ANNEX

Smart Water Cities Project
Case Studies

1. Algarrobo (Spain)
2. Busan Eco Delta City (Republic of Korea)
3. Ciudad Juarez (Mexico)
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7. Nakuru (Kenya)
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This Annex contains nine case studies, written by 37 authors, on the use of smart water technologies in different regions around the world (see Table 20). Scholars and practitioners submitted their case studies proposals in a joint open call, issued by IWRA, K-water, and AWC, and their proposals were selected for development into the case studies part of this report. Various selection criteria have been employed to ensure a diverse range of case studies for the report. These include geographical location, type of city, scale and water challenge, and regional/national policies and strategies.

All authors received guidelines for facilitating the writing of the cases, which included a discussion of the concept "Smart Water Cities" and questions that their case studies were to reflect on. Authors were provided with a guiding document with a contextual background of the project aiming to ensure that they each presented comparable information and reflected upon key themes and questions. They were also allowed to provide an individualized narrative for their case study, as well as were given full freedom to present their cases in the manner of their preference. So, while each case study follows a similar structure and answers to similar questions, they also reflect the particularities that the individual authors have preferred to highlight. Full texts were reviewed by a committee of experts who provided comments and recommendations to the drafts and requested authors to resubmit second versions addressing reviewer comments and feedback. The final versions were submitted some weeks later, and are, with minor modifications, included as such in this report.

To establish the content of the case studies, the authors have been provided with a structural guide that their chapters should address. They are as follows:

1. Title
2. Short abstract (of no more than 200 words)
3. Introduction to the study
4. Characteristics of the city, including location, size, density, socio-economic development, and speed of urbanization
5. Key water urban challenge(s) addressed and contextual background information for understanding the challenge (for instance, authors may indicate elements of the water status of the city, such as water availability and consumption and water quality, etc.)
6. The innovative smart water technology solution proposed. Authors refer to the scale and timeframe of the smart water project, as well as any KPIs and standards.
7. Technical and non-technical requirements for the implementation of the smart water technologies. If applicable, authors refer to the agencies and companies supporting the implementation of the smart water solution, as well as the government policies that have supported it.
8. Policy implications, recommendations, or next steps, as appropriate to each case study. Authors address issues related to capacity building, governance structures or institutions, awareness raising, education initiatives, etc.
9. Acknowledgments (if applicable)
10. References
11. Appendix of photos, tables, and/or figures with captions.

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1.

Algarrobo (Spain)

RichWater® system for water reclamation in Algarrobo Municipality

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Algarrobo, Spain

Abstract
Municipalities are aware of their role in supporting the sustainable economic development of their cities and regions. Sustainability is key especially in strategic sectors based on the availability of natural resources, like water. The implementation of water reuse schemes is of special relevance in water scarce areas where the lack of irrigation water limits agricultural production, economic growth, jobs creation, and the development of other important economic activities such as tourism. These relevant challenges at urban level have been addressed by RichWater project in La Axarquia (Málaga, Spain) where the economy is strongly based on agriculture and tourism under the current lack of water availability and the pressures suffered by the Municipality to comply with regulatory and economic regional stakeholders.

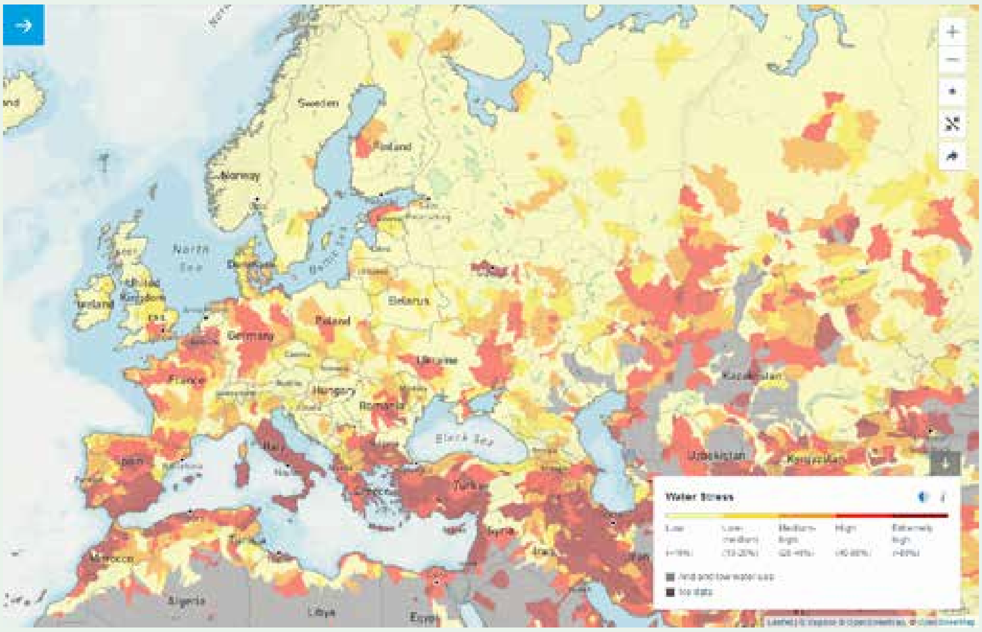
The project implemented in Algarrobo Municipality (Málaga, Spain), counted with the commitment of the municipalities and other relevant stakeholders (farmers and farmers associations, irrigation communities, the private sector, and academia) who are in need of innovative solutions for accessing alternative water sources and ensuring livelihoods. Smart approaches to reclaimed waters create important market opportunities for subtropical crops production in this area of the Spanish south.

RichWater project has demonstrated an innovative two-in-one solution: wastewater treatment and reclamation technology based on a low-cost and energy-efficient Membrane Bioreactor (RichWater MBR) designed to deliver a nutrient rich effluent for agricultural irrigation and fertilization and to support the transition to a more sustainable economy and a more sustainable agrifood system.

RichWater development has followed an open innovation approach, taking into account first-hand inputs from water operators, farmers and irrigators, public administration, local action groups, as well as inhabitants from the region who has also been involved in project activities. RichWater added value is based on this participatory and bottom-up approach, and it is still evolving in accordance with further requirements. All stakeholders must be part of the development and the solution which increases the potential success in its implementation and market penetration.

Introduction
Considering 'unconventional' water resources is getting more necessary in future hydrological planning. Growing population, the need to produce more food, and current consumption patterns are leading to a steady increase of water and demand for fertilizers (nutrients), putting a growing pressure on water resources which is further exacerbated by the negative effects of climate change. It is expected that around 52% of the world's population will live in water-stressed regions by 2050 (Kölbel et al., 2018).

Figure 1. Water Stress Map



In this context, the use of reclaimed water has a strong potential to provide a reliable alternative source for a number of uses, including agriculture irrigation and fertilization, street cleaning, garden irrigation or other industrial uses– provided that it is treated and/or used safely (WWDR, 2020) and according to appropriate standards and methods (i.e. Guidelines for better water reuse in Europe[1], ISO/TC 282 Water reuse[2]). The use of reclaimed water is also well-recognized as a safe and recommended measure for climate change adaptation and mitigation (WWAP, 2017). It is also essential in meeting the United Nation 2030 Agenda.

Concerns about efficient water use are getting more and more important at the global level and in Europe in the recent past, as reflected in relevant strategic documents, such as the Green Deal, the New Circular Economy Action Plan, and others. Indeed, water reuse is commonly and successfully practiced in several EU Member States, such as Israel, California, Australia, and Singapore. However, this practice is so far deployed below its potential in the EU. According to Water Reuse Europe 2018[3], only 2% of treated wastewater is reused in Europe. More than 40,000 million of m^3 of wastewater are treated in EU every year, but only 964 million of m^3 of this treated wastewater is reused[4]. These figures are expected to grow in the future, with the biggest potential for reuse in Portugal and Spain.

The use of reclaimed water has a huge potential for complementing conventional water resources needed in agriculture production–the backbone for stable food supply in Europe. Agriculture accounts for 40-60% of total water consumption in Europe; most of it is used for irrigation. In southern Member States, agricultural water abstraction accounts for approximately 80% of total water abstraction[5].

1. ec.europa.eu/jrc/en/news/guidelines-better-water-reuse-europe
2. www.iso.org/committee/4856734.html
3. www.water-reuse-europe.org/about-us/wre-activities/water-reuse-europe-review-2018/#page-content
4. EC Infographics: Water is too precious to waste. Available at: ec.europa.eu/environment/water/pdf/water_reuse_factsheet_en.pdf (consulted on 07/07/2021)
5. EEA 2021, Water resources across Europe — confronting water stress: an updated assessment

The implementation of water reuse projects such as RichWater in the Municipality of Algarrobo is of special relevance in water scarce areas where lack of irrigation water is limiting agricultural production and economic growth. Moreover, water scarcity is likely to limit the creation of jobs, since about three out of four jobs in the global workforce are dependent on water (WWAP, 2016).

RichWater project has demonstrated an innovative wastewater treatment and reclamation technology based on a Membrane Bioreactor (RichWater MBR) which has been designed to reuse the effluent in agricultural irrigation and fertilization. This reuse works to reduce pressure in water sources from European regions that are suffering from droughts and water scarcity. In addition, it supports the transition to a more sustainable economy, as the use of reclaimed water for agriculture fertigation, contributing not only to water circularity, but also to closing the nutrient cycle through the valorisation of nutrients embedded in the urban wastewater.

In order to overcome current barriers for the implementation of RichWater MBR, the technology has been verified by the European Commission Environmental Technology Verification (ETV)[6], a tool that helps innovative technologies reach the market. ETV is a service provided by the European Commission through which innovative technologies are verified by qualified third parties, called "Verification Bodies", that use test results to assess claims about the performance and produce a "Statement of Verification". This third-party validation is based on the internationally recognised ISO standard 14034.

The results of the verification process show the performance efficiency of RichWater MBR[7] in treating and reclaiming urban wastewater and delivering high quality nutrient-rich effluent for its reuse in agriculture fulfilling the legal framework. The quality standards applicable for the project are included in the Spanish Royal Decree 1620/2007, which regulates the use of reclaimed water for different purposes in Spain, including agriculture irrigation.

The ETV allows stakeholders such as farmers and public administration to access verified data which prove the RichWater MBR claims included in the Statement of Verification. RichWater MBR is one of the 16 verified technologies in the field of Water Treatment and Monitoring within the ETV programme.

Characteristics of the city

The case study is located in Algarrobo Costa, located in the Algarrobo Municipality, in the province of Malaga, Andalusia, in southern Spain. The municipality belongs to the coastal area of La Axarquía and is 34 kilometers from the city of Málaga. It is bordered on the north by the municipality of Arenas and Sayalonga, by Vélez-Málaga on the east and west, and to the south, the Mediterranean Sea.

6. (2021, October 26). EU Environmental Technology Verification (ETV). Eco-innovation Action Plan - European Commission. Retrieved October 30, 2021, from ec.europa.eu/environment/ecoap/etv.
7. (2021, January 12). RichWater series 2018. Eco-innovation Action Plan - European Commission. Retrieved October 30, 2021, from ec.europa.eu/environment/ecoap/etv/richwater-series-2018_en.

Figure 2. Location of La Axarquia
Source: De Tyk, based File: Andalucía-loc.svg by user: Miguillen - Trabajo propio, CC BY 3.0, commons.wikimedia.org

The municipality has a population of 6,444 residents, of which there are 3,238 men and 3,206 women. Its surface area is 9.73 km^2 and has a density of 662,3 inhabitants/km^2.[8] Main economic activities of the municipality of Algarrobo are agriculture, fishing, and tourism.

La Axarquía, which is composed by 31 municipalities, is known for being the **only area in Europe that produces** tropical fruits. Spain is the only European country with a significant commercial production of avocado and mango, 10,000 hectares and 5,000 hectares, respectively[9]. In Malaga, there are 7,000 hectares of avocado, producing 61,000 tons (2018/2019)[10] and more than 4,000 of mangoes producing 36,000 tons (2018)[11]. Market demand is increasing fast, especially for avocado, due to its global recognition as a “super food” with health benefits. The growth in demand and prices are setting up avocado as one of the top crops to be traded.

Thus, production is a local and regional economic pilar. Municipalities are committed to implementing smart approaches for supporting farmers to take advantage of this important market opportunity. There is a strong interest in the region to have access to scientific results on the cultivation of avocados and mangos with reclaimed water.

