

# Reimagining urban water systems

The City Water  
Optimization Framework

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## About this report

**This report was developed by The Economist Intelligence Unit, supported by DuPont Water Solutions.**

Through comprehensive desk research, literature reviews and expert interviews, this report investigates the case for water optimization at the city level and presents the findings of a novel urban water optimization benchmarking framework that can help decision-makers assess their current performance across a range of operational, regulatory and policy domains.

First, the paper explores the water crisis facing the world's cities and discusses progress in shifting from water scarcity to abundance. The report then presents the City Water Optimization Framework.

The Economist Intelligence Unit bears sole responsibility for the content of this report. The findings and views expressed herein do not necessarily reflect the views of the partners and experts. The report was produced by a team of in-house researchers, writers, editors and graphic designers, including:

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## Rethinking the water crisis

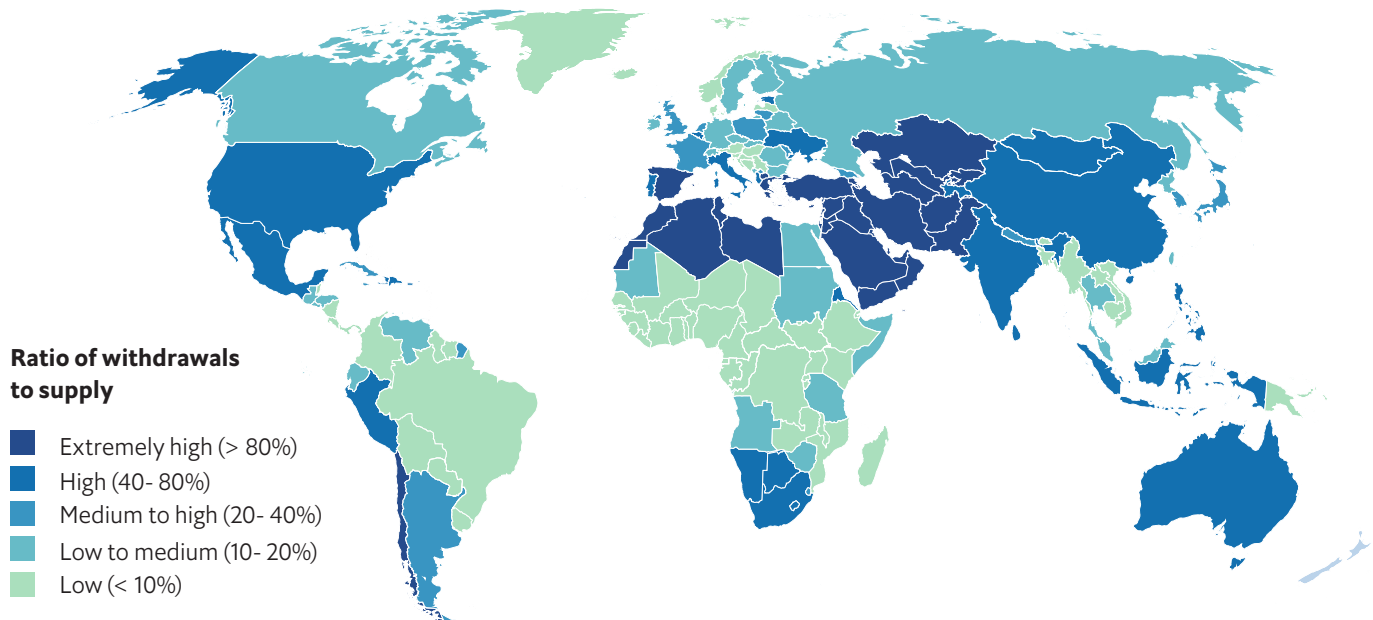
Quickening urbanization, population growth, climate change and economic development are placing pressure on water systems. A quarter of the world's population face extremely high levels of water stress, with the prospect of taps running dry. Dubbed "Day Zero", this issue has loomed dangerously close in cities from Cape Town to São Paulo.<sup>1</sup> A total of 44 countries face either "extremely high" or "high" water-stress levels, according to the World Resources Institute, which also predicts a swathe of water-vulnerable geographies by 2040 (see Figure 1).<sup>2,3</sup> At the same time, rising sea levels place a growing number of geographies, particularly in East and South-east Asia, at a higher risk of flooding, which can overwhelm sanitation systems and pollute drinkable water sources (see Figure 2).

**44 countries**  
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high" or "high" water-stress  
levels, according to the  
World Resources Institute

1 "Release: Updated Global Water Risk Atlas Reveals Top Water-Stressed Countries and States," World Resources Institute, July 16, 2020, <https://www.wri.org/news/2019/08/release-updated-global-water-risk-atlas-reveals-top-water-stressed-countries-and-states>.  
2 Rutger Willem Hofste et al., "17 Countries, Home To One-Quarter Of The World's Population, Face Extremely High Water Stress," World Resources Institute, August 26, 2019, <https://www.wri.org/blog/2019/08/17-countries-home-one-quarter-world-population-face-extremely-high-water-stress>.  
3 Andrew Maddocks, Robert Samuel Young, and Paul Reig, "Ranking the World's Most Water-Stressed Countries in 2040," World Resources Institute, August 2, 2019, <https://www.wri.org/blog/2015/08/ranking-world-s-most-water-stressed-countries-2040>.

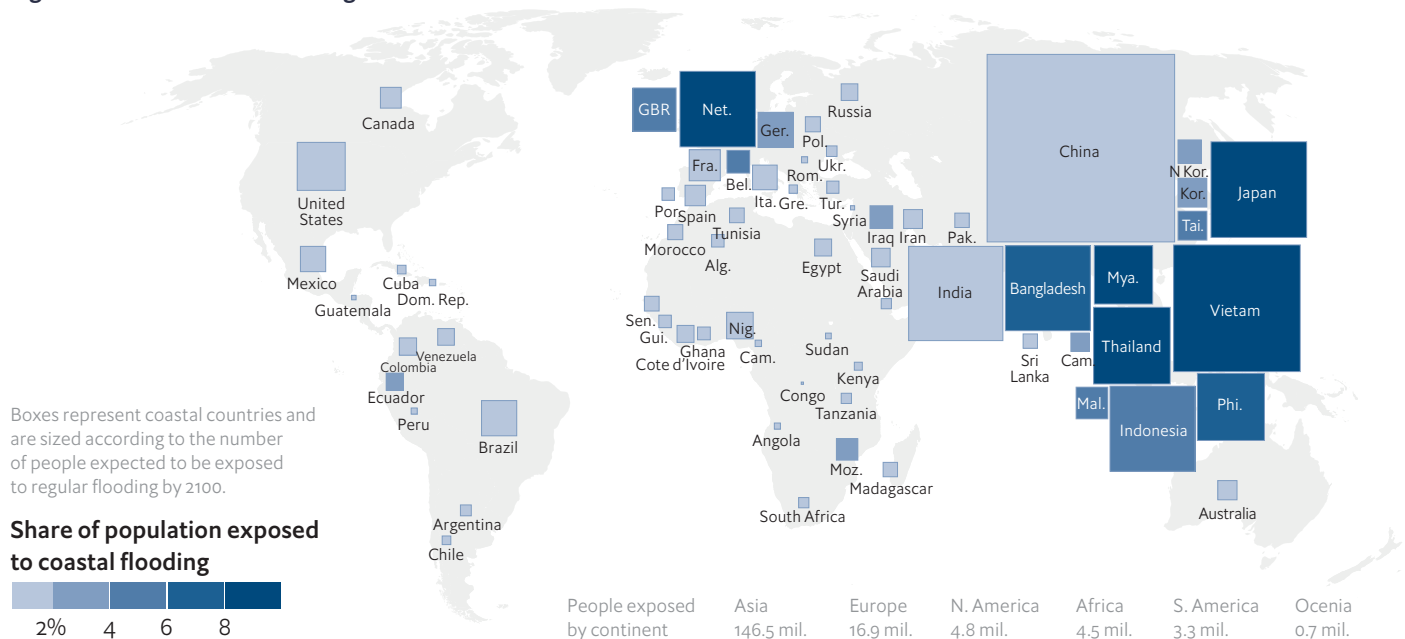


Figure 1. Water stress by country in 2040



Note: Projections are based on a business-as-usual scenario using SSP2 and RCP8.5.  
Source: World Resources Institute

Figure 2. Risk of coastal flooding in 2100



Global estimates of population number (square size) and proportion (square colour) at risk from coastal flooding by 2100 by country. Assumes current emissions trends continue, and a central estimate of sea level rise.

Source: Climate Central<sup>4</sup>

<sup>4</sup> Robert McSweeney, "China Tops New List of Countries Most at Risk from Coastal Flooding," Carbon Brief, October 5, 2020, <https://www.carbonbrief.org/china-tops-new-list-of-countries-most-at-risk-from-coastal-flooding>.

