cost, maximum cost-effective conservation potential target, and technical maximum conservation potential. This grading allows an upper target while starting with a least-cost, readily achievable target. Notable for application in the PRC, LADWP's WCP uses multiple tools, including earned media opportunities (WCP updates), social media (facts, web links, reminders, and videos), print materials (fact sheets and message on bills), media advertising, education (focus on grades 4–12 lesson packages), training (hands-on workshops), and city ordinances (plumbing codes and landscape ordinances). The landscape ordinances have immediate results and specifically include the Retrofit-on-Resale Ordinance, requiring that upon the sale of an existing building, all plumbing fixtures must be brought up to current code to advance the replacement of old, inefficient plumbing fixtures with efficient toilets and water-saving features to conserve water.

Case Study 3—Phoenix, US: passive groundwater recharge, low-impact development, and drought-tolerant urban landscaping. The city of Phoenix located in the harsh and water-starved Arizona state implements a comprehensive WCP with landscaping as the most relevant part for the water-stressed BCR. Phoenix does not rely on rainfall as a water resource and, thus, the WCP focuses on drought-tolerant landscaping, efficient use of reclaimed water for nonpotable purposes, groundwater management, and aggressive leak detection and repair programs. The WCP was initiated in the mid-1990s and, since then, the average per person water usage dropped 25%. In 2013, the total municipal water production in Phoenix was the lowest since 1995, even with a 30% increase in population. Phoenix decided to exceed the state's water conservation requirements and set a target of "no-drop in the groundwater table level or quality" to achieve sustainable water security. The city now recycles 100% of its wastewater after treatment for reuse in agriculture, energy generation, urban landscaping, aquifer recharge, and riparian wetland maintenance.

The Phoenix Parks and Recreation Department is the city's largest water user in charge of maintaining more than 180 parks as well as providing city landscaping. The WCP started a revolution with the use smart technology to monitor and distribute water throughout the greater Phoenix area. Smart water management includes simple measures such as reduced irrigation frequency cycles, drip irrigation, drought-tolerant landscaping, and mandatory skipping-watering days when the temperatures are cooler. Smart irrigation technology means smart controller installations in all the parks and irrigation areas to minimize water runoff in public, private, and agricultural areas; and collecting excess water for reuse. In 2014, smart water upgrades resulted in $400,000 in annual savings, as well as substantial water saving.

[4] ADB. 2011. *Report and Recommendation of the President to the Board of Directors: Proposed Multitranche Financing Facility to the Socialist Republic of Viet Nam for the Water Sector Investment Program. Tranche 1.* Manila.

Phoenix also found that tree cover is critical to reduce urban heat, but also important for water management, even in a low rainfall area like Phoenix. Trees absorb water through evapotranspiration and lower humidity and temperature; even though trees have a water demand, the water investment is returned with a short payback. Many cities have a documented "urban heat island phenomenon" that can translate to about 5.5 degrees Celsius temperature increase compared to surrounding rural areas, depending on heat emissions and tree cover; Phoenix is about 8 degrees Celsius warmer in areas without tree cover.

Case Study 4—Amsterdam, Netherlands: active groundwater recharge. The Netherlands is well known for its prowess in water management. One key tool—MAR —helped for over 75 years to secure drinking water resources and stabilize its coastline. Initially, aquifers were recharged passively, but now, MAR is accomplished using multiple techniques and technologies, with infiltration basins proved to be the least expensive and most flexible. Since 1853, the city of Amsterdam relies on groundwater abstraction from the coastal sand dunes. Artificial recharge started in 1957 to prevent seawater intrusion into the dune area water supply and to secure sustainable groundwater elevations. MAR consists in pretreatment and transportation of surface water from the Rhine river to the dune area infiltration basins, and then recovered via abstraction canals and underground collection systems. Smart water management includes monitoring wells, piezometers, and surface water quality stations, feeding several groundwater models that predict groundwater elevations, groundwater flows, and simulate fresh or salt water interfaces. Data-driven system operations are immediately responsive to emergencies, including interruption of transport pipelines or accidental pollution.

MAR is also used to store water in dedicated aquifers from a variety of water resources, including surface water, treated effluent, stormwater, and rainwater. The monitoring and evaluation follows a formal process: initially, the quantity and quality of the water resources are both assessed; then, the aquifer storage capacity is monitored to transfer the intended volume of water; finally, the infiltration capacity requirement is evaluated to determine the infiltration basins design, taking into account environmental impacts (usually positive) and costs. The total cost is a combination of land use, transportation (both in terms of capital and operation cost), and level of water treatment required by water resources. In addition, infiltration basins' design parameters incorporate ecology and biodiversity protection and public consultation. The design also needs to consider either large basins or multiple smaller infiltration basins with maintenance, recharge zones, and water quality as key design criteria. Constructed wetlands can be incorporated into the MAR to help with the recharge, but also to control high solids concentrations and nutrients, both of which can clog basins.