This case study is on the use of reclaimed water based on municipal wastewater, to irrigate and fertilize avocado and mangoes trees, in addition to tomatoes plants, as a non-conventional water source to cover crops water demand. Based on the figures given by the head of the Association of Municipalities, if all wastewater available in the region is reclaimed, this would cover 25% of water demand for current crops production.

The positive impacts are at the environmental level–by decreasing pressure on water bodies and eutrophication–and at the socio-economic level–by promoting local economies and job creation and implementing circular economy models allowing closing water and nutrients loops.

8. www.ayuntamiento-espana.es/ayuntamiento-algarrobo.html
9. www.freshplaza.com/article/2148459/spain-avocados-and-mangoes-the-most-profitable-crops/
10. www.projargroup.com/perspectivas-de-crecimiento-del-cultivo-del-aguacate-en-espana/
11. www.freshplaza.com/article/9258184/growing-loyalty-to-spanish-mangoes-in-europe/

Key urban challenges addressed

Water scarcity is a limiting factor for the production of higher value crops, such as subtropical crops (e.g., avocados, mangoes, custard apples, etc.), which is an essential activity for economic development and job creation in La Axarquía. In 2016, the subtropical fruit sector had a turnover of 149 million euros in the province of Malaga, the vast majority produced in the La Axarquía region[12]. In addition, more than 25% of the workers affiliated to Social Security in the region belonged to the agricultural sector, which confirms the importance of agriculture in the economic structure of the region[13]. The lack of water also induces conflicts with other sectors (i.e. tourism), as the Axarquía is a destination with a large holiday influx.

The RichWater project originated from the need to guarantee water access for irrigators of subtropical crops in the region of La Axarquía. These represent a large percentage of the total irrigated agricultural area (about 40%)[14]. Algarrobo Municipality as well as the Association of Municipalities of La Axarquia were very concerned about both, their role in supporting this relevant economic activity of the region and the role of water. In La Axarquia, reclaimed water is an alternative resource of high strategic value in the short-medium term as they are suffering from water shortages that are more and more frequent. Therefore, the local administrations are looking for innovative and competitive solutions for water reclamation and implementation projects. In addition, the Provincial Council of Málaga is asking the municipalities to develop Climate Change Plans and implement integrative solutions for the management of sustainable water.

When the project was approved in 2016, BIOAZUL, project coordinator, together with the partner IHSM La Mayora, started looking for a pilot site location and proposed it to Algarrobo Municipality. The RichWater approach was the solution they were looking for and it provided us with the demo site (wastewater treatment plant and an area owned by the city hall to perform the agronomic trials), as well as provided the contact to all relevant local actors. These contacts crystalised in a formal agreement with the municipality of Algarrobo, the association of municipalities of La Axarquia, and the wastewater treatment operation company, AXARAGUA, which was signed in October 2016. Thus, government, academia, industry, and citizens collaborate together to facilitate the adoption of reuse solutions that cope with the lack of water in the region. Furthermore, as a result of the networking activities carried out within the frame of RichWater, a working group has been set up with key players in the region of La Axarquia, showing their interest and support in the project and its continuity. These agents are the association of Municipalities of La Axarquía, the city council of Algarrobo, the Community of Irrigators of Algarrobo, AXARAGUA, as operator of the wastewater treatment stations of Axarquía, and the Spanish Association of Tropical Crops. The four components of the quadruple helix ensure the real commitment of all actors involved in decision making and the value chain. The objective is to extend the working group and to find external funding to continue with RichWater project activities. The current working group has created an operational group within the EIP-Agri called "AXARQUIA Sostenible" which has already obtained funds from the

12. cadenaser.com/emisora/2017/03/17/ser_malaga/1489744734_242335.html.
13. cederaxarquia.org/axarquia/estrategia-de-desarrollo-local-2014-2020/
14. cederaxarquia.org/axarquia/estrategia-de-desarrollo-local-2014-2020/

regional government to carry out the submission of an implementation project proposal, which was submitted In October 2020 (resolution is pending).

The main source of conventional water for irrigation in the region is the dammed waters from La Viñuela reservoir. In previous years, the amount of water has decreased to less than 30% throughout the year, putting agricultural production at risk. For example, by 29 June 2021, the volume was 50 hm^3, 30.30% of its capacity, 7.88% less than the same week in 2020 (63 50 hm^3) and 31.58% less the same week 10 years ago (102 hm^3).[15]

Andalusia, due to its location in the Mediterranean basin, is a territory for which climate change may risk a reduction in precipitation between 15 and 20% by the year 2050.[16]

Irrigated agriculture is the main water use in Andalusia, with more than 1,000,000 ha of surface. Climate change scenarios for 2050 show an increase in the annual demand for irrigation water of around 20%, an extension of the duration of irrigation campaigns, as well as an increase in peak demand above 10% during summer. If measures aimed at making efficient use of water are not implemented, the water availability scenarios will be deficient. In the case of the province of Malaga, the average annual temperature increase is estimated at 3.6°C in the worst-case scenario, which gives us an idea of the level of water stress these highly dependent crops will be subjected to.

The lack of water due to climate change and population, in terms of both quantity and quality, is therefore a limiting factor for the production of these high value-added crops and the development of other important economic activities, such as tourism, could enter into conflict and discourage the economic development of the municipality and the region. These are the challenges to be addressed at an urban level by the municipalities and to which resolution contributes the RichWater project.

Innovative Smart Water technology solution proposed

Richwater system, with 150m^3 treatment capacity/day of urban wastewater, has been piloted in the operating municipal wastewater treatment plant (WWTP) located in the municipality of Algarrobo within Malaga province (Spain) (36°45'12.1"N 4°02'55.7"W). The urban wastewater plant is managed by AXARAGUA[17] a private-public partnership created by the Association of Municipalities of La Axarquía and treats wastewater from the population of ca. 6,500 inhabitants.

15. www.redhidrosurmedioambiente.es/saih/resumen/embalses.
16. www.juntadeandalucia.es/medioambiente/portal_web/web/temas_ambientales/clima/actuaciones_cambio_climatico/adaptacion/escenarios/elaboracion_escenarios/clima.pdf
17. (2021, October 26). Las reservas de agua de la Axarquía. Axaragua. Retrieved October 30, 2021, from www.axaragua.com.

Figure 3. Algarrobo WWTP and RichWater MBR location
Google maps link: https://goo.gl/JUnQdb.

The RichWater system is composed of four modules: i) wastewater treatment module consisting of a Membrane Bioreactor (MBR); ii) mixing unit; iii) fertigation module; and iv) control and monitoring unit.

The core part of the RichWater system is the Membrane Bioreactor (MBR). It is a compact system for decentralized urban wastewater treatment based on membrane technology. The RichWater MBR system is a logical integration of technologies arranged in a process that leads to obtaining an effluent with the required quality. The processes that make up the complete system are listed below:

- Pre-treatment: Rotary sieve with internal feed with perforated mesh of 2 mm pitch. As the system is in the municipal WWTP facilities, we avoid incorporating grit removal and degreasing processes to capture the water after this process already installed in the main plant.
- Secondary treatment or biological treatment: Composed of two stages:
  - Biological reactor: aeration basin where the bulk of the biological degradation of the contaminants in the wastewater takes place.
  - Membrane tank: where the ultrafiltration membrane module is submerged. This MBR system is configured with the membrane tank separated from the biological reactor for a matter of practicality in maintenance work (chemical cleaning). The concentrated liquor in the filtration process is recirculated to the biological reactor.
  - Tertiary treatment: part of this treatment is given by the separation action exerted by the membranes as a physical barrier against particles larger than the pore of the membrane. In addition, the tertiary treatment is completed with an ultraviolet disinfection system.

Figure 4. RichWater MBR system
Source: BIOAZUL

All processes are controlled by the centralized control system, which also generates data and statistics that allow for optimizing both the treatment process and the maintenance work.

Sludge treatment was not included in this process due to a matter of process optimization, since the municipal WWTP has a sludge treatment system and allowed us to divert the purged sludge in the RichWater MBR system to its dehydration plant.

The design produces high quality effluent that meets the requirements for reclaimed water used for irrigation of crops for human consumption while maintaining high content level of nutrients. It allows to achieve an optimal and simultaneous irrigation and fertilization effect.

RichWater MBR has been verified by an external certified entity, IETU (Poland), under the EC Environmental Technology Verification Programme. The verification sampling campaign took place from the 24th of September 2018 to the 11th of December 2018. A total of 16 samples of the influent entering to RichWater MBR and 16 samples of the RichWater MBR effluent were taken. The total duration of each composite sampling was 24h. Grab samples of influent and effluent for microbiological analyses were collected on Tuesdays and Thursdays. These samples were taken within 2 hours after the autosampler completed the 24-hour sampling. Grab samples of the mixed liquor for MLSS, MLVS analysis were taken from the aeration and membrane tanks on the same days as the samples for microbiological analyses i.e. every Tuesday and Thursday, also within 2 hours after the autosampler completed the 24-hour sampling.

For the RichWater MBR ETV verification, performance parameters and the given limits were assessed, as well as operational parameters as shown in Table 1 and Table 2. The quality of the reclaimed wastewater (effluent) and operational parameters in relation to the performance claims for verification and legal requirements (if applicable) are presented below. The declared values were given at the beginning of the verification and the results obtained during the tests performed for assessing the RichWater MBR.

For some quality parameters the average values are better that the ones declared: Nitrates: 92,31 mg/L; Phosphorus <8 g/m^3, Turbidity 0.69 NTU, BOD5 <15 g O2/m^3, COD was 23,67 g O2/m^3 and Suspended solids < 8 g/m^3. Regarding Process parameters, verification show good performance for wastewater flow, HRT and MLSS concentration in the biological reactor and OLR.

Table 1. RichWater MBR performance indicators

Performance parameters Declared Values	ETV results
Nitrates ≥ 50 mg/l	The average value was 92,31 mg/l, above the declared level. Effluent quality better than declared.
Phosphorus ≥ 1.5 mg P/l	The average value was 4.34 mg P/l, above the declared level. Effluent quality better than declared.
Potassium ≥ 15 mg/l	The average value was 14,43 mg/l Slightly below the declared level.
BOD5 ≤ 25 mg O2/l	The average value was <15 mg O2/l Effluent quality better than declared.
COD ≤ 125 mg O2/l	The average value was 23,67 mg O2/l Effluent quality better than declared.
Suspended solids ≤ 20 mg/l	Concentration below detection limit for all effluent samples (<8 mg/l) Effluent quality better than declared.
Turbidity ≤ 10 NTU	The average value was 0.69 NTU Effluent quality better than declared.

Performance parameters Declared Values	ETV results
Escherichia Coli max 50 CFU/100 mL	In 94% of effluent samples, the concentration was below 50 CFU/100 mL. Only on 09.10.2018 Escherichia Coli content was 90 CFU/100 mL, but it was below the maximum admitted values of this parameter defined for TWW use on tree crops at RD1620/2007 (100 CFU/100 mL).
Legionella spp. max 1000 CFU/L	94% of effluent samples did not contain Legionella. Only on 16.10.2018 Legionella content was 1200 CFU/L. The maximum admitted value of this parameter is 1000 CFU/L for at least 90% samples (RD1620/2007). The sample that exceeds the maximum admitted value did not exceed the maximum deviation limit of 1 logarithmic unit.
Nematodes max 1 egg/10 L	100% of effluent samples did not contain Nematodes.

Table 2. RichWater MBR operational indicators

Operational parameters Declared Values	ETV results
Wastewater flow in the range of 0-10 m^3/h	The wastewater flow in the range of 0.41-4.85 m^3/h,
HRT in the biological reactor in the range of 30-10 h	HRT in the biological reactor in the range of 9.86- 115.90 h
MLSS concentration in the biological reactor $\leq$ 6 kg/m^3	The average concentration of MLSS in the biological reactor 3.476 kg/m^3
OLR < 0.5 kgBOD5/kg ·d	The average value of the parameter 0.08 kgBOD5/kg ·d
DO concentration in the biological reactor in the range of 1.5-2.0 mg/l	DO concentration in the range of 0.05- 2.4 mg/l (DO concentration different than declared)

RichWater MBR allows the production of high-quality reclaimed water rich in the most important plants macronutrients, Nitrogen, Phosphorus and Potassium, as shown in Table 3. Therefore, the reclaimed water has a double effect: irrigation and fertilization. The use of this nutrient rich reclaimed water allows the total or partial replacement of chemical fertilizers from non-renewable resources.