Cities are currently home to more than half of the world's population,<sup>5</sup> a proportion that is projected to reach 68% by 2050.<sup>6</sup> This makes water-related stress a central policy concern for municipal leaders and governments. Many cities will, on current trends, face intensifying shortages of freshwater in the years ahead, especially across the Middle East and Central Asia (see Figures 3 and 4). By 2050, 685 million people living in over 570 cities will face at least a 10% decline in freshwater availability due to climate change.<sup>7</sup>

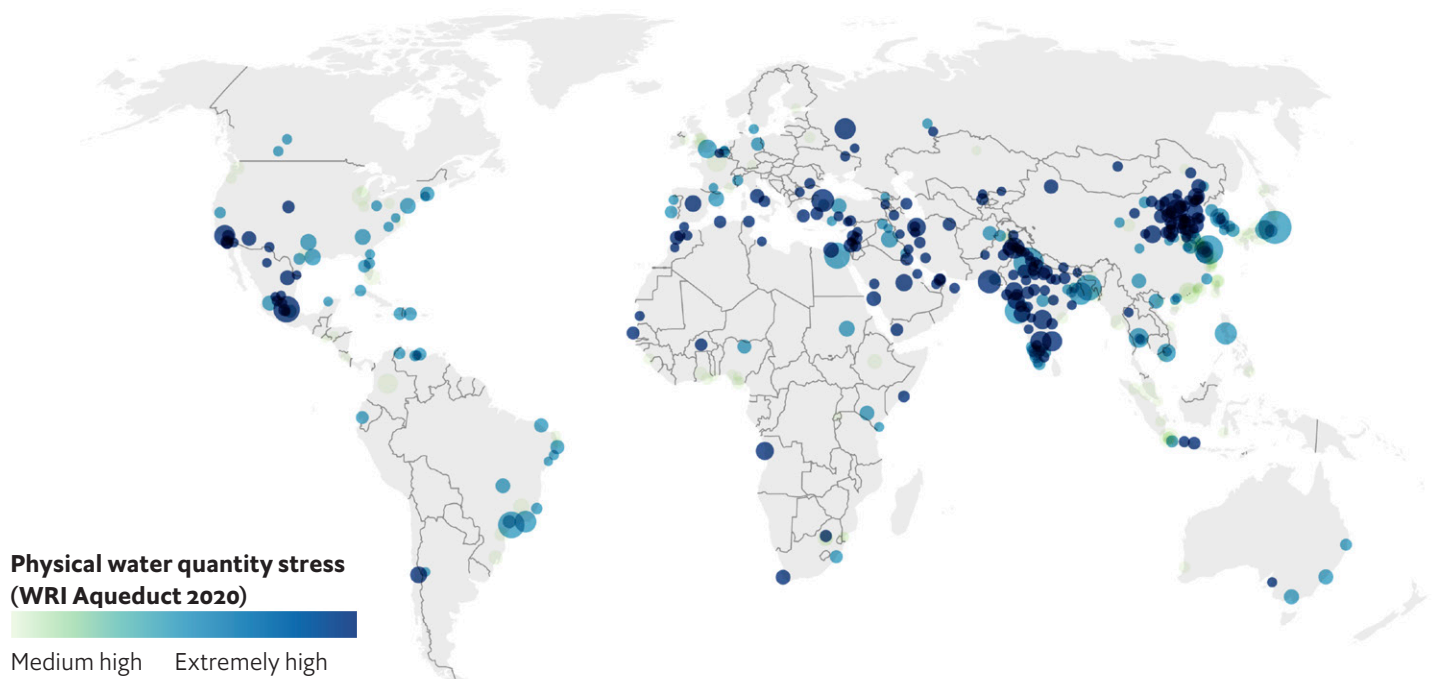
The water crisis can be averted. Large quantities of water are wasted due to aging infrastructure and inefficient management. These issues can be tackled through active maintenance, prompt repair, more robust materials and data analytics. More rainwater could be harvested through innovations such as retention basins, rain gardens and green roofs, while

advances in membrane technology are lowering the cost and energy-intensity of seawater desalination.

Flooding caused by poor urban planning, such as lack of permeable surfaces, can damage sanitation infrastructure and clean water supplies. To protect against this type of flooding, "sponge city" approaches and other nature-based innovations, such as adding more vegetation-rich surfaces and green spaces, aim to absorb and channel water to reduce flood risk.

Concentrated solar power could offer one route for arid countries to harness their naturally abundant sunshine in order to address water scarcity.<sup>8</sup> Through careful planning, effective governance and technology adoption, there can be abundant and affordable water supplies for everyone both now and in the future.

**Figure 3. Physical water quantity risk in urban areas, 2020**



Urban areas are urban agglomerations with a population greater than or equal to 500,000 (UN 2020). Physical risks quantity measures risk related to too little or too much water, by aggregating all selected indicators from the WRI Aqueduct Physical Risk Quantity category. Higher values indicate higher water quantity risks.

Source: World Resources Institute (2020)

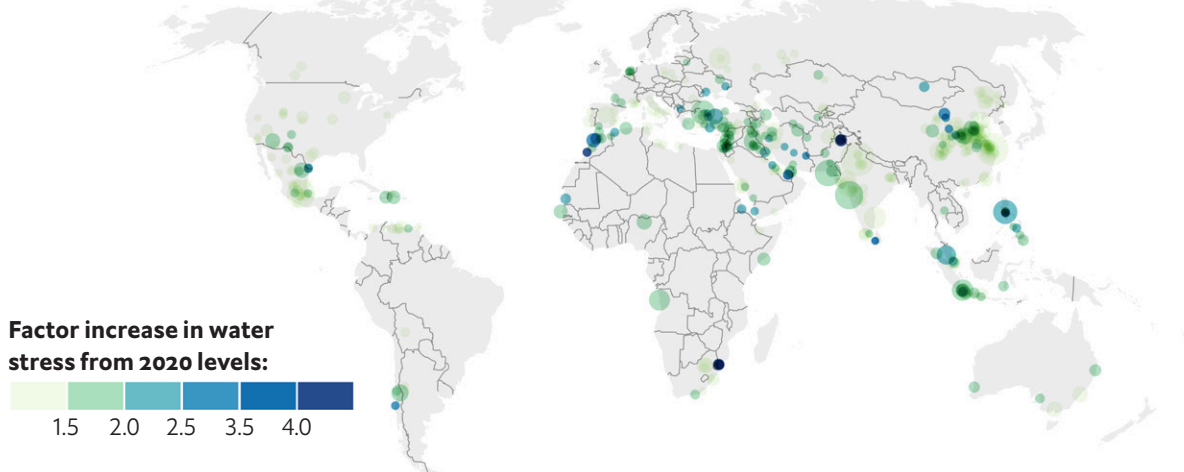
5 "Urban Population (% of Total Population)," from United Nations Population Division. World Urbanization Prospects: 2018 Revision., The World Bank, last modified 2021. <https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS>.

6 "68% Of the World Population Projected to Live in Urban Areas by 2050, Says UN," United Nations Department of Economic and Social Affairs, May 16, 2018, <https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html>.

7 "The United Nations World Water Development Report 2020: Water and Climate Change," UNESCO, UN Water, March 21, 2020, <https://www.unwater.org/publications/world-water-development-report-2020/>.

8 Molly Walton, "Desalinated Water Affects the Energy Equation in the Middle East – Analysis," IEA, October 1, 2018, <https://www.iea.org/commentaries/desalinated-water-affects-the-energy-equation-in-the-middle-east>.

Figure 4. Projected increase in water stress in urban areas, 2030



Urban areas are urban agglomerations with a population great than or equal to 500,000 (UN 2020). Water stress is an indicator of competition for water resources and is defined informally as the ratio of demand for water by society divided by available water.

Source: World Resources Institute (2020)

Singapore is the totemic example. Though one of the world's scarcest freshwater locations, the city-state has ensured adequate water provision by enhancing cross-government collaboration, emphasizing circularity and reuse, and investing in innovations such as membrane separation technology for seawater.<sup>9</sup> This example shows that water availability is not the preordained result of an environmental lottery, but rather is determined by policy choices.

The covid-19 crisis has been a wake-up call for cities in the developing world to address water-access deficits. More frequent handwashing has resulted in significantly increased water usage across the globe, putting pressure on already strained water sources and highlighting the multidimensional importance of ensuring water security. Indeed, thorough handwashing is a critical public health measure in densely populated emerging market cities, where physical distancing is less practical or often impossible.<sup>10,11</sup>

An estimated 1.8 billion people are at higher risk of covid-19 because they work in or use health facilities

without adequate clean water, according to the World Health Organization.<sup>12</sup> Best practices also determine that patients should be provided with their own sanitation facilities to reduce infection risks, increasing water usage above normal levels.<sup>13</sup> In the UK, a water utility provided additional supplies to London's NHS Nightingale Hospital, a new, special-purpose covid-19 facility set up to assist the National Health Service in managing the deluge of patients.<sup>14</sup>

The covid-19 pandemic has already been a positive impetus for much-needed action. In several Sub-Saharan African countries, such as Rwanda and Ethiopia, there has been a marked increase in access to handwashing facilities across a range of public spaces including community centers, bus terminals, schools and truck stations.<sup>15,16</sup> However, there is much further to go. An estimated two billion people lacked access to handwashing facilities in 2019, which has public health implications across a range of communicable diseases beyond covid-19.<sup>17</sup>

9 Peter Joo Hee Ng and Celine Teo, "Singapore's Water Challenges Past to Present," *International Journal of Water Resources Development* 36, no. 2 (2020): pp. 269-277, <https://doi.org/10.1080/07900627.2019.1680350>.