RESULTS AND DISCUSSION

Enhanced Water Conservation Methods Proposed for Beijing

Low-flow fixtures and labeling. Current water conservation measures include the use of water-saving fixtures and labeling systems that are not yet formalized or universally applied. The water-saving labeling scheme with a logo representing various levels of water savings is ready to launch in 2019 in the PRC market. A system using fixture rebates on tariff to promote wider use and labeling water use rates on appliances is recommended. The use of water-saving fixtures, labeling systems, and rebate programs will result in lower water use with minimum investment. Minimum water efficiency standards for fixtures and appliances with a proper labeling system can reduce water use by up to 30% in residential buildings through appliance labeling regulations; performance standards for fixtures and appliances; testing program in agreement with the manufacturers and suppliers; and publication, promotion, and education materials for both manufacturers and consumers.

Constructed wetlands and MAR. To implement the national sponge city program, the BCR needs to identify groundwater balances, draw-down rate, and water volumes required to stabilize groundwater depletion. Recharging groundwater with treated effluent is done in western countries through infiltration wells, wetlands, and impoundments; and the Beijing study demonstrates strong potential. Two of Beijing's wastewater treatment plants (WTPs) successfully use wetlands for polishing effluent: this can be upscaled with land availability and cost as limiting factors. The redesign of existing canals, impoundments, lakes, and rivers should include enhanced groundwater infiltration. With the planned upgrades to tertiary wastewater treatment in the BCR, the resulting treated effluent can be used for MAR in the newly redesigned waterways with minimized clogging. The new waterways are beautified, contribute to the greening of the city, and increase land capture to help offset and partly recover the investment cost of a sponge city. The BMG plans 47 recycling plants and upgrades of 20 existing plants with advanced technologies. While the current plan is to reuse treated effluent for landscaping, MAR would be a better option.

Stormwater. Within Beijing's core city (inside the 4th ring road), the drainage network is combined collecting both rainwater and wastewater; therefore, stormwater recycling is only a cost-effective option in the peri-urban areas (outside the 4th ring road). Currently, stormwater occurring between May and August in lower frequency and intensity due to climate change impacts limits the opportunity for reuse. Gray-water collection treatment and recirculation is not common; separate gray-water systems were piloted in some buildings, but due to noise, high investment and operation cost, and low water price, the demonstration did not take off.

Water for urban forests and landscaping. The Beijing Forestry Bureau (BFB) uses 600 million m^3 of water per year to irrigate urban forests and landscaping. Over the next 3 years, the BFB will plant an additional 300 million trees with a high potential to reuse effluent. A study funded by ADB in partnership with the Bill & Melinda Gates Foundation concluded that the water content in the treated sludge is a cost-effective method to irrigate urban forests and nurseries' trees in water-stressed cities, in general, and in Beijing, in particular. Project preparation started in 2019 to enhance fecal sludge management in Beijing and other cities, and safely reuse the treated sludge for irrigation. To improve water conservation, the BFB is experimenting with native and drought-tolerant flora species, but the demand of residents and developers for high water-consuming flowers and urban landscaping continues to grow. New tree plantings are 90% native species and use on average 50 to 100 liters of water per tree per year. Enhancing biodiversity by planting native species is in competition with drought-tolerant species, both for trees and landscaping.

Social Dimension, Education, and Public Policy

Water conservation requires addressing institutional, capacity, and public education hurdles, along with technical and policy issues. Institutionally, water conservation crosses several themes and sectors and, thus, many government agencies, civil society, and the private sector are involved: Institutional arrangements and stakeholders' engagement are key success factors for any water conservancy program. Water production, treatment, distribution; and then wastewater collection, treatment, and disposal usually are a city's largest energy consumers. Educating residents as water consumers and stakeholders on the greenhouse gas (GHG) implications from the water and sanitation sector can draw strong public support for water conservation, in addition to health and environmental co-benefits. Having all government agencies on board helps with both implementation and education of the water conservation program. Most of the policies required for water conservation in the BCR are either in place (NRW national targets, national sponge city program, water and wastewater tariffs, limits on water abstraction, and others) or under consideration (such as rebates and labeling), so public support is the next hurdle for the successful implementation of a comprehensive and enhanced WCP.