Table 3. Summary of RichWater MBR removal performance

	BOD5 (mg O2/l)	COD (mg O2/l)	TS (mg/l)	TN (mg N/l)	Nitrates (mg N/l)	TP (mg/l)	TK (mg/l)	Turbidity (NTU)
Influent								
Min	93,00	239,00	106,00	25,00	<5	3,30	8,80	2,60
Max	232,00	646,00	397,00	67,00	<5	12,00	25,00	349,00
Average	163,25	408,31	210,06	38,81	<5	5,97	14,81	120,48
Efluent								
Min	<15	15,00	< 8	16,00	5,20	0,16	8,10	0,16
Max	<15	32,00	< 8	45,00	40,68	12,00	24,00	2,30
Average	<15	23,67	< 8	26,00	20,85	4,34	14,43	0,69
Removal %	90,81%	94,20%	96,19%	33,01%	-316,97%	27,31%	2,62%	99,43%

Technical and non-technical requirements for the implementation of the smart water technologies.

In addition to RichWater system technical performace, it is necessary to have a common vision, as well as support and engagement of all value chain stakeholders in the territory and beyond and the legal framework that allows successful and wide implementation. In addition, we have count with the market demand as a driver to push the smart technology.

Stakeholders representing the cuadruple helix have fully committed with the Richwater approach as they understand the use of reclaimed water as an adaptation and mitigation measure for climate change effects that will lead to less availability of water in the region.

Several agencies support Richwater project[18]: The European Commission, Andalusian Regional Government, and EIP Agri and BRIGAID project. The work started with the Horizon 2020 Fast Track to Innovation project formed by 6 international partners and co-funded by the European Commission. The project received 1.67M€ funding from the EC for implementing the project activities in the 33 months of the project's duration (February 2016–October 2018). Partners from three countries (Austria, Germany, and Spain) collaborated to facilitate the adoption of reuse solutions that cope with the lack of water in the region and contributes to boost the agricultural sector: Technology providers: BIOAZUL (MBR module), PESSL, and SMS (sensors), and ISITEC (control module); as well as Academia: CSIC-IHSM (fertigation module) and TTZ (mixing unit).

In addition, 20,325 € funding were mobilized from BRIGAD project[19]. Under BRIGAID, in a six-month period, BIOAZUL developed a nutrient balance calculation tool that calculates the amount of fertilizer needed for irrigation when using reclaimed water. This solution optimizes the use of fertilizers, taking into account the existing nutrients contained in the reclaimed water and therefore, reduce costs for farmers while avoiding an excess of fertilizers that may end up in the eutrophication of other water bodies (e.g. aquifers).

Furthermore, as the project was strategic for municipalities of the region, an Operational Group was created with several territorial stakeholders: the municipality of Algarrobo, the association of municipalities of La Axarquia, AXARAGUA as operator of the wastewater treatment stations of Axarquía; Algarrobo Irrigators Community, the Spanish Association of Tropical Crops and CSIC-IHSM. The group applied for 5,000€ EIP-Agri funding to consolidate the working group, to enlarge the group with new key members, to carry out awareness and dissemination activities, and to enable the innovation project to continue with the activties performed under RichWater.

An extended Operational Group applied in October 2020 for EIP Agri funding to implement the innovation project for 254,993.22€ funding. The extended

18. BIOAZUL. (n.d.). Innovative Wastewater Treatment Technology. Richwater. Retrieved October 30, 2021, from richwater.eu/.
19. BRIGAID is not over yet! BRIGAID EU project is getting to the end, BRIGAID in a nutshel!We are proud of our achievements. ?//brigaid.eu#brigaid_eu #EASME #H2020 #ClimateInnovationWindow Reply on Twitter 1303960430092718083Retweet on Twitter 13039604300927180832Like on Twitter 13039604300927180832Twitter 13039604300927180, & We just published our latest news on BRIGAID. (n.d.). Bridging the gap for Innovations in Disaster Resilience. Brigaid. Retrieved October 30, 2021, from www.brigaid.eu.

group includes producers Associations, such as TROPS and ASAJA, technology providers such as SERAGRO, and the region Local Action Group, CEDER.

The access to further funding will allow activities to continue, further evaluating the revenues for the municipality by "selling" the water to irrigators, decreasing the amount of water and chemical fertilizers consumed, and increasing production capacity.

RichWater is perfectly aligned with the national and European legal framework: Spanish Royal Decree 16020/2007 on water reuse, Water Framework Directive 2000/60/EC, Circular Economy package, Green Deal, Nitrates Directive 91/676/EEC, Urban Waste Water Directive 91/271/EEC, and the recently published Regulation 2020/741 on minimum requirements for water reuse. Moreover, the use of reclaimed water contributes to the achievement of the SDGs, specially to the SDG2 (Zero Hunger), SDG 5 (Gender Equality), SGD 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation, and Infrastructure), SGD12 (Responsible Consumption and Production), and SGD13 (Climate Action) among others.

RichWater uptaking also supports the implementation of several regional policies and strategies. These include the Andalusian Water Pact, which foresees the implementation of water resue projects, the Circular Bioeconomy Strategy with identified the potential of water and nutrient circularity by the waterwater reclamation, and the Andalusian Climate Action Plan which seeks to transit to a decarbonised economy.

Last but not least, the RichWater project has been recognized at both the national and international level.

In July 2019, RichWater was selected as a Water Oriented living lab by Water Europe and ENOLL as one of the 105 research settings that met assessment criteria (see page 41)[20].

In October 2020, the project received the "Malaga Viva" award from the Malaga Provincial Council for the commitment to using reclaimed water in agriculture as a measure in the fight against climate change.

In June 2021, RichWater was the winner of the Water Europe Innovation Awards 2021 in the modality Water Technology & Infrastructure for its highly promising capability of saving fresh water and fertilizers in agriculture.

Policy implications, recommendations, or next steps

Reclaimed water use is a safe and reliable alternative for agriculture that has certain advantages over other conventional sources. It is a decentralized resource in the territory, has continuous availability, does not depend on climatic events, and provides nutrients that can be directly assimilated by plants.
RichWater acts as a driver in the modernization of agricultural technology and generates quality employment in the design, manufacturing, and

20. Water europe launches new publication 'atlas of the European Water Oriented Living Labs'. Water Europe. (n.d.). Retrieved October 30, 2021, from watereurope.eu/water-europe-launches-new-publication-atlas-of-the-european-water-oriented-living-labs/.

commissioning stages, as well as in the maintenance and operation. Moreover, the availability of reclaimed water for agriculture plays a fundamental role in the so-called “rural renaissance,” allowing the conservation of the rural environment and its ecosystem services and contributing to avoid rural depopulation. It promotes the labor integration of women, which makes up 29% of the workforce in Europe, as one of the main vectors for rural innovation and entrepreneurship.

Reclaimed water use contributes to farmer water sovereignty since its combination with more conventional water sources avoids supply cuts and the consequential losses to food production. It implies a reduction in demand and water pressure on sources for drinking water which may be used for other priority uses, such as tourism or industry.

Lastly, RichWater allows nutrient recovery, reducing the risk of environmental problems (e.g. eutrophication) due to their excess in water bodies. These nutrients are directly assimilated by plants, which leads to savings in chemical fertilizers and consequent economic savings for farmers and irrigation communities. This means a lower carbon footprint since CO_2 emissions are avoided by the production, packaging, and transportation of fertilizers.

At this stage, the ETV verification has recognized the potential of RichWater to provide an effluent to be used in irrigation which is safe and which optimizes the amount of nutrients for the plants. ETV verification helps innovators with the technology commercialization by providing confidence to potential clients and guarantees that performance data is credible and accurate. These guarantees are particularly relevant in the context of water reuse since negative public perception has been recognized as one of the main barriers for the use of reclaimed water in agriculture.

The next steps of the project are mainly focused on continuing with innovation activities, together with all territorial stakeholders, to get sound results on the use of reclaimed water in the productivity of plants, quality of fruits and biodiversity of the soil. This is what the municipalities are requesting for the further implementation of water reuse projects in the municipalities of the La Axarquia Region. Hopefully, these activities will be implemented with EIP Agri funding for the Operational Group innovation project.

The recent approval of EU Regulation 2020/741 implies the application of more stringent standards in terms of water quality for reuse in agriculture. This scenario implies further investments in wastewater treatment and reclamation to comply with the new legal requirements. In this sense, membrane technologies as RichWater have proven to be a reliable solution to extend water reuse.

Finally, RichWater has proven its potential to fertigate and provide nutrients to the plant. This is one of the main benefits of using reclaimed water for irrigation. Nutrients contained in the reclaimed water are directly assimilated by the plants and can therefore partially replace conventional chemical fertilizers. This then accounts for economic savings to farmers and a reduction on the dependency of chemical fertilizers. Cost-benefit analyses are to be performed to demonstrate economic savings as well as the ecological footprint assessment and environmental benefits of using reclaimed water.

Acknowledgements

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Busan Eco Delta City (Republic of Korea)

Suhyung Jang, YuJin Lee, Jin Kim, Jae Hwan Park, Do Kyoon Kim,
Sung-Phil Jang and Koo Ho Jeong

Busan City (Republic of Korea)

Introduction

Busan is the 2nd most populated city in Korea with 3.3 million residents. Between Nakdong River and West Nakdong River, Busan Eco Delta City (BEDC) is being developed by Busan Metropolitan Government, K-water, and Busan Metropolitan Corporation since 2012 under the MOLIT's waterfront development project in accordance with the Special Act on the Utilization of Waterfronts (Figure 1).

Figure 1. Map of Busan and Location of Busan Eco Delta City
Source: Modified from K-water (2018)[1]

The main purpose of the BEDC development is to vitalize economic growth in Busan metropolitan area which has a population of nearly eight million and facilitate cultural and leisure activities along the rivers. Putting in the capital of 660 trillion KRW (about 660 billion USD), new urban districts of housing, commerce, R&D, and logistics will be constructed in the 11.8 km^2 area of BEDC until 2023. Also, this new town will be home for 76,000 people with 30,000 new housing.

For the following sections, Busan Eco Delta Smart City and its Key Performance Indicators (KPIs) are represented.

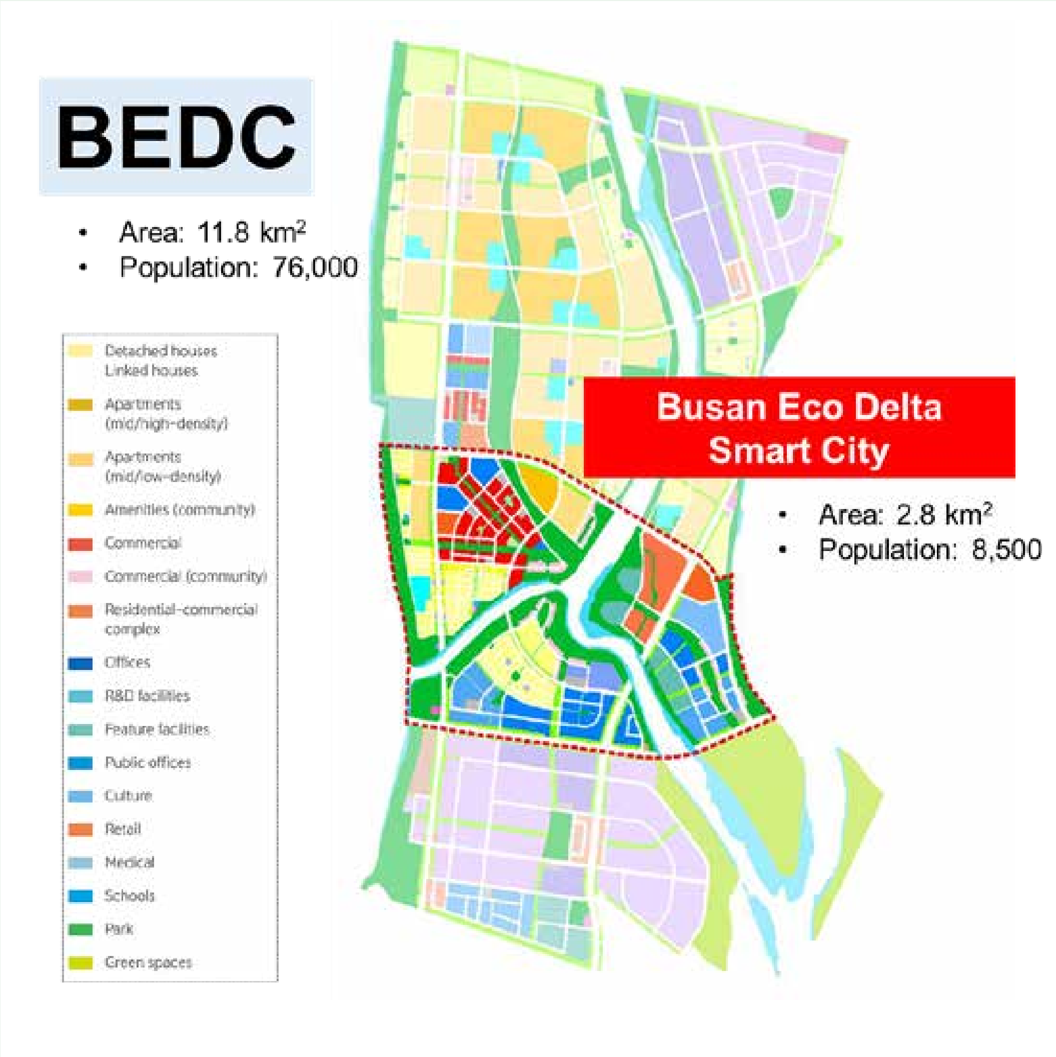
Busan Eco Delta Smart City

In 2018, the PCFIR of Korea announced a plan for the National Pilot Smart City in which the development of Busan Eco Delta Smart City (BEDSC) was included. The main purpose is to present future smart city models and create innovative industrial ecosystems while freely demonstrating and integrating the 4IR technologies[2]. Located in the center of BEDC (see Figure 2), BEDSC

1. K-water. 2018. Busan Eco Delta Smart City Master Plan.
2. Smart City Korea. 2021. Busan Eco Delta Smart City [Online]. https://cutt.ly/jU0wDVL (Accessed on 29 September 2021)

development aims to adopt smart 4IR technologies for achieving quality of life for citizens' and facilitate inclusive growth and fair opportunity in environment, safety, education, and culture[3].