10 "When and How to Wash Your Hands," Centers for Disease Control and Prevention, November 24, 2020, <https://www.cdc.gov/handwashing/when-how-handwashing.html>.

11 Janette Neuwahl Tannen, "For the Poor, Little Access to Clean Water Increases COVID-19 Risk," *News @ The U*, University of Miami, May 29, 2020, <https://news.miami.edu/stories/2020/05/for-the-poor-little-access-to-clean-water-increases-covid-19-risk.html>.

12 "Almost 2 Billion People Depend on Health Care Facilities without Basic Water Services – WHO, UNICEF," World Health Organisation, December 14, 2020, <https://www.who.int/news/item/14-12-2020-almost-2-billion-people-depend-on-health-care-facilities-without-basic-water-services-who-unicef>.

13 "Water, Sanitation, Hygiene, and Waste Management for SARS-CoV-2, the Virus That Causes COVID-19," World Health Organization, July 29, 2020, <https://www.who.int/publications-detail-redirect/WHO-2019-nCoV-IPC-WASH-2020.4>.

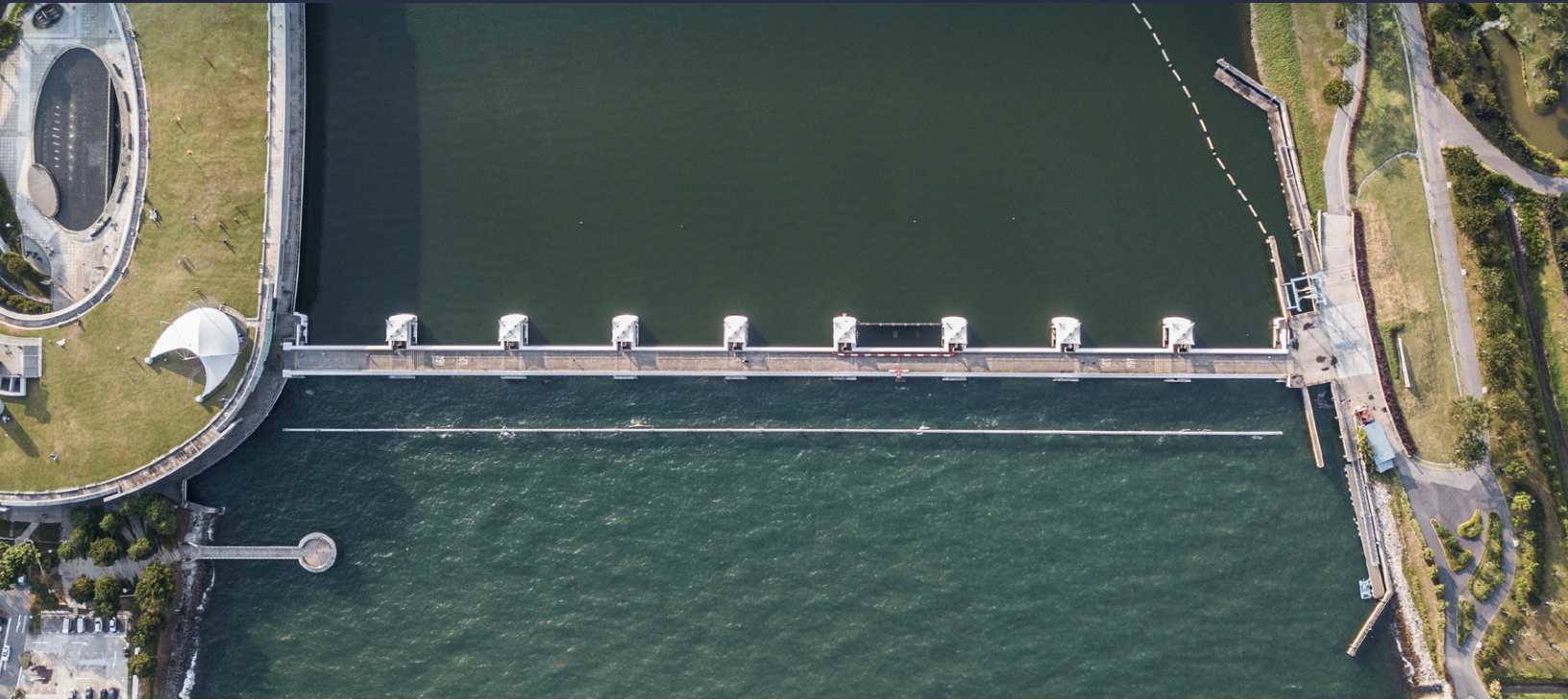
14 "Coronavirus - Thames Water Specialist Teams Work to Protect Water Supply to NHS Nightingale Hospital and Other Institutions," *Water Briefing*, April 7, 2020, <https://www.waterbriefing.org/home/company-news/item/17148-coronavirus-thames-water-specialist-teams-work-to-protect-water-supply-to-nhs-nightingale-hospital-and-other-institutions>.

15 Betsy Otto et al., "Combating the Coronavirus Without Clean Water," *World Resources Institute (blog)*, April 8, 2020, <https://www.wri.org/blog/2020/04/coronavirus-water-scarcity-hand-washing>.

16 "Water and Sanitation in a Post-COVID World," *The Lancet Global Health* 8, no. 9 (September 8, 2020), [https://doi.org/10.1016/S2214-109X\(20\)30368-5](https://doi.org/10.1016/S2214-109X(20)30368-5).

17 Charles W Schmidt, "Lack of Handwashing Access: A Widespread Deficiency in the Age of COVID-19," *Environmental Health Perspectives* 128, no. 6 (June 29, 2020), <https://doi.org/10.1289/EHP7493>.





## Shifting from scarcity to abundance

As Singapore demonstrates, cities in even the least naturally water-abundant geographies can meet the needs of their citizens and industry with the right combination of policies, investments and technologies. To move from the prospect of water-stress to a future of abundance and accessible water, stakeholders need to optimize water systems at every stage, from harvesting and protecting upstream supplies to conservative usage and recycling.

A water-optimized city means everyone has access to safe, affordable and reliable water both now and in the future. These urban environments can also accommodate growing populations and adapt to the pressures climate change places on existing water systems, such as less predictable precipitation and rising temperatures. All users do more with less, thanks to the minimization of waste and active reuse of wastewater.

Achieving an optimized urban water system requires commitment and evidence-based decision-making that combines multiple disciplines and tools, including:

- water technologies (such as more advanced desalination and purification systems, and data-driven software and sensors to analyze water quality and system performance);
- engineering and infrastructure innovations that can harvest more freshwater and protect sanitation systems from damage due to flooding;
- public health communications; and pricing policies that encourage conservation without limiting access. In the following section, examples from a range of geographic and economic contexts illustrate the ways that cities can achieve this.



## Harnessing and filtering upstream water

For many cities, water optimization starts with the source. Cities can diversify and protect their water supply portfolio through multiple means, including desalination, regulation preventing unsustainable groundwater exploitation, and aquifer protection and recharge.

Desalination removes salt and impurities from seawater through reverse osmosis, pushing water through membranes that restrict the entry of salt. Malta has invested in desalination of seawater and brackish water (non-ocean water with high salinity), while Windhoek in Namibia, has improved water security through careful aquifer management and water recycling.

Alongside diversifying water-source portfolios, protecting existing natural water sources is also vital to ensuring adequate supply now and in the future.

Managed aquifer recharge—the process of watering a site to replenish water stores—has been used to combat water scarcity in Africa, the Middle East, Australia, Europe, Jamaica and across the US.<sup>18,19</sup> The Central Arizona Project operates six recharge initiatives that can store over 370 million cubic meters of surplus water per year.<sup>20</sup> Purpose-built recharge structures, such as injection wells and infiltration basins, have been utilized in Berlin, Germany<sup>21</sup> and Flanders, Belgium.<sup>22</sup>

Measures to protect upstream water sources include commissioning water utilities to control water-well use (Lima, Peru) and bans or moratoria on urban water-well drilling (Ribeirão Preto, Brazil and Nairobi, Kenya).<sup>23</sup>

18 "Transforming Water-Scarce Cities into Water-Secure Cities through Collaboration," World Bank, May 15, 2017, <https://www.worldbank.org/en/news/feature/2017/05/15/water-scarce-cities-initiative>.