Financing Options and Upscaling

There are several accepted methods to finance a WCP and MAR. The most common is through increasing tariffs that leads to water savings. Currently, the PRC's water and wastewater tariffs are 30% to 70% lower than most western countries, as indicated in the table below. Government's targeted subsidies and incentives (rebates) can also help drive the market and provide required gap financing for upfront capital expenditures. Rebates from revolving funds for water-saving fixtures are successful in many countries (e.g., US). The proposed implementation of a carbon tax in the PRC, that could apply to water, would increase tariff and reflect the true cost of climate change mitigation impacts. As such, true GHG emissions from water operations could exceed 1 million tons carbon dioxide per year in Beijing, resulting in drastic tariff increase.

Urban Water and Wastewater Tariffs (CNY/m^3)

City	Water Tariff	Wastewater Tariff
Beijing (PRC)	4.00	1.50
Shanghai (PRC)	3.45	1.70
Shenzhen (PRC)	3.57	0.90
Chongqing (PRC)	3.50	1.00
Manila (Philippines)	1.95	-
Busan (Republic of Korea)	5.40	2.90
50 cities (US)	9.90	12.26
Paris (France)	12.50	14.20

CNY/m^3 = yuan per cubic meter, PRC = People's Republic of China, US = United States.

Source: Global Water Intelligence Tariff Survey 2014.

Another common method of financing is through public–private partnerships, with the use of private institutional and commercial financing or blended financing. For instance, a water fixture rebate fund (Southern California case study) could be financed and managed by the private sector with water savings valued through tariff or carbon tax. MAR using treated effluent could also be operated as a service by the private sector with an optimization of the initial high capital costs.

CONCLUSIONS

This study concludes that the PRC, in general, and Beijing, in particular, are well on the way to enhanced WCPs. The discussion highlights several methodologies and high-level technologies and policies that can help accelerate water conservation implementation using international best practices case studies. Raising tariffs always has the most immediate results supporting water conservation, driving the use of water-saving fixtures and boosting the treated effluent reuse business. A carbon tax would support climate change mitigation efforts to reduce water and carbon footprints of the water and sanitation sector, resulting in lower GHG emissions.

A revolving fund to finance water tariff rebates for water-saving fixtures could decrease water consumption by about 10% (Ho Chi Minh City case study). Commercial banks could run the fund with replenishment though documented water savings. Combined with increased public awareness and education, water-saving fixture programs can be very successful.

MAR with treated effluent reuse is one of the most cost-effective water conservation measures for the BCR, with high potential in other water-stressed cities to restore both quantity and quality of groundwater. This is critical for sustainable water security under the water–food–energy nexus for cities, agriculture, and energy generation.

Currently over 90% of wastewater in the BCR is centrally collected and treated, but two major issues prevent recycling: (i) effluents are not consistently meeting the prescribed legal discharge standards for reuse and (ii) effluent reuse delivery methods from the WTPs to the consumer are expensive, with dedicated investment required for distribution. Both water quality and delivery issues can be solved with high-level technology upgrades and access to finance. WTPs' operational improvement and implementation of a monitoring and evaluation program would increase consistency in the treated effluent water quality (and improve asset management), combined with upgrading of the other plants would increase production for recycled and reuse water. The BMG plans to reinforce the construction and upgrade of pipelines for reuse effluent (over 1,200 km). Cooling water at power plants and industrial sites represents the largest use of reuse effluent in the BCR, and the market has considerable room to grow with a consistent high-quality reuse effluent produced and distributed.

FURTHER READING

Allen, R., F. Gichuki, and C. Rosenzweig. 1991 CO2-induced climatic changes and irrigation-water requirements. *Journal of Water Resources Planning and Management.* 117(2). pp. 157–178.

ADB. 2013. *Report and Recommendations to the President: Proposed Loan and Technical Assistance.* Beijing Enterprises Water Group, Limited Environmental Group. Manila.

ADB. 2012. *Development of Nonrevenue Water Action Plan for the Beijing Waterworks Group: Second Report.* Manila.

ADB. 2018. *Managed Aquifer Recharge with Infiltration Basins: Demonstration Project on Artificial Groundwater Recharge in Beijing, People's Republic of China.* Manila.

ADB. 2011. *Report and Recommendation of the President to the Board of Directors: Proposed Multitranche Financing Facility to the Socialist Republic of Viet Nam for the Water Sector Investment Program.* Manila.

A. Snow. 2018. 'Urban Island Effect' Compounds Phoenix's Sweltering Heat. *The Associated Press*. 27 July.

E. Thompson. 2017. Modeling Beijing's Water Crisis. *EOS 98*. 25 October.

J. Zheng. 2016. Beijing Taps New Water Source. *China Daily*. 26 February.

United States Environmental Protection Agency. 2010. *Cases in Water Conservation: How Efficiency Programs Help Water Utilities Save Water and Avoid Costs.* US.

Shimizu, Y., S. Dejima, and K. Toyosada. 2012. The CO_2 Emission Factor of Water in Japan. *Water*. 4(4). pp. 759–769.

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