Figure 2. Map of Busan Eco Delta City and Busan Eco Delta Smart City
Source: Modified from K-water (2021)[4]



Since the development has started from scratch in an open area of 2.8 km^2, specific urban challenges from every aspect in the city of Busan as well as general ones in and outside of Korea were considered when planning BEDSC development. These include environmental issues, population decrease (Busan/Korea and some developed world) and growth (most developing world), global competitiveness, etc. Consequently, ten innovative strategic objectives were set for BEDSC development in which Smart Water is included (see Figure 3). Thus, more than 100 smart technologies in water, safety, energy, mobility, health, education, and living will be applied in the entire smart city, which will make BEDSC a living testbed for smart 4IR technologies R&D[5].

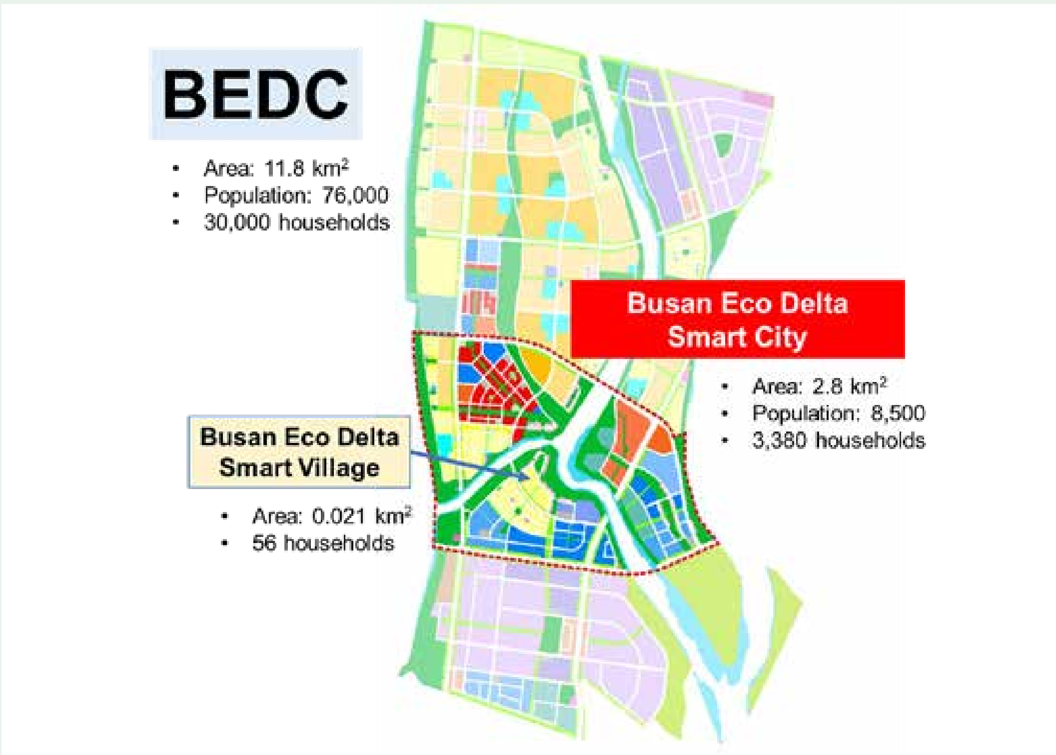
3. K-water. 2018. Busan Eco Delta Smart City Master Plan.
4. K-water. 2021. [Internal Document].
5. K-water. 2018. Busan EDC Smart City Concept Plan [in Korean].

Figure 3. Ten Strategic Objectives in Busan Eco Delta Smart City Development
Source: K-water (2018)[6]

Busan Eco Delta Smart Village

Since 2020, a special village with 56 new houses, called Busan Eco Delta Smart Village (BEDSV), has been built in BEDSC (see Figure 4). This is the first smart residential village where people will settle down in the National Pilot City of Korea[7]. Citizens will live in the houses and have hands-on experience with smart 4IR technologies. Afterwards, they will provide their feedbacks, which will be reflected when applying the technologies in the entire BEDSC. Therefore, this village will be the living lab in BEDSC.

Figure 4. Map of Busan Eco Delta Smart Village
Source: Modified from K-water (2021)[8]

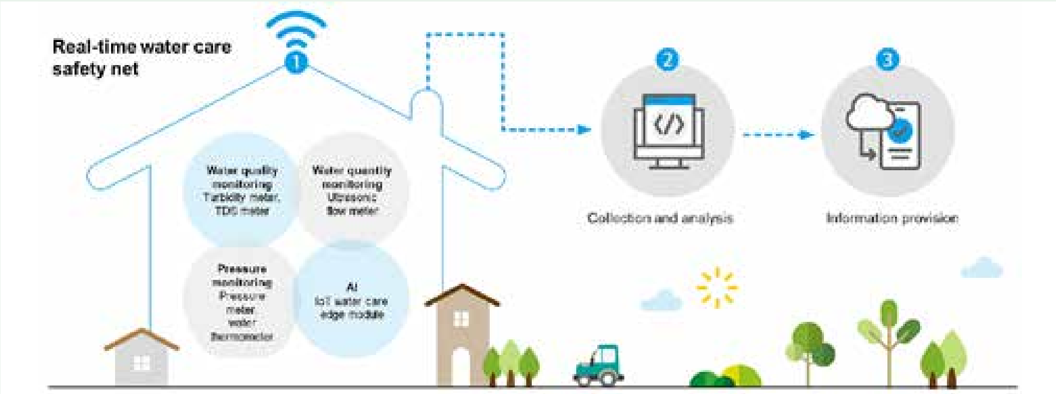


6. K-water. 2018. Busan Eco Delta Smart City Implementation Plan (Summary) [in Korean].
7. Smart City Korea. 2021. [Busan] Introducing Busan Eco Delta Smart Village [Online]. https://cutt.ly/rU0eoZ8 (Accessed on 29 September 2021)
8. K-water. 2021. [Internal Document].

BEDSV is also referred to as a Water Energy Science Village because its specialized features of applying water and energy technologies in its housing complex. Clean water produced from a decentralized smart water treatment plant will be distributed to each building. Afterwards, water quality such as turbidity and total dissolved solid (TDS), quantity such as water flow and pressure in each house will be monitored and analyzed through real-time water care safety net so that residents can freely drink and enjoy tap water with comfortable water pressure at home (see Figure 5). Moreover, BEDSV will be the first housing complex in the nation to acquire Zero Energy Building (ZEB) Level 1[9]. Renewable resources such as water-thermal, geothermal, and solar energy will be used in the buildings.

Figure 5. Real-Time Water Care Safety Net in Busan Eco Delta Smart Village

Source: K-water (2020)[10]

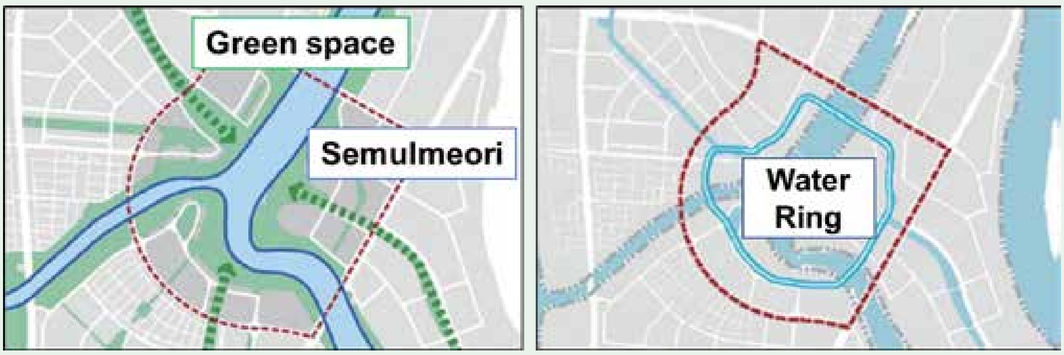


Eco-friendly waterfront city to enjoy the richness of the true nature

In the center of BEDSC, there is a geographical setting called Semulmeori where three natural streams of water (West Nakdong river, Macdo river, and Pyeonggang stream) meet. BEDSC development chose Semulmeori where people, water, nature, and city would be interconnected[11]. Green spaces and artificial water rings will be constructed along Semulmeori so that ecological as well as cultural and leisure activities can be thriving in this central area, surrounded by 54 km of waterfront (see Figure 6).

Figure 6.Green Space and Artificial Water Ring Along Semulmeori in BEDSC

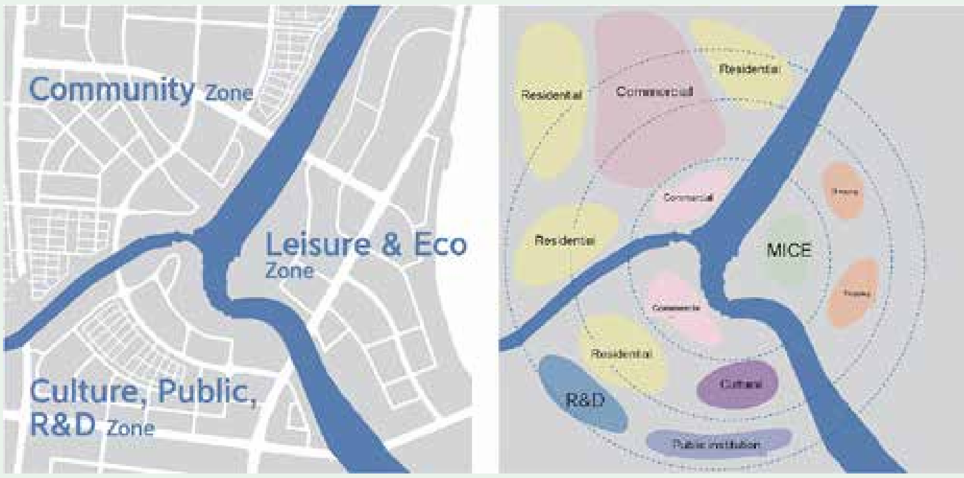
Source: K-water (2018)[12]



9. In 2017, Zero Energy Building certification was enforced in Korea in accordance with the Green Building Construction Support Act. The certification has five levels regarding energy independence of the buildings. ZEB Level 1 is given to the buildings with more than 100% energy independence, which signifies higher energy generation than consumption in the buildings.
10. K-water. 2020. Future that You Experience the First: Busan Eco Delta Smart Village [in Korean].
11. K-water. 2018. Busan Eco Delta Smart City Master Plan.
12. K-water. 2018. Busan EDC Smart City Concept Plan [in Korean].