19 Karen G Villholt et al., eds., *Advances in Groundwater Governance* (London, UK: CRC Press, 2018). <https://www.un-igrac.org/sites/default/files/resources/files/advances-in-groundwater-governance.pdf>

20 "Central Arizona Project (CAP) Recharge Program," Central Arizona (CAP) Recharge Program, (Esri, December 21, 2020), <https://storymaps.arcgis.com/stories/70f626809fd84e228cof32aef4222dda>.

21 Janek Greskowiak et al., "Modeling seasonal redox dynamics and the corresponding fate of the pharmaceutical residue phenazone during artificial recharge of groundwater," *Environmental Science & Technology* 40, no. 21 (November 1, 2006). <http://doi.org/10.1021/es052506t>.

22 Emmanuel Van Houtte and Johan Verbauwhe. "Sustainable groundwater management using reclaimed water: The Torreele/St-André case in Flanders, Belgium," *Aqua*, 61 no. 473 (December, 2012) <http://doi.org/10.2166/aqua.2012.057>.

23 Stephen Foster, "Global Policy Overview of Groundwater in Urban Development—A Tale of 10 Cities!" *Water* 12 no. 456 (February 8, 2020) <http://doi.org/10.3390/w12020456>.



In addition to protecting against overdraw, cities can reduce upstream water losses caused by evaporation. The city of Los Angeles released 96 million shaded balls into the LA reservoir, the state's largest in-basin facility, to cover the surface and slow evaporation by reflecting the sun's rays. This method is expected to save 300 million gallons of water a year.<sup>24</sup> Regulations and enforcement to restrict upstream pollution of aquifers and unsustainable exploitation of groundwater are also critical to protecting urban water sources.<sup>25</sup>

Cities can harness more upstream water and protect against the negative impacts of floods, inundation and pollution, thereby protecting the sanitation system through nature-based solutions. Rain gardens and retention basins, for instance, can collect, store, filter and treat water runoff. Such innovations have been deployed in cities including Singapore, Limassol (Cyprus), Portland (United States) and Uppsala (Sweden).<sup>26,27,28</sup> Philadelphia (United States) is building an extensive network of rain gardens, green roofs and wetlands to prevent runoff from overwhelming sewers and polluting waterways.<sup>29</sup>

In China, a network of 16 cities has, since 2015, explored a nature-based "sponge city" strategy, which improves urban permeability to reduce

flooding and increase water harnessing.<sup>30,31</sup> Sponge city approaches involve implanting more vegetation-rich surfaces to absorb water and increasing infrastructure permeability to allow more water to descend to the water table.<sup>32</sup> Projects in Wuhan and Xiamen have reportedly performed well in managing heavy rainfall in recent years.<sup>33</sup> Chinese cities have also reduced pollution from waste dumps and water runoff. Haikou removed 85% of nitrogen and phosphorus from its water supply by making a terraced, constructed wetland, while Sanya reduced urban water inundation by creating a "green sponge" zone in the city, a process described as "eco-puncture".<sup>34</sup> Singapore is another advocate of this approach. The city-state has installed multiple structures to capture rainwater in gutters, barrels, tanks and reservoirs and put it to use. Changi Airport has also adopted this system, with nearly a third of its water sourced from captured rainwater.<sup>35</sup>

There is no single solution to protecting and diversifying water sources at an urban level, as each city faces its own ecological and hydrological dynamics. But the above examples demonstrate that cities across a range of geographical and economic circumstances have been able to take concrete measures and achieve tangible beneficial outcomes.



24 Alice Walton, "Millions of Shade Balls Helping Protect California's Precious Water," *Los Angeles Times* (August 13, 2015), <https://www.latimes.com/local/lanow/la-me-ln-shade-ball-water-20150812-htmlstory.html>.

25 "Chapter 2. Groundwater Degradation and the Limits of Hydrological Information," *Groundwater Management - The Search for Practical Approaches* FAO water Reports (25), 2003, <http://www.fao.org/3/y4502e/y4502e04.htm#bm04>.

26 Georgia Priari, "Proceedings Promoting the Use of Public Areas for Sustainable Stormwater Management in Cities with Mediterranean Climate", Proceedings 2, no. 632 (August 3, 2018) <http://doi.org/10.3390/proceedings2110632>.

27 Georgina Laurensen et al., "Chapter Four. The Role of Bioretention Systems in the Treatment of Stormwater," in *Advances in Agronomy*, 120. (December, 2013) 223-274. <https://doi.org/10.1016/B978-0-12-407686-0.00004-X>.

28 Tobias Robinson et al., "Raingardens for stormwater management – potential of raingardens in a Nordic climate" Trafikverket, (October 16, 2019) <https://www.diva-portal.org/smash/get/diva2:1370826/FULLTEXT01.pdf>.

29 Bruce Stutz, "With a Green Makeover, Philadelphia Is Tackling Its Stormwater Problem," *Yale Environment* 360, March 29, 2018, <https://e360.yale.edu/features/with-a-green-makeover-philadelphia-tackles-its-stormwater-problem>.

30 Asit K Biswas and Kris Hartley, "China's 'Sponge Cities' Aim to Re-Use 70% of Rainwater – Here's How," *The Conversation*, June 24, 2020, <https://theconversation.com/chinas-sponge-cities-aim-to-re-use-70-of-rainwater-heres-how-83327>.

31 "Kunshan," International Water Association, accessed January 18, 2021, <https://iwa-network.org/city/kunshan/>.

32 "Sponge Cities: What Is It All about?," World Future Council (January 20, 2016), <https://www.worldfuturecouncil.org/sponge-cities-what-is-it-all-about/>.

33 Hu Meidong et al., "Sponge cities' soak up rain, pain" *China Daily USA* (August 4, 2016) [http://usa.chinadaily.com.cn/china/2016-08/04/content\\_26345067.htm](http://usa.chinadaily.com.cn/china/2016-08/04/content_26345067.htm).

34 "Sponge Cities: Leveraging Nature as Ecological Infrastructure," Centre for Liveable Cities, Singapore, Webinar. <https://www.clc.gov.sg/events/webinars/view/sponge-cities>.

35 Chris Weller, "Singapore Has Come up with an Ingenious Way to Save Water," *Business Insider* September 14, 2015, <https://www.businessinsider.com/singapore-is-a-city-sized-sponge-2015-9?r=US&IR=T>.





## Water-wise usage

Encouraging responsible water usage both by citizens and businesses is critical to reduce pressure on water systems. Cities can rationalize water usage through financial, behavioral and engineering approaches. These can span from optimizing water distribution network maintenance to introducing smart meters and Internet of Things (IoT)-based water quality management.

Reducing water leakage from pipes is an effective way to stretch existing resources. Tokyo is among the global leaders in recognizing the importance of infrastructure maintenance as part of a water optimization strategy. The city's efforts to quickly detect and fix leaks more than halved water waste between 2002 and 2012, through a combination of rapid repair and replacement of pipes and utilization of more durable materials (most leakage is caused by cracked or corroded pipes).<sup>36</sup> Another example comes from Las Vegas,

Nevada, which has installed acoustic sensors to monitor aging pipelines for leakage.<sup>37</sup>

In an era of increasing connectivity, technologies such as electronic, internet-enabled ("smart") meters offer new possibilities for infrastructure monitoring and maintenance. Smart metering and real-time feedback can improve visibility and awareness among water-users, as well as allowing utilities to monitor water usage in real-time. While smart meters are commonly used in the energy sector, and have been shown to reduce consumption by 5-20%,<sup>38</sup> they also hold promise for the water sector. Small-scale studies have found water usage reductions of 7.9% following the introduction of smart meters (Queensland, Australia)<sup>39</sup> and 6.6% (Iowa, United States).<sup>40</sup> Evidence from various countries shows when smart metering is combined with other consumer-centric methods, such as email notifications and dashboards, water usage drops by a fifth (19.6%) on average.<sup>41</sup>

36 "Case Study: Tokyo, World Leader in Stopping Water Leakage," C40, January 17, 2012, [https://www.c40.org/case\\_studies/tokyo-world-leader-in-stopping-water-leakage](https://www.c40.org/case_studies/tokyo-world-leader-in-stopping-water-leakage).

37 "Las Vegas Valley Water District on the Cutting Edge of Aging Water Infrastructure Management and Leak Detection," Internet of Things, GSMA, September 15, 2016, <https://www.gsma.com/iot/resources/las-vegas-valley-water-district-cutting-edge-aging-water-infrastructure-management-leak-detection/>.

38 Julien Harou et al., "Developing New Dynamic Pricing Mechanisms", Smart H2O, 2016, <https://cordis.europa.eu/docs/project/docs-projects-cnec-2-619172-080-deliverables-001-sh2od52uompolimiwp5dynpricingv21.pdf>.

39 Kelly S. Fielding et al., "An Experimental Test of Voluntary Strategies to Promote Urban Water Demand Management," *Journal of Environmental Management* 114 (January 15, 2013): 343–51, <https://doi.org/10.1016/j.jenvman.2012.10.027>.

40 Thomas Erickson et al., "The Dubuque water portal: evaluation of the uptake, use and impact of residential water consumption feedback," CHI 12: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (May, 2012) Austin, Texas, USA: ACM. <https://doi.org/10.1145/2207676.2207772>.

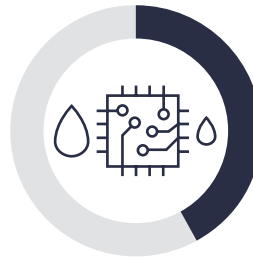
41 A.L. Sonderlund, et al., "Using Smart Meters for Household Water Consumption Feedback: Knowns and Unknowns," *Procedia Engineering*, 89, (2014) 990–997 <https://doi.org/10.1016/j.proeng.2014.11.216>.

Along similar lines, smart city initiatives that integrate sensors and data through the use of IoT, hold promise for water management. One smart irrigation management system uses cloud-based data analytics to calculate local evapotranspiration values by analyzing humidity, solar radiation and temperatures. In 2015, it saved over 15 billion gallons of water, including one million gallons in Salem City, Utah. It was also responsible for a 42% reduction in water use across the Monterey Peninsula Unified School District in California.<sup>42</sup>

IoT-based water quality sensor technology, which combines sensors in water systems with cloud-based analytics, can measure a range of water quality-related parameters including dissolved oxygen levels (which influences the toxicity of elements such as zinc, lead and copper), turbidity (the number of particles such as plant waste, sand and silt),<sup>43</sup> bacterial levels, temperature, pH, conductivity (an indicator of the presence of pollutants such as heavy metals), phosphates and salinity.

Companies including Nokia, Microsoft and Huawei are actively investigating the development of digital water-quality monitoring, while Ericsson initiated a cloud-based water-quality initiative in Stockholm, Sweden.<sup>44</sup> A pilot initiative in Bristol, UK—a remote, real-time high-frequency water-quality monitoring system—demonstrated the feasibility of cloud-based, in-situ monitoring technology to track indicators including temperature, dissolved oxygen and pH.<sup>45</sup> Robotic devices such as autonomous underwater vehicles can enable real-time monitoring of groundwater quality.<sup>46</sup>

Measures to influence consumers should not be underestimated. Daily consumption decisions that result in incrementally higher water usage per consumer, from leaving taps on while brushing teeth to the length of time spent showering, can combine to form a large share of a city's water demand. Cape Town's success in avoiding a "Day Zero" crisis



Smart metering reduced water use by **42%** across California's Monterey Peninsula Unified School District.

has been credited in no small part to the voluntary collective efforts of all citizens to be water-wise.<sup>47</sup> Public awareness campaigns and nudges to promote a culture of water conservation have delivered dividends elsewhere too. In Bogota, Colombia, a public information campaign that included stickers, daily reports of water consumption published in prominent newspapers, television advertising and minor sanctions on businesses with the highest consumption levels achieved not just short term but also long term behavior change.<sup>48</sup> A randomized trial in the US found that sending a one-time message encouraging consumers to reduce their water use had an equivalent impact on usage as a 12-15% increase in prices.<sup>49,50</sup>

The demonstrated efficacy of behavioral nudges is significant because deterring water use via price increases the risk of severe equity impacts for those with limited means to pay. Cities need to ensure affordable access to water while simultaneously discouraging the excess consumption that may result from low prices. One method policy-makers can use to balance equity and conservation is the distribution of means-based subsidies. Chile, for example, introduced a two-tier tariff (peak/off-peak) and a user subsidy funded by state and municipality contributions. Over 683,000 households, around 12.4% of urban customers in 2018, were eligible for the subsidy on a means-tested basis. The country has been highlighted as a reference case for peers in terms of targeting water access.<sup>51</sup>

42 "GSMA Smart Cities Guide: Water Management," Internet of Things, GSMA, November 3, 2016, <https://www.gsma.com/iot/resources/gsma-smart-cities-guide-water-management/>.

43 Sathish Pasika and Sai Teja Gandla, "Smart Water Quality Monitoring System With Cost-Effective Using IoT", *Heliyon* 6, no. 7 (2020), <https://doi.org/10.1016/j.heliyon.2020.e04096>.

44 Daniel Paska, "Digitalized Water and Smart Cities – How Can Telecommunication Networks be Used for Environmental Resilience?",

*ITU Journal: ICT Discoveries*, no. 2 (2018), <https://www.itu.int/en/journal/002/Documents/ITU2018-3.pdf>.

45 Yiheng Chen and Dawei Han, "Water quality monitoring in a smart city: a pilot project," *Automation in Construction* no. 89, (2018) 307-316. <https://doi.org/10.1016/j.autcon.2018.02.008>.

46 Matthew Dunbabin and Lino Marques, "Robots For Environmental Monitoring: Significant Advancements And Applications", *IEEE*

*Robotics & Automation Magazine* 19, no. 1 (2012): 24-39, <https://doi.org/10.1109/MRA.2011.2181683>.

47 Charlotte Edmond, "Cape Town Almost Ran Out Of Water. Here's How It Averted The Crisis", *World Economic Forum*, August 23, 2019, <https://www.weforum.org/agenda/2019/08/cape-town-was-90-days-away-from-running-out-of-water-heres-how-it-averted-the-crisis/>.

48 "World Development Report 2015: Mind, Society, and Behaviour" World Bank, 2015, <http://documents1.worldbank.org/curated/en/645741468339541646/pdf/928630WDR0978100Box385358B00PUBLIC0.pdf>.

49 Paul J Ferraro, Juan Jose Miranda and Michael K Price, "The Persistence Of Treatment Effects With Norm-Based Policy Instruments: Evidence From A

Randomized Environmental Policy Experiment", *American Economic Review* 101, no. 3 (2011): 318-322, <https://doi.org/10.1257/aer.101.3.318>.

50 Juan Jose Miranda and Paul Ferraro, "Can Behavioral Change Support Water Conservation? Examples From The US, Colombia And Costa Rica", *World Bank Blogs*,

March 28, 2017, <https://blogs.worldbank.org/latinamerica/can-behavioral-change-support-water-conservation-examples-us-colombia-and-costa-rica>.

51 Daniel Antonio Narzetti and Rui Cunha Marques "Models of Subsidies for Water and Sanitation Services for Vulnerable People in South

American Countries: Lessons for Brazil" *Water*, 12 no. 7, (2020): 1976; <https://doi.org/10.3390/w12071976>.





## Recycling and reuse, from fertilizer to drinking water

Wastewater treatment is the final part of the optimization chain. Defined as any used water containing substances such as human waste, food scraps, oils and chemicals, or storm runoff,<sup>52</sup> it must be treated to reduce risks both to the environment and human health. With proper treatment, wastewater can also be recycled for safe human consumption.

One facility, in Orange County, California, uses reverse osmosis to replenish drinking water supplies with up to 100 million gallons of municipal wastewater a day. Microfiltration removes microorganisms and particles, after which water is processed to remove chemicals, viruses and pharmaceuticals. In the final stage, advanced oxidation disinfects the water, which is then used to replenish aquifers and bolster the city's water supply.<sup>53</sup>

<sup>52</sup> "Wastewater Treatment Water Use", USGS, 2021, [https://www.usgs.gov/special-topic/water-science-school/science/wastewater-treatment-water-use?qt-science\\_center\\_objects=0#qt-science\\_center\\_objects](https://www.usgs.gov/special-topic/water-science-school/science/wastewater-treatment-water-use?qt-science_center_objects=0#qt-science_center_objects).

<sup>53</sup> "Pure Success: Turning California Wastewater into Drinking Water" DuPont Water Solutions (2019), <https://www.dupont.com/content/dam/dupont/amer/us/en/water-solutions/public/documents/en/45-Do1768-en.pdf>.