Moreover, commercial, cultural, and residential districts as well as R&D zones will be integrated around Semulmeori, which will make BEDSC more attractive and livelier (see Figure 7). A commercial and business district will be located with an 8 m wide, 1.2 km waterway running through it, and a district with an area of 0.69 km^2 will be designed into a multi-functional culture and leisure district[13]. The roads with priority for pedestrians will be constructed to connect residential areas in the 4.6 km smart community street, and bicycle roads with a total length of 48 km will be built to help promote public transportation. These roads will make access to rivers and parks in less than five minutes. Consequently, BEDSC aspires to be a city with an optimal arrangement of nature, scenery, and culture along the waterside by maximizing the value of waterways. In the city, work and leisure would balance well, and people would be able to enjoy walking and running while appreciating and preserving ecological values.

Figure 7. District Planning Along Semulmeori in Busan Eco Delta Smart City
Source: K-water (2018)[14]



Busan Eco Delta Smart City Platform[15]

In conventional smart cities, data platforms were separately developed and operated by each service and infrastructure. These separate platforms incurred high development costs as well as difficult application and validation of new ideas. However, BEDSC itself will behave as an unrestricted convergence platform where open data can be collected and shared among services and infrastructure in the city (see Figure 8). Moreover, digital twin technology will establish an augmented city platform of BEDSC (see Figure 9).

13. K-water. 2018. Busan Eco Delta Smart City: Master Plan Summary.
14. K-water. 2018. Busan EDC Smart City Concept Plan [in Korean].
15. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Figure 8. City as Platform in Busan Eco Delta Smart City
Source: K-water (2018)[16]

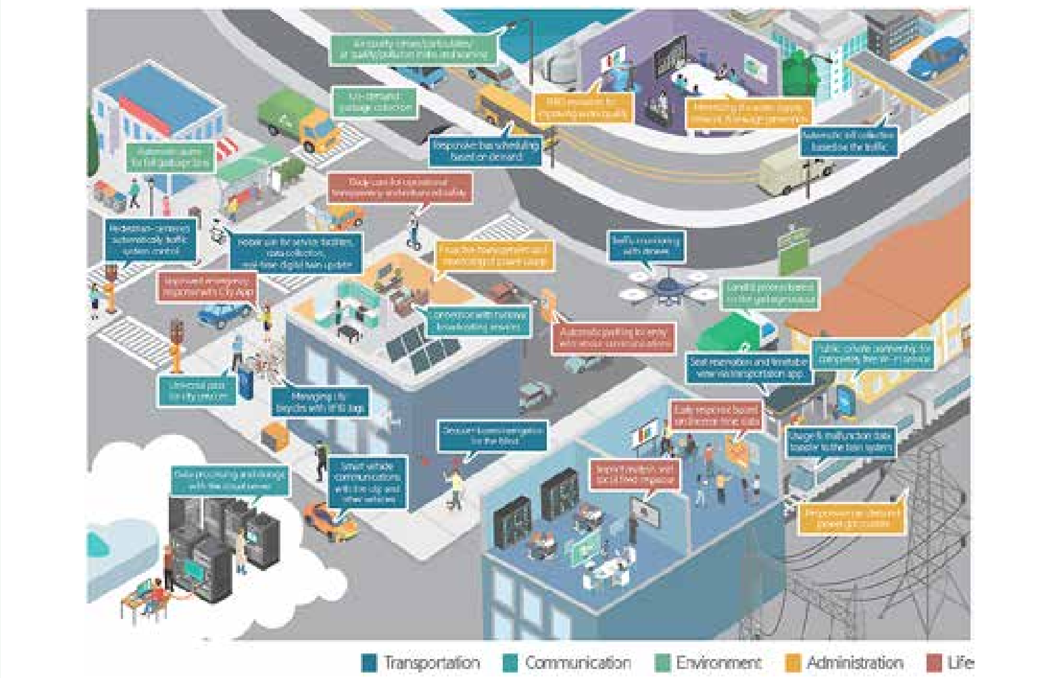
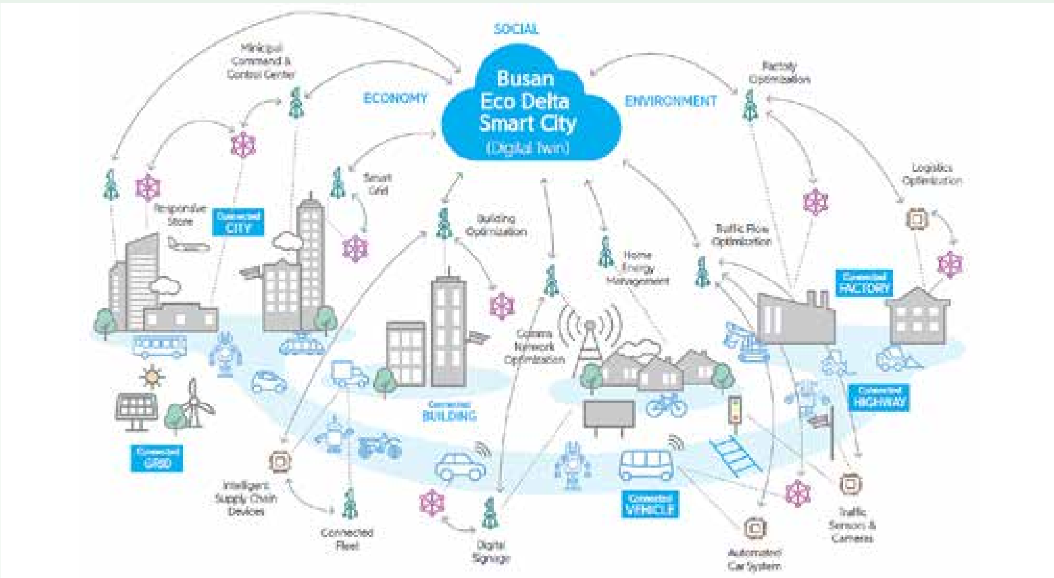


Figure 9. Application of Digital Twin Technology in Busan Eco Delta Smart City
Source: K-water (2018)[17]



K-water's 50-year water management expertise and know-how in Busan Eco Delta Smart City

BEDSC will showcase the collection of water management technologies from K-water's 50 year-expertise and know-hows, which will facilitate natural water cycle restoration in the city. Smart water infrastructure and services will be provided all around the BEDSC, such as precipitation forecast and urban water-related disaster response systems, Low Impact Development (LID) infrastructure and services, stream quality improvement infrastructure and services, smart

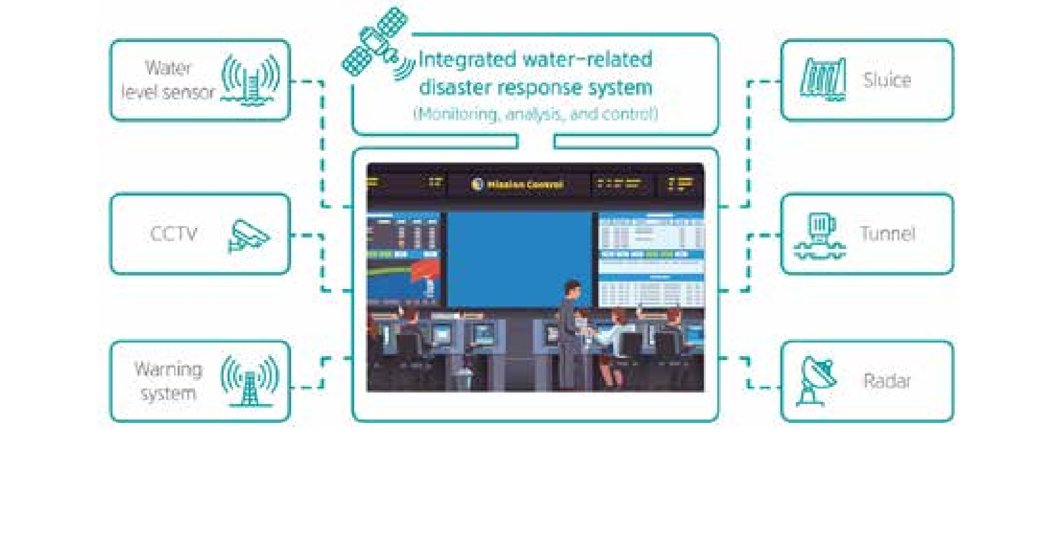
16. K-water. 2018. Busan Eco Delta Smart City Master Plan.
17. K-water. 2018. Busan Eco Delta Smart City Master Plan.

water treatment plants, SWM infrastructure and services, and water recycling systems (see Table 1). Moreover, for the first time in Korea, renewable energy based on water-thermal energy will be implemented for heating and cooling (see Figure 10).

Table 1. Smart Water Infrastructure and Services in Busan Eco Delta Smart City
Source: K-water (2018)[18]

Smart water infrastructure and services	Example
Precipitation forecast and urban water-related disaster response systems	Water level sensors CCTVs Warning systems Radars Sluices Tunnels
LID infrastructure and services	Permeable paving Bioswales Constructed wetland Rooftop gardens Rain gardens Percolation trenches
Stream quality improvement infrastructure and services	Eco-filtering system
Smart water treatment plants	Small-sized multi-story water treatment facilities
SWM infrastructure and services	Block flowmeter systems Water quality gauges Water leak detectors Automatic drains Water-NET operation/management system Information apps Water quality display boards Drinking fountains Water coordinators Water doctors
Water recycling systems	Highly advanced wastewater treatment plants

Figure 10. Water-Thermal Energy Supply in Busan Eco Delta Smart City
Source: K-water (2018)[19]



18. K-water. 2018. Busan Eco Delta Smart City Master Plan.
19. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Advanced urban flood response system

In BEDSC, there is continuous analysis of localized rainfall around the city with high-precision small precipitation forecast radar and preparations for flooding. These radars are connected to a data platform. This will allow emergency resilience in the smart city. Given the increasing flood risk due to climate change, the early detection system based on the water management platform will forecast a 6-hour lead time to flooding.

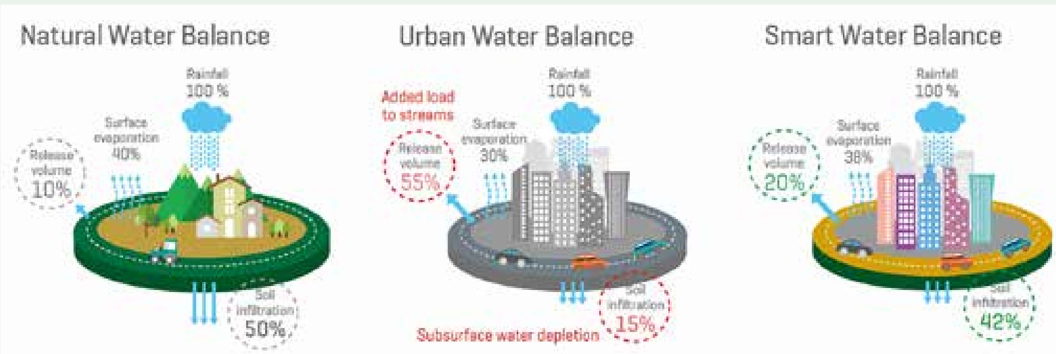
Moreover, there is continuous monitoring of water infrastructure, such as the water level, sluices, and drain system in link with the cross-city operation center for implementation of the integrated water-related disaster response system. This includes the installation of 70 sensors and 10 CCTVs for real-time data collection and monitoring, along with the forecast, analysis, and warning systems against flooding, drought, and water contamination.

Figure 11. Integrated Water-Related Disaster Response System
Source: K-water (2018)[20]

Introduction of Low Impact Development (LID)

Controlling the impervious areas to restore the water cycle will be part of the comprehensive water cycle management in BEDSC to tackle various issues arising from rainwater runoff in urban areas.