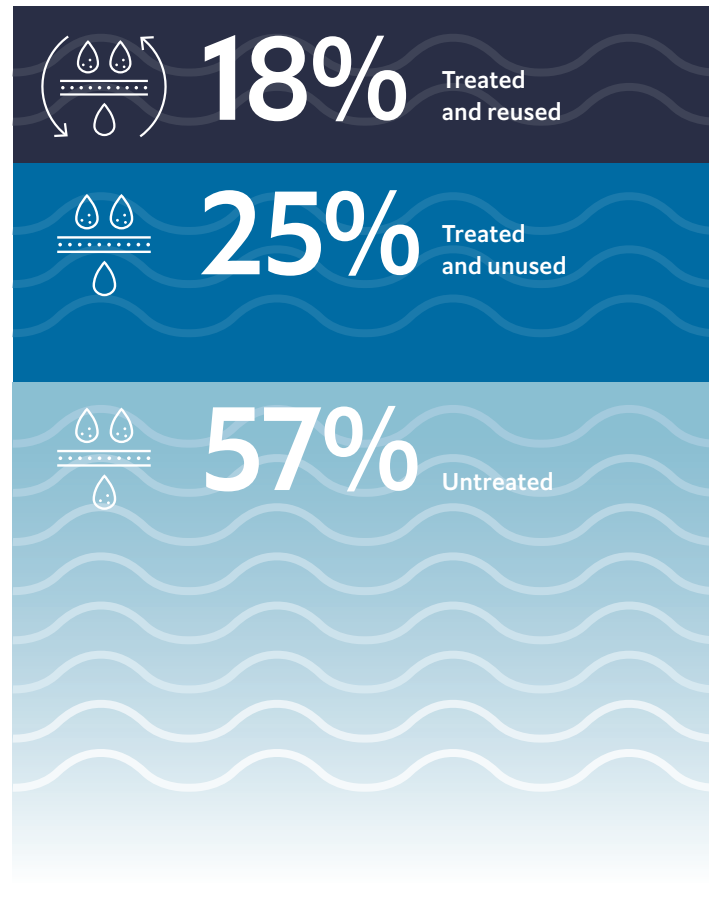


In addition to potable and non-potable (but useful) water, the wastewater treatment process can capture various other valuable commodities, such as energy and agricultural inputs. In this manner, wastewater treatment can actually be a source of income for utilities rather than simply an expense. Sewage sludge, produced during the wastewater treatment process, contains biological nutrients that can be used for composting and energy generation. In Xiangyang, China, a reuse initiative aims to recover 96% of nitrogen and 99% of phosphorus from treated sewage for use in soil fertilization, and will also enable the production of 45.4 million cubic meters of natural gas.<sup>54</sup> As well as harnessing resources from waste, this process also reduces the emissions and pollution that would otherwise have resulted from sludge disposal.<sup>55</sup> The water operator receives a government subsidy, revenue through the sale of compressed natural gas to the municipal taxi fleet and income from the sale of biochar and saplings also produced in the process.

Wastewater has been reused to both support industrial activity and provide revenue to utilities in numerous other cities. Examples include the sale of treated effluent for a power plant's cooling towers (San Luis Potosi, Mexico), the sale of recovered phosphorus for fertilizer (Chicago, Illinois)<sup>56</sup> and the outsourcing of municipal wastewater treatment to mining companies, in exchange for the use of the resulting treated wastewater (Arequipa, Peru).<sup>57</sup> In Durban, South Africa, the sale of treated wastewater to two industrial users freed up sufficient potable water to serve 400,000 additional people in the city.<sup>58</sup>

Water treatment and reuse is especially critical in arid regions. Oman, which ranks 15th on the World Resources Institute's list of water-stressed countries,<sup>59</sup> treats 100% of its collected wastewater and reuses 78%.<sup>60</sup> Yet it is an outlier in the region. The World Bank estimates that 57% of wastewater in the Middle East and North Africa region goes untreated and a further 25% is treated but not reused (see Figure 5).

**Figure 5. Share of collected wastewater that is untreated, treated and reused in irrigation in MENA**



Note: Figures were generated by summing country-level data on wastewater treated and reused from FAO AQUASTAT. Country-level data are based on estimates provided by the governments and are subject to variations in estimation methods and year of collection.

Source: World Bank<sup>61,62</sup>

54 Xiaotian Fu et al., "Sludge To Energy: An Environment-energy-economic Assessment of Methane Capture From Sludge in Xiangyang City, Hubei Province" World Resources Institute, Working Paper (March 2017) [https://files.wri.org/s3fs-public/Sludge\\_to\\_Energy\\_An\\_Environment-Economic\\_Assessment\\_of\\_Methane\\_Capture\\_from\\_Sludge\\_in\\_Xiangyang\\_City\\_Hubei\\_Province\\_1.pdf](https://files.wri.org/s3fs-public/Sludge_to_Energy_An_Environment-Economic_Assessment_of_Methane_Capture_from_Sludge_in_Xiangyang_City_Hubei_Province_1.pdf).

55 Ibid.

56 Jay Landers, "Chicago To Add Nutrient Recovery To Largest Plant | ASCE", ASCE: American Society of Civil Engineers, 2021, <https://www.asce.org/magazine/20131105-chicago-to-add-nutrient-recovery-to-largest-plant/>.

57 "Wastewater: From Waste to Resource The Case of Arequipa, Peru," World Bank Group - Water Global Practice, 2019, <https://openknowledge.worldbank.org/bitstream/handle/10986/33110/Wastewater-From-Waste-to-Resource-The-Case-of-Arequipa-Peru.pdf?sequence=1&isAllowed=y>.

58 "Wastewater: From Waste to Resource The Case of Durban, South Africa," World Bank Group - Water Global Practice, 2018, <https://openknowledge.worldbank.org/bitstream/handle/10986/29489/124334-WP-15-3-2018-15-30-54-WSouthAfricaDurban.pdf?sequence=5&isAllowed=y>.

59 "Aqueduct Beta: Country Rankings" World Resources Institute, <https://www.wri.org/applications/aqueduct/country-rankings/>.

60 Hofste et al., "17 Countries, Home To One-Quarter Of The World's Population, Face Extremely High Water Stress."

61 "Beyond Scarcity: Water Security in the Middle East and North Africa", MENA Development Report, World Bank Group, 2018, <http://hdl.handle.net/10986/27659>.

62 Hofste et al., "17 Countries, Home To One-Quarter Of The World's Population, Face Extremely High Water Stress."

With proper treatment, recycled water can be safe for human consumption. Treatment is applied at increasingly granular levels, from the removal of grit and larger objects to fine particles to bacteria, viruses, chemicals and parasites.<sup>63</sup> Once evaluated rigorously against safety and quality standards, the recycled water is then fed back into the drinking water distribution system or used to replenish natural systems, such as lakes, aquifers and reservoirs.<sup>64</sup> Cities can also increase the safety of water reuse by decentralizing infrastructure to reduce contamination. Researchers at the Rice Brown School of Engineering, exploring Houston as a model, found that decentralization of water treatment facilities reduces contamination from transportation and logistics, and that decentralized potable reuse could provide up to 28% of Houston's water supply. This, in turn, reduces the draw on surface water sources (rivers, reservoirs or wells).<sup>65</sup>

One key challenge for water reuse, in particular human consumption of recycled water, is public opposition stemming from fears of drinking water that fails to meet quality and health standards. In recent years, several high-profile drinking water scandals, such as the high lead content found in water in Flint, Michigan, and links between chemical contamination of drinking water and certain types of cancer have stoked these fears.<sup>66</sup> However, if recycled water quality can be proven to be consistently safe, public attitudes could improve. Such a shift depends on participatory,



**40%**  
of Singapore's  
potable and  
non-potable  
water is  
from re-used  
supplies

accessible communications efforts that disseminate information accurately and consistently.<sup>67</sup> In San Diego, a shift to a more open and participatory approach to water reuse led to a considerable change in public opposition, with 73% of the public supporting the effort by 2012, up from 26% in 2004.<sup>68</sup>

As these examples demonstrate, with the right tools and policies in place, urban water systems across a range of geographic and economic contexts can work towards optimization. Measuring progress towards that goal, however, requires a clear, evidence-based framework. In the next section, The Economist Intelligence Unit outlines a new benchmarking framework for city-level water optimization.

63 "Urban Waste Water Treatment For 21st Century Challenges", European Environment Agency, October 9, 2019, <https://www.eea.europa.eu/themes/water/european-waters/water-use-and-environmental-pressures/uwwtd/urban-waste-water-treatment>.

64 Cecilia Tortajada and Pierre van Rensburg, "Drink More Recycled Wastewater" *Nature*, December 31, 2019, [https://www.nature.com/articles/d41586-019-03913-6?utm\\_source=fbk\\_nnc&utm\\_medium=social&utm\\_campaign=naturenews&sf227261853=1](https://www.nature.com/articles/d41586-019-03913-6?utm_source=fbk_nnc&utm_medium=social&utm_campaign=naturenews&sf227261853=1).

65 Lu Liu et al., "The Importance Of System Configuration For Distributed Direct Potable Water Reuse", *Nature Sustainability* 3, no. 7 (2020): 548-555, <https://doi.org/10.1038/s41893-020-0518-5>.

66 Sydney Evans, Chris Campbell and Olga V. Naidenko, "Cumulative Risk Analysis Of Carcinogenic Contaminants In United States Drinking Water", *Heliyon* 5, no. 9 (2019): e02314, <https://doi.org/10.1016/j.heliyon.2019.e02314>.

67 Cecilia Tortajada, "Contributions Of Recycled Wastewater To Clean Water And Sanitation Sustainable Development Goals", *Npj Clean Water* 3, no. 1 (2020), <https://doi.org/10.1038/s41545-020-0069-3>.

68 Tortajada and Rensburg, "Drink More Recycled Wastewater."



## Benchmarking city-level water optimization

Evidence-based approaches with proven real-world outcomes, along with a benchmark that can allow cities to compare and contrast their performance against relevant peers, can be a decision-making aid that helps city officials uncover resources that may have been hitherto hidden or under-utilized.