Figure 12. Smart Water Balance Concept
Source: K-water (2018)[21]



20. K-water. 2018. Busan Eco Delta Smart City Master Plan.
21. K-water. 2018. Busan Eco Delta Smart City Master Plan.

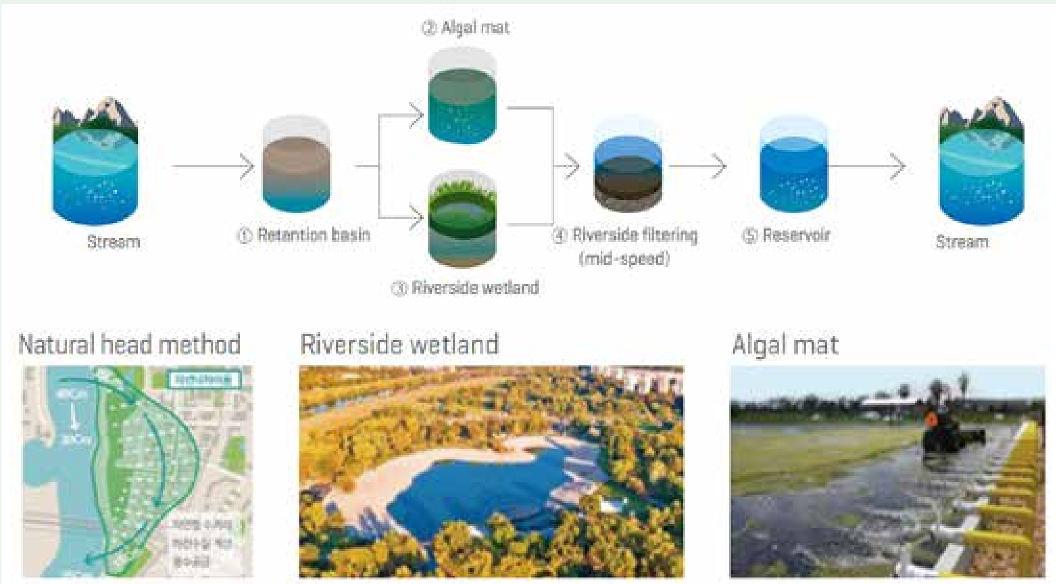
Water quality improvement of city stream

BEDSC includes the river delta and waterfront environment, as well as the Pyeonggang stream and Macdo river that flows through the city. The eco-filtering system aims to improve the water quality of these two waterways, with plans to turn the area into a water cycling park later. The Smart Water Management (SWM) technology will be used with the entire water supply process to obtain real-time quality information and to build the pollution management system.

There will be custom-built, green infrastructure for water cycling and recovery in the city connecting the roads, parks, riverside public facilities, and buildings to reduce non-point pollution that is common in urban basin areas.

BEDSC will achieve its status both as an international waterfront city and a national pilot project by improving the water quality of the two waterways crossing the area, Pyeonggang stream and Macdo river, to Class 2 or better.

Figure 13. Eco-Filtering: Key Technology and Process
Source: K-water (2018)[22]



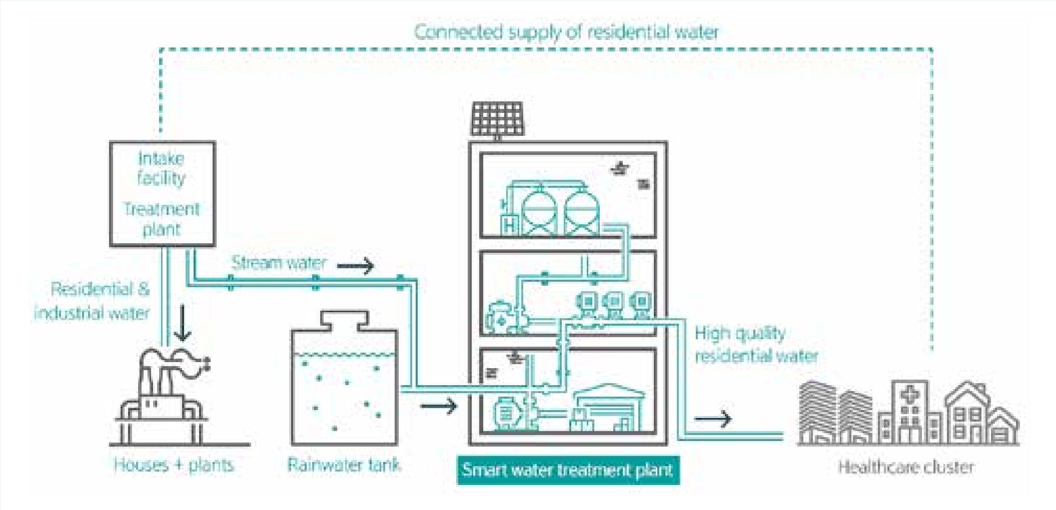
Smart water treatment plant

In the current water supply system in Korea, purified water is delivered to the final consumer from a large water treatment facility near the water source. While the conventional water supply system travels a long distance through tunnels, it is exposed to various risks, such as water leakage and water pollution.

To solve these problems, BEDSC is planning to build advanced small-scale treatment facilities inside the city. It will help reduce water loss and the use of chlorine, ensuring the quality of drinking water.

22. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Figure 14. Smart Water Treatment Concept Design
Source: K-water (2018)[23]



Smart Water Management (SWM)

The SWM system to be implemented in BEDSC uses a scientific approach to converge and manage water resources and the entire water supply cycle of purification, distribution, use, and reuse.

SWM technology will allow access to live information on water quality and quantity throughout the water supply process and to provide user-centric services. This includes ICT application in water supply processes from source to tap for real-time monitoring and remote control of water quality and quantity, as well as smart meters installed in households to provide data about amount used and enable other assistive services, such as the leak alarm and motion detection.

The SWM will be a complete water management model that expands water management from resource-centered to all areas of water flow, aiming to secure the reliability, safety, and efficiency of water supply by designing and operating the Smart Water Grid (SWG).

Figure 15. Smart Water Management (SWM) Design
Source: K-water (2018)[24]

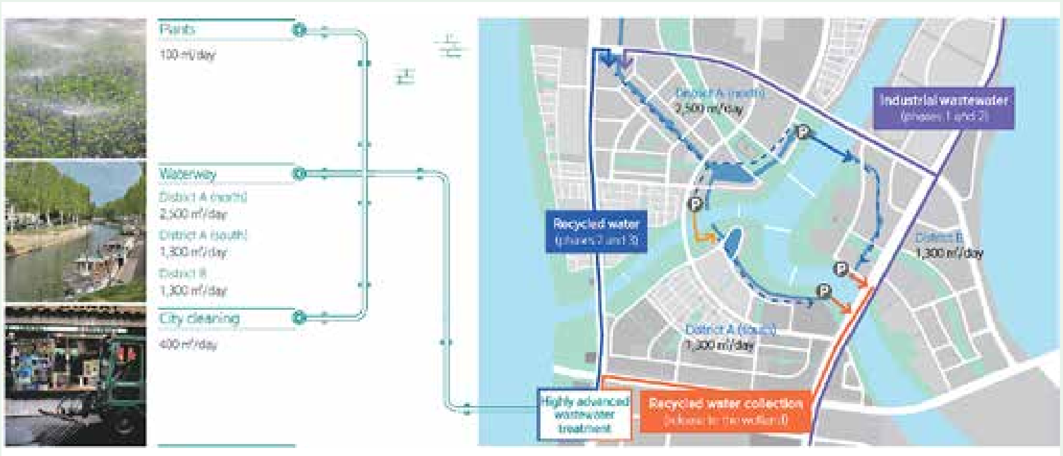
23. K-water. 2018. Busan Eco Delta Smart City Master Plan.
24. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Water recycling system

Wastewater from households and restaurants in BEDSC will be processed through an advanced water treatment system, and the treatment facilities will be equipped with reuse pressure systems. A recycling facility will be built in the sewage treatment plant with dedicated tunnels and a pressure system to supply and recover reusable water.

The complete wastewater reuse policy in BEDSC will be a proactive measure to protect water rights and counter water shortage problems. In BEDSC, 10% of wastewater generated in the city will be reused. Wastewater will be treated in an economically friendly way and reused for main waterways (91.1% of reused water), gardening (7.1%), and cleaning (1.8%).

Figure 16. Water Reuse Concept Design
Source: K-water (2018)[25]



Heating and cooling for the city using hydrothermal energy

BEDSC will offer a showcase of various water technologies incorporating the surrounding waterways. The city will utilize renewable water-thermal energy from differing temperatures of rivers and wide-area water sources to make the city eco-friendly for heating and cooling and reducing fossil fuel consumption.

Key Performance Indicators for Busan Eco Delta Smart City

KPIs for BEDSC were developed to achieve the vision, "a place of innovation and international leadership". The KPIs consists of six core objectives with 28 indicators to prevent and tackle current urban issues by fostering 4IR technologies and improving quality of life (see Table 2). With the KPIs, BEDSC would be a space where nature, people, and technology come together.

25. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Table 2. Key Performance Indicators for Busan Eco Delta Smart City
Source: K-water (2019)[26]

Urban issue	Key Value	Core objective	KPI	Solution
Natural disasters	People	1. 5 years longer healthy life	1. To improve the water quality of Pyeonggang Stream and Macdo River to Class II or better	Water quality management
			2. Early flood detection - 6 hours ahead	Flood forecasting
			3. Reduction of earthquake early warning time to 20 seconds or less	Surface ground monitoring
Social disaster			4. Lowering of road accident rate to under 46%	Road accident prevention
			5. 100% complete early fire response in 5 minutes	Fire prevention and response
			6. 25% reduction in 5 major crime rates	Crime prevention and response
Health			7. 4.5-year increase in average life expectancy	Improved pedestrian zone
			8. Plus 3 years in healthy life expectancy	Smart healthcare
Living environment		2. 50 : 50 work & life balance	9. 76.16 m^2 of park space per capita	Recreational space
			10. 20,000 m^2 of festival street (40 m wide, 500 m long)	Culture/festival street
			11. 100% ICT-based learning	Smart education
			12. 15% reduction in time on housekeeping	Home IoT
Workplace environment			13. 40 weekly working hours	Smart office

26. K-water. 2019. Key Performance Indicators for Busan Eco Delta Smart City.

Urban issue	Key Value	Core objective	KPI	Solution
Transportation	Nature	3. 20% more renewable energy	14. 50% reduction in carbon emissions	Electric vehicle; road restructuring
Renewable energy			15. 120% of required power from renewable sources	Water-thermal energy; hydrogen fuel cell; photovoltaics, ESS
Construction			16. Zero-energy houses for 56 homes	Zero-energy housing zone
Water		4. 100% recycling rate	17. 100% wastewater reuse	Wastewater reuse, etc.
			18. 20% reduction in water usage and unused waste per person	SWM
			19. Impervious area down to under 15%	LID
			20. 16.5% of required power from wastewater-thermal energy	Sewage heat energy
Waste			21. 35% of required power from SRF	Incineration heat energy
Life-related services	Technology	5. 125-hour savings a year	22. 5 hours less waiting for medical consultation	Remote diagnosis
			23. 21 hours less spent in administration	e-Government
			24. 35 hours less spent on providing security and safety annually	City safety
Transportation			25. Over 20% of mobility enabled by bicycles	Shared bicycles
			26. 4 hours saved annually to find parking space	Smart parking
			27. 60 hours less time wasted on road annually	Smart traffic lights & smart road
Construction & innovative industrial ecosystem		6. 28,000 new jobs	28. 28,000 new jobs	Smart tech applications & city development; startup supports (acceleration/ incubation); validation & commercialization; R&D project development

Ciudad Juarez (Mexico)

Case study proposal: Ciudad Juarez, Mexico smart network for meter reading and pressure control management

Oscar Ibáñez, Jesus Lazo, Ramiro Meza, and Aníbal Miranda

Ciudad Juarez (Mexico)

Abstract

Ciudad Juarez, Mexico, is located on the largest desert latitude of the globe. It is part of a twin cities bi-national community with its twin city of El Paso, Texas, USA, integrating around 2.5 million people sharing the same two aquifers.

Our main concern and what motivated this smart project is reducing the Non-Revenue Water (NRW) while maintaining our current 24/7 service. To meet these two premises, we designed a master plan to reduce water loss by implementing technological changes that allow us to get modern technologies, achieve our main goals, and be ready for further advances with other sensors installed on our water network.

We also designed a financial master plan to fund an initial and internal smart network. The strategy was to capture incomes due to a more accurate registration of our most significant water use as very few accounts mean a considerable quantity of incomes according to our Pareto analysis of users-consumption-payment optimal figures.

Presently, we have a smart water infrastructure running which is reading 7,000+ smart meters every hour and 40 pressure control points reducing flow during the night; we funded this project through billing increments and savings because of NRW reductions.

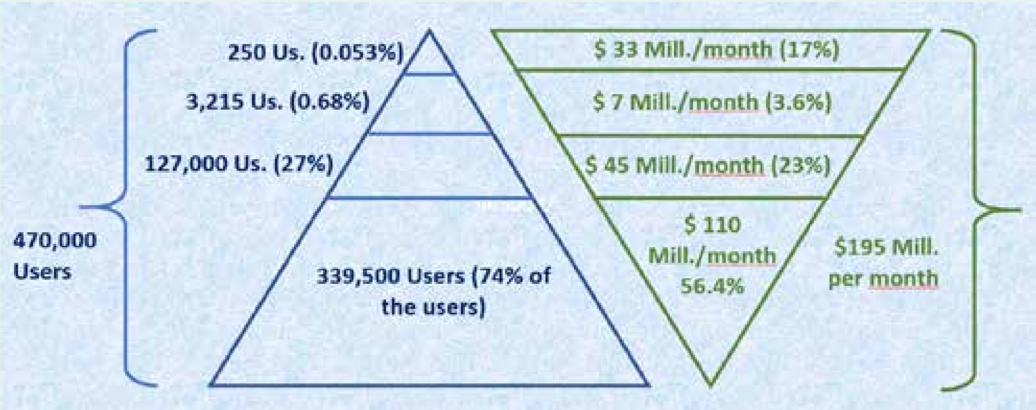
Introduction

Our starting point of the Key Performance Indicator (KPI) called Non-Revenue Water (NRW) was around 47% which was a bad KPI figure; at the same time, however, it means a double improvement opportunity. If we could reduce the NRW, we can increment our billing and reduce our operating costs. To work in both directions, we decided to implement new metering technology associated with a Radio Frequency (RF) fixed network with the capability to read in an hourly base water meters and pressure sensors. Additionally, we installed the necessary equipment to reduce water loss through some pressure control projects.

After some pilot projects that used different smart meters and reading systems, we finally decided to move forward looking for the best of the critical components of a smart network: extremely accurate meters, no moving part meters with a Ratio of at least 400 to get more incomes, and an automatic metering infrastructure (AMI), sometimes called fixed network reading system with the capability to read other sensors like leaks detectors or pressure sensors.

Our objective was to get enough funds to advance with new technology without incurring debt. We did a Pareto analysis of the number of users against income (see Figure 1). It was fundamental to define the way to go in terms of quantities and time frame for this ambitious project in a top-down sense, getting funds to finance the next stage.

Figure 1. Pareto analysis showing number of users associated with the corresponding billing in Mexican pesos.



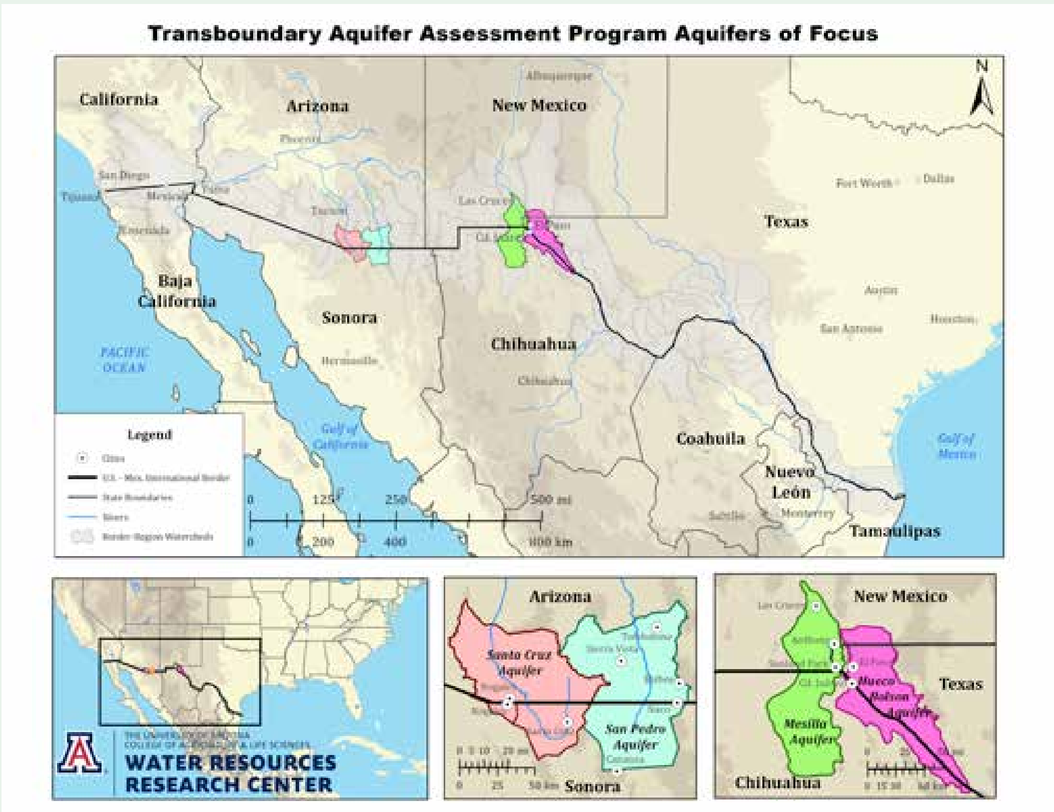
We did not cover all the users, but we were able to track those that are most profitable for us and the best in terms of billing.

This benefit allowed us to buy meters, an RF network, and a pressure control system. The savings of water in some districts meant savings on energy, better pressure in other areas, and a reduction of the volume of water that we were losing before. Thanks to this project, we were able to recover and sell to other users.

Characteristics of the city

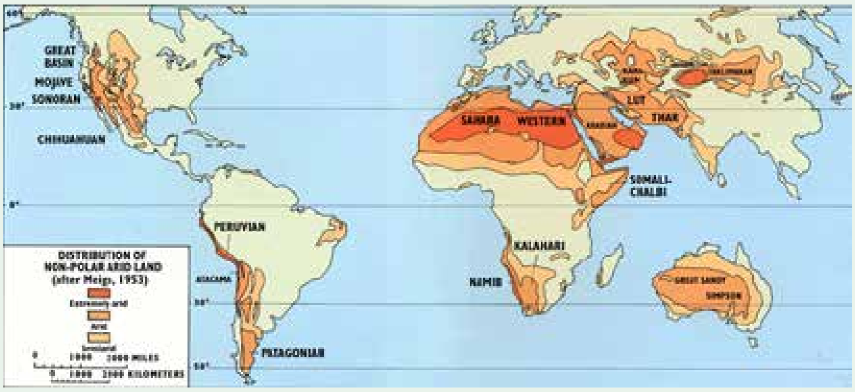
Ciudad Juarez gets its fresh water from two transboundary aquifers, named 'Hueco' and 'Mesilla', both shared with the USA (USGS, Transboundary Aquifer Assessment Program (TAAP), 2017).

Figure 2. Location of the two shared aquifers with the USA



Juarez is in the Chihuahuan desert, experiences very dry weather with a maximum average temperature of 40.9°C, and a minimum average temperature of -2.6°C. They experience a rainy season in summer. The Chihuahuan desert is at the same desertic latitude as the Sahara and Arabic deserts.

Figure 3. Worldwide North Desert Latitude (USGS, Map of distribution of non-polar arid lands, 1997).

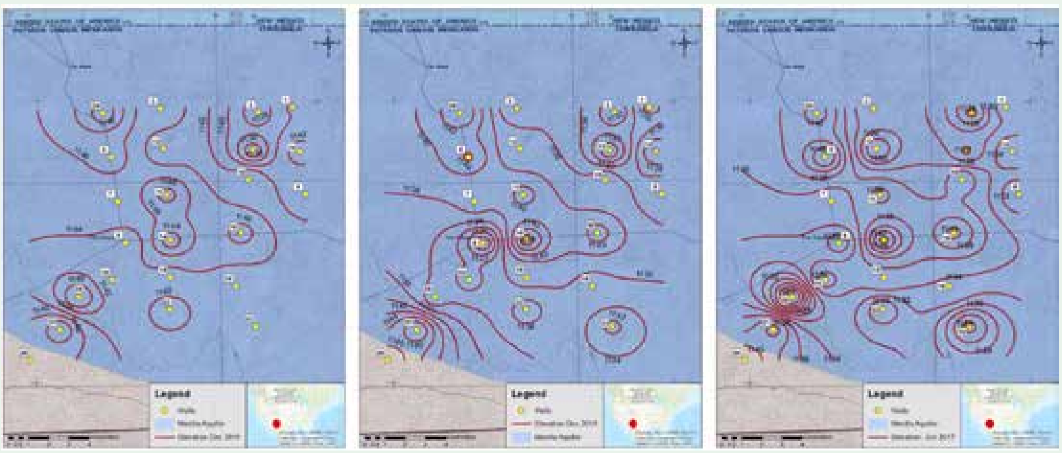


Ciudad Juarez has around 1,500,000 million settled people (INEGI, Censo de Población y Vivienda, 2020) and is served by the utility company named 'Junta Municipal de Agua y Saneamiento de Ciudad Juarez' (JMAS Juarez).

Despite being in a desertic latitude, JMAS Juárez provides water service 24 hours a day, 7 days a week. This utility company gets 100% of the fresh water from active water wells that pump around 200 million cubic meters per year at an annual growing rate of approximately 1% (JMAS, 2020).

Due to the extracted volume of water and the increment of the population, the hydric stress has been a critical concern for many years. Figure 4 shows the dynamic of levels of 'Mesilla' transboundary aquifers in 2100, 2013, and 2017 years (Garcia-Vazquez, 2021).

Figure 4. 'Mesilla's Aquifer Dynamic.



In April 2017, the state agency, named 'Junta central de Agua y Saneamiento del Estado de Chihuahua' (JCAS), devised a long-term hydric plan called, 'Plan Estatal Hídrico 2040' (PEH-2040), with eight strategic objectives. The hydric plan is a great tool to innovate on water distribution and conservation. The improvement of water metering and water controls has been one of the project resulting from the hydric plan.

Key water urban challenges addressed

Main reasons to move forward through Smart Water technologies

We devised a holistic solution which includes four components: (1) Smart meters with excellent accuracy, that are long-lasting, require minimum maintenance, and are read on an hourly basis to learn how users consume the water; (2) Pressure control valves (PCV) programmed with pressure level setting points for reducing the pressure during night and diminishing pipe leaks caused by overpressured lines (due to the typical nightly low water consumption); (3) An advanced metering infrastructure (AMI) to read meters and sensors continuously without people; and (4) A Cloud software platform implementation. Each of these technologies are beneficial for our NRW reduction purposes and for promoting water conservation practices of users with smart meters installed.

Starting point to pursue these objectives

With our focus on diminishing water losses, we define an estimation of our circumstances thanks to the most informed people in our utility company. We maintain a firm commitment to clarifying the concepts (see Table 1).

Table 1. First approach of NRW elaborated internally by JMAS in August 2019

TABLA DE AGUA NO CONTABILIZADA BASADA EN LA IWA, LA AWWA Y CONDICIONES ESPECIALES DE JMAS
Tabla inicial con estimaciones gruesas

					M3	LPS	%	
Volumen introducido al sistema m³/ año	Consumos autorizados	Consumo autorizado facturado m³/año	Consumo facturado medido	Controlado			43%	Agua comercializada m³/año
			Consumo facturado no medido	Cuotas fijas, consumo promedio			10%	
		Consumo autorizado no facturado m³/año	Consumo no facturado medido	Edificios publicos, escuelas publicas, oficinas de gobierno			7%	Agua no comercializada m³/año
			Consumo no facturado no medido	Parques publicos, reparto de agua en pipas por reportes de contingencias, cosumo en hidrantes			6%	
	Perdidas de agua	Perdidas aparentes m³/año	Consumo no autorizado	Tomas clandestinas			7%	
			Errores de medicion.	Medidores dañados, obsoletos, mal dimensionados, anomalias de medicion			6%	
		Perdidas reales m³/año	Erstimacion de fugas en la red	Fugas visibles, fugas no visibles			11%	Agua en perdidas y desperdcio real m³/año
			Disperdicio en limpieza de agua por temas de calidad	Desperdicio de agua en desfogues por reportes de agua con arena, desfogue en el arranque de pozos por los apagones de energia electrica			8%	
			Fugas en conexiones domiciliarias	Fugas provocadas por conexión directa de usuarios			2%	
Agua alumbrada			Concepto	Ejemplo			100%	

Elaboración inicial de esta tabla de ANC

ing. Ramiro Meza-Gestion de presiones y sectorización de la JMAS de Ciudad Juárez
Anibal Miranda, Consultor de la JMAS-Pulso del Agua Agosto del 2019

Valores conocidos
Valores estimados

To clarify the estimated figures shown in yellow, we got very accurate consumption measurements of the big users and public buildings; we bought electronic smart meters, sometimes called non-moving part meters (electromagnetic and ultrasonic), which commonly have wider measurement range than mechanical types.

We thought that if we could get good and frequent information about typical consumption of specific accounts, group of users, consumption per tariff, consumption per type of business, measurement of water in the inlet of private neighborhoods, etc., we could start a program of water balance in private neighborhoods to help us locate water losses.