To support decision-makers, The Economist Intelligence Unit, supported by DuPont Water Solutions, has developed the City Water Optimization Framework (see Figure 6). This benchmarking framework offers quantitative and qualitative indicators to measure the extent to which city-level water systems are equipped with the policies, infrastructure and systems to optimize their water supply, distribution and treatment

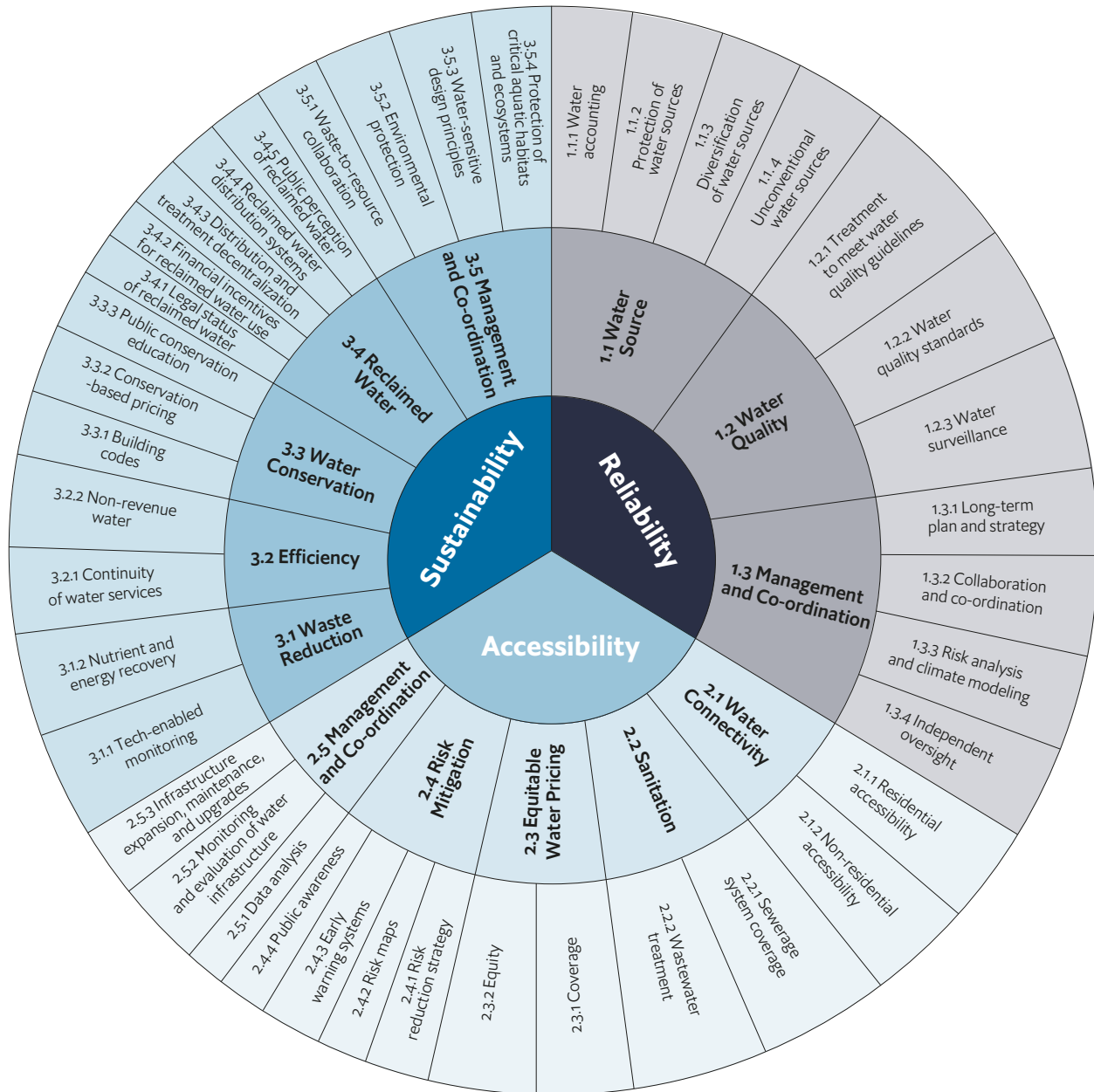
networks. Optimization, in this context, means *when everyone has access to safe, affordable and reliable water both now and in the future.*

This framework captures optimization levels throughout the water usage chain, from protecting water sources to water treatment levels. It covers the degree to which norms, standards and guidelines are applied, the level of collaboration across government, the presence of long-term strategies, and the scale of public awareness and communications. It also emphasizes the importance of early-warning systems, disaster readiness, equitable pricing and financial incentives, along with the adoption of relevant technologies like artificial intelligence, machine learning and smart meters.



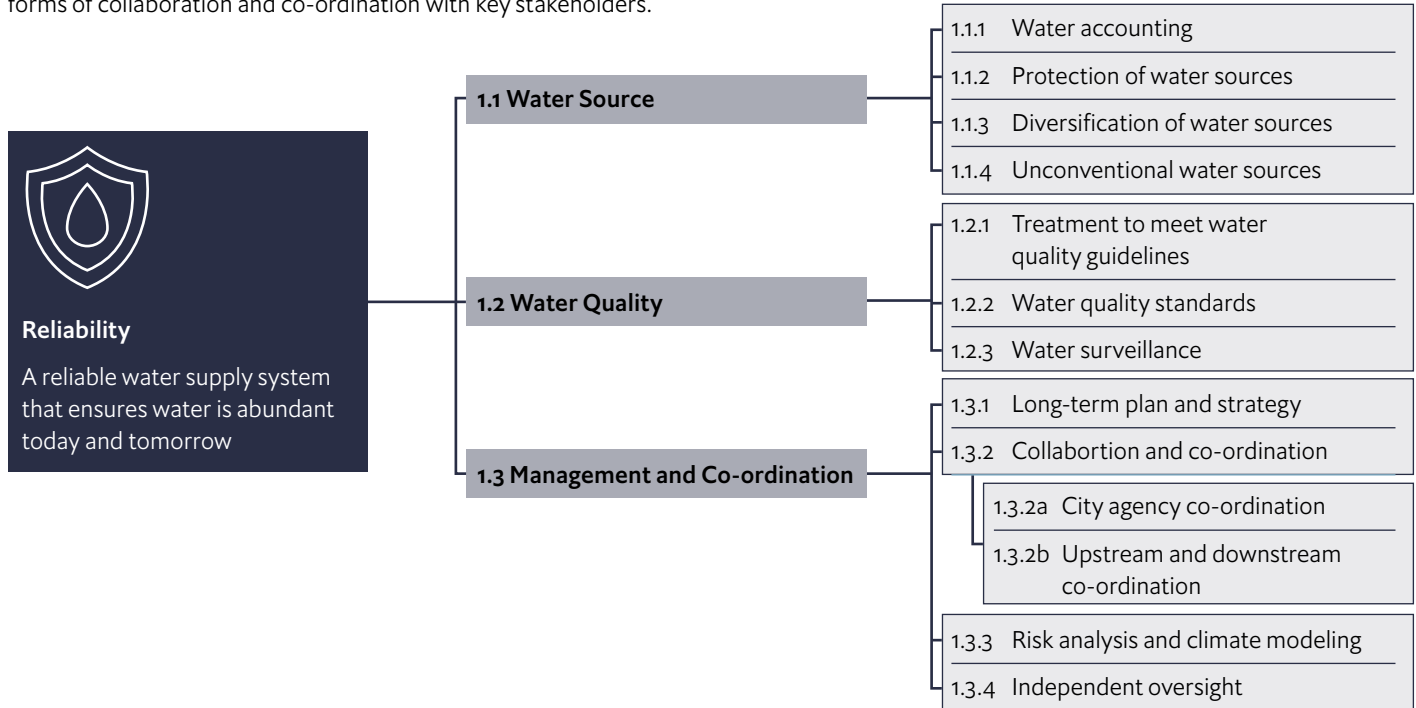


Figure 6. City Water Optimization Framework

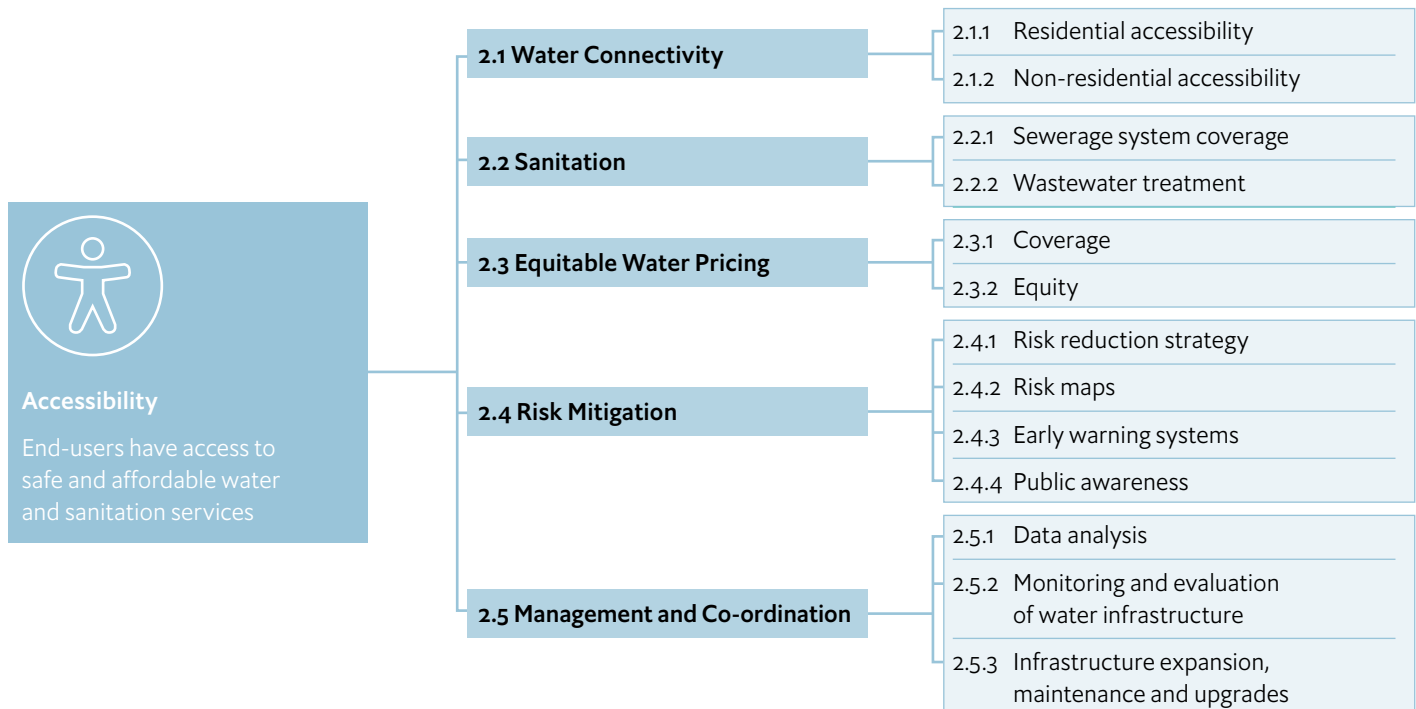


The framework comprises more than 40 indicators organized across three categories: **Reliability, Accessibility and Sustainability.**

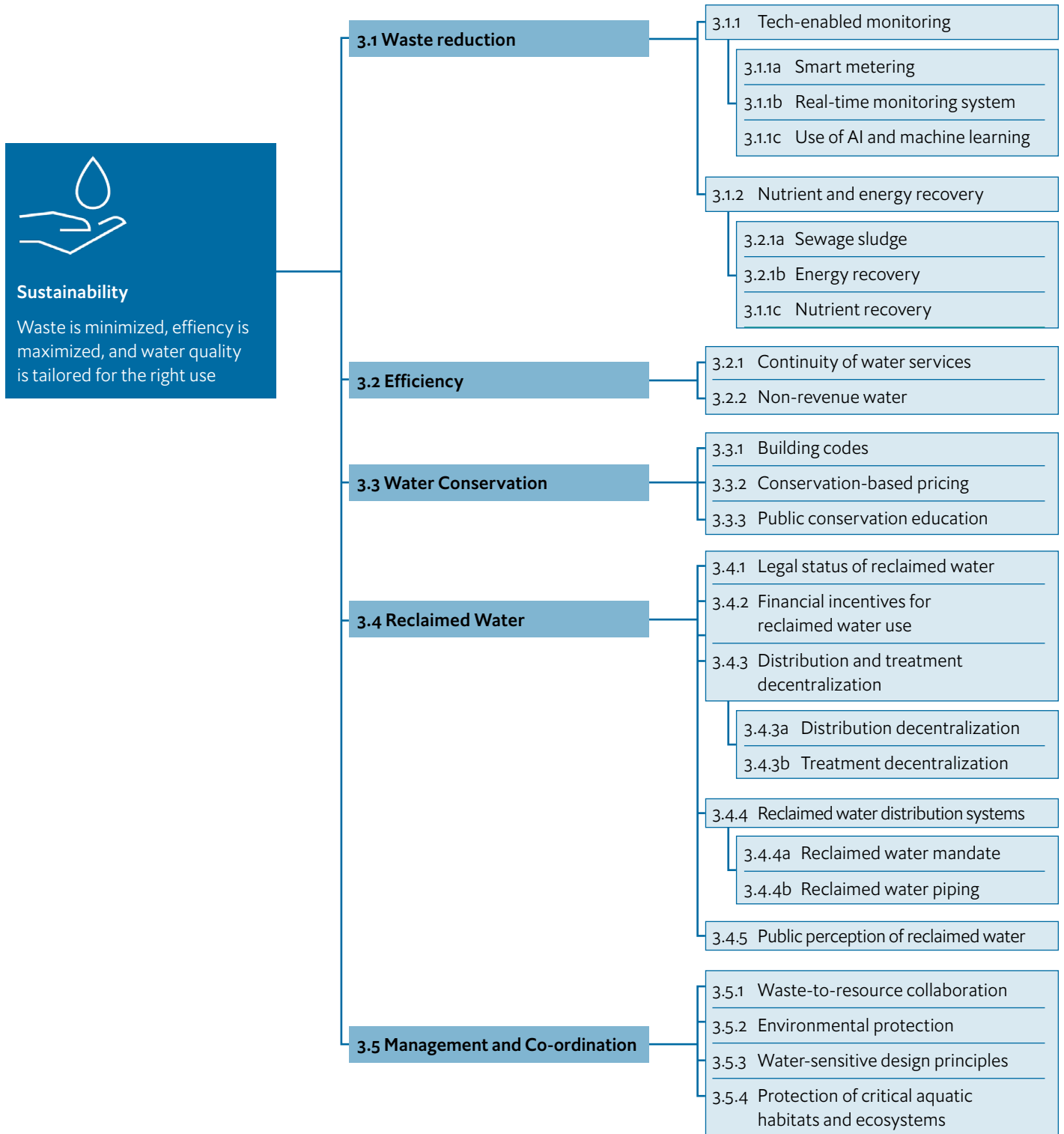
**Reliability:** A reliable water system must ensure water is abundant today and tomorrow, through dependable water sources, water quality, and effective management and co-ordination. The reliability domain focuses on how effectively cities harness water, the standards and protocols they apply to ensure water quality, and their level of strategic and long-term planning and forecasting, supported by the right forms of collaboration and co-ordination with key stakeholders.



**Accessibility:** End-users must have access to safe and affordable water and sanitation services, which entails sufficient levels of water connectivity and sanitation, equitable water pricing, and the presence of safety provisions to minimize risks of disruption, including risk mapping and mitigation, early warning systems, monitoring, and public awareness about urban hazards.



**Sustainability:** Cities need to draw more value from water to make it go further. The sustainability domain assesses the degree to which waste is minimized, efficiency is maximized and water quality is tailored for different use cases. This includes the presence of waste reduction innovations such as smart meters and nutrient and energy recovery, pricing policies to encourage conservation, levels of water reclamation, and public attitudes to water reuse, as well as the intersection of water with building codes and ecosystem protection.





## The framework development process

The benchmarking framework was developed based on a targeted literature review of critical current concepts, best practices and policy themes surrounding urban-level water management, including reliability, equitable access and sustainability, as well as consultation with urban water management experts from across the globe.

A draft framework was presented to an independent panel of experts from academia, research organizations, the private sector and non-government organizations to help validate findings and improve the framework's preliminary structure. The Economist Intelligence Unit then revised the framework based on feedback from the independent panel of experts.

To ensure that the framework can be productively applied to various economic and development contexts, we tested it on two pilot cities: Los Angeles (United States) and Chennai, India. Final revisions were made to the framework based on the pilot city findings.

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## The framework value proposition

The value of the City Water Optimization Framework lies in its ability to help decision-makers understand best practices in their domain, measure how their city performs against peers and best practices, and track progress over time. By focusing on specific and achievable policies, protocols and tactics, the benchmark is intended to offer clear, evidence-based and actionable measures for city decision-makers to understand how their own city performs against the benchmark. Combined with analysis of case study evidence, it can support city officials and policy communities in making well chosen and timely investments to increase water availability and ensure quality, access and sustainability.

The framework aims to shift the discourse on water availability from that of "doom and gloom" to finding practical solutions to avert a water shortage crisis. The ultimate goal of the framework is to initiate a dialogue on how technological advancements and best practices can be leveraged to achieve a water optimized city, and provide a tool for city planners to learn from their peers in other locations that have been able to overcome water-related challenges. The framework strives to pave the way for a future where water is abundant, accessible and affordable.

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