Innovative smart water technology solution proposed

Another goal for hiring the consultant company was to develop the cloud platform which would receive readings and transform them into useful information for making decisions and training our people in smart non-moving parts meters, network technology, and software platforms.

We relocated people with technical backgrounds from several departments within our utility company to create a team and learned from the hired consultant company about this smart network technology. This interdisciplinary team was very successful; we had good rapport with the consultants, resulting in an effective implementation of this technology. Now, many of our people use the smart network technology terminology as everyday language and people are excited and engaged.

Scale

Our master plan was aligned with the Pareto analysis as described in the introduction of this report. The plan was to advance in three stages of no-moving part meters purchases. We decided to go with different brands and vendors to meet with our purchasing law to avoid giving advantage to a specific brand and to make sure that our needs were clear to all vendors. Thus, we generated an open and fair competition among vendors. We offered them down payments and paid quickly to assure safe commercial terms.

Timeframe of the smart water project

In 2018, we initiated the first stage of this project with only 250+ users. The selection of users was based on our Pareto analysis of users with higher incomes. The selection reflected the biggest consumers with old mechanical meters. High billing represented around 17% of our income, and the selected technology was Arad-made with cellular gateways. These meters resulted in an increment of 13% in the cubic meters registration compared to the average of the three previous years and their corresponding billing increment.

The second stage of the smart water project was in June 2019 when we acquired 3,000+ additional meters to replace old mechanical meters installed in commercial and industrial customers. The selected RF fixed network was Flexnet from the company Sensus; we deployed 15 RF collectors covering more than 70% of the city area where these big consumers were spread out. The first and second stages covered almost 3,500 users (only 0.73% of our customers that represented around 20.6% of our incomes); with these smart meters, we incremented their water registration and billing, so we did not need any loans. Overall, it was a very profitable project and allowed us to advance to the next stage, which is currently in progress.

KPIs and standards adhered to

Our lack of experience on these technologies and few international figures regarding experiences disappointed us. We found several cases of this type of project in a worldwide frame, but nothing relevant in Mexico or Latin America. We traveled to Albuquerque, New Mexico (US) to see a project of 100,000 smart meters working there. We had the opportunity to ask a water utility company directly about their experience implementing smart water networks.

We didn’t find real examples of registration increment because of better meter accuracy of the electronic meters, so we decided to advance with no other figures than our numbers of billing increment and savings on water with the PC projects. We aimed to take advantage of the data coming from hourly readings.

Main results in terms of water consumption knowledge

With the cloud platform, our consultant company designed several dashboards and reports to meet our needs. We gained a lot of knowledge about water consumption. The figures which follow show several consumption profiles from our platform that reflect the hourly data readings:

Figure 5. Hourly flow graph of a specific district useful for planning water wells pumping

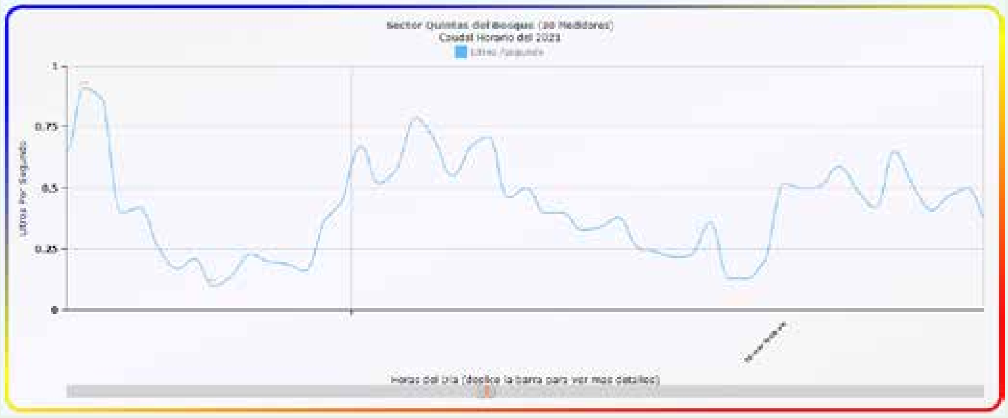


Figure 6. Daily consumption of a group of users corresponding in this case to the commercial group with smart meters, useful for better water distribution

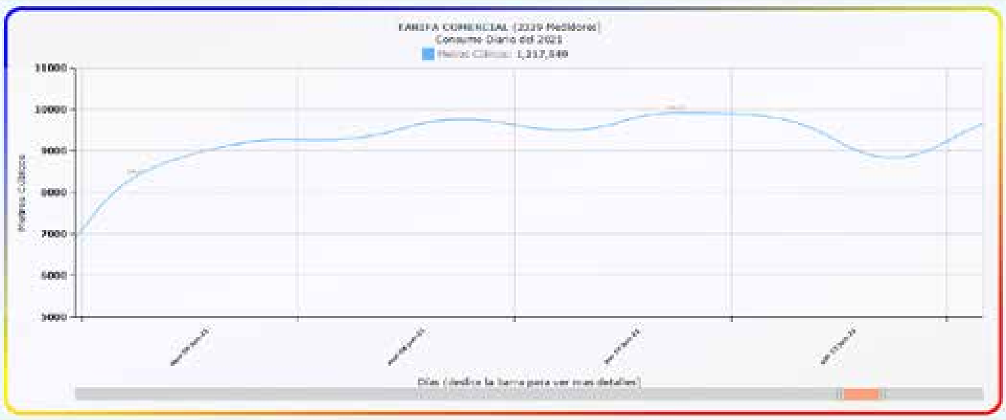


Figure 7. Monthly consumption of treated water of a specific account for planning our incomes

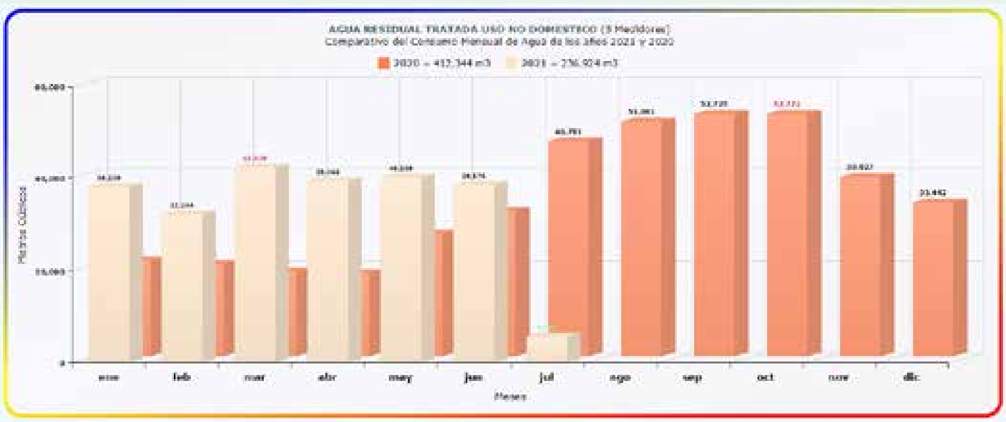
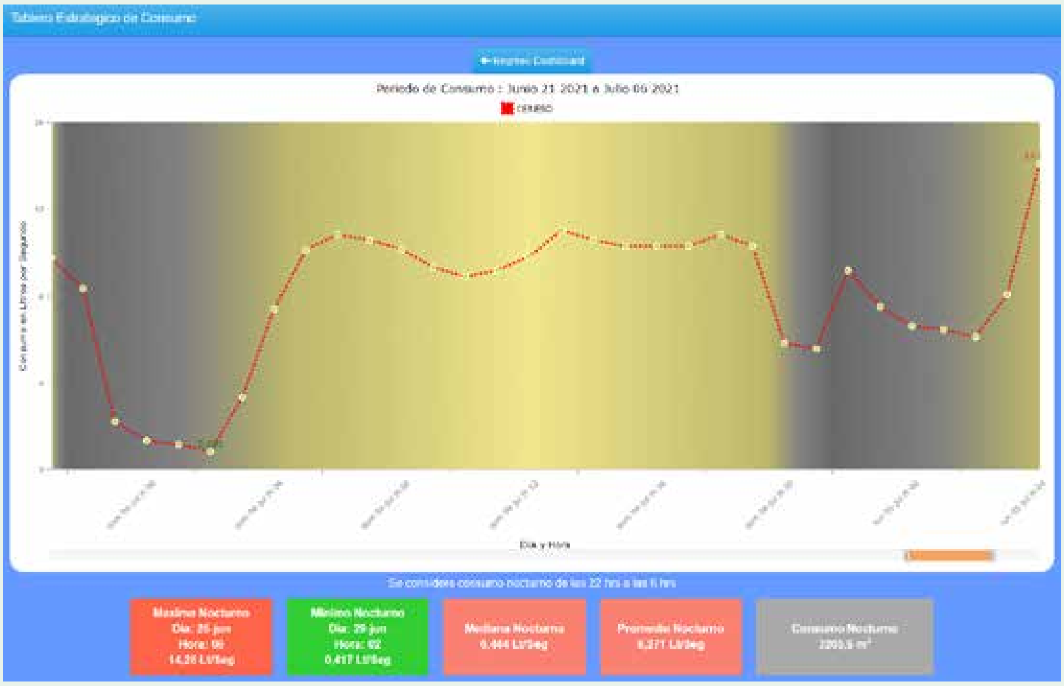


Figure 8. Hourly consumption of a specific account. In yellow, consumption during the day. In gray, nightly consumption. Useful for pressure control projects



Results from the pressure control systems

A representative case of PC was implemented in an area named, 'Riberas del Bravo'. This water district serves 15,000 water connections under a low-efficiency connection, is supplied by 2 tanks and 2 deep wells connected to the distribution pipelines. Additionally, irregular topography of the area causes high pressure and strong transitory phenomena.

Because of this situation, a pressure control pilot project was implemented with the international company SUEZ, installing smart meters at the outlet of the tanks, as well as single and double control points with pressure regulating and sustaining pressure valves.

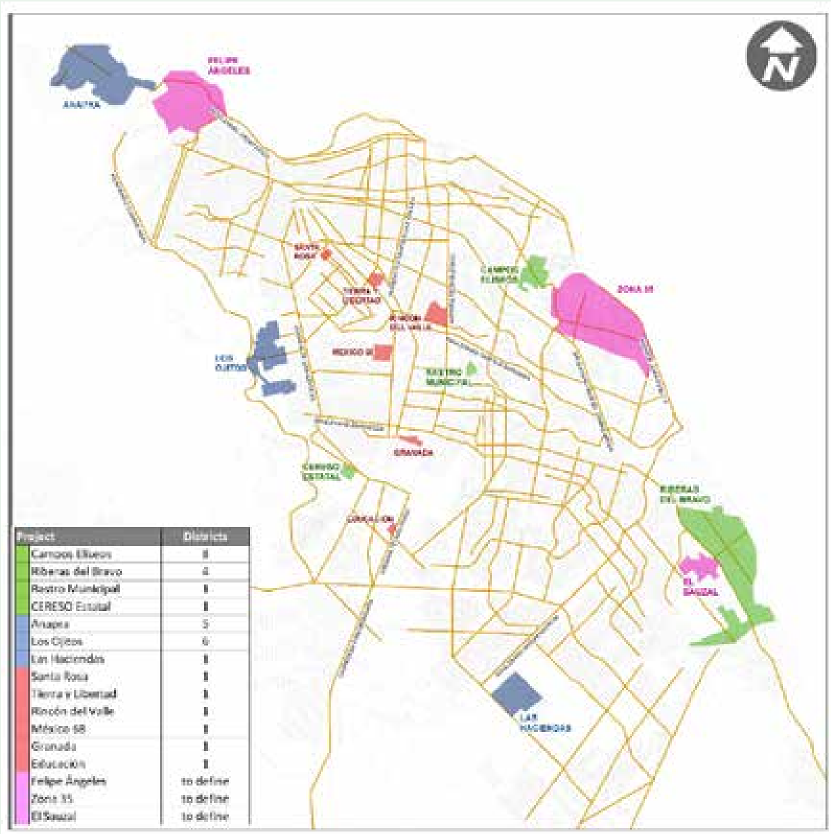
These valves were controlled using monitoring and control equipment, which allowed establishing of optimal pressure setpoints and the reduction of average service pressure and occurrence of transients. Minimum night flow rates were reduced by up to 80%. This project, 'Riveras del Bravo', by itself, represented an important saving of 1,047,370 m^3 in a year, which means around 0.5% of total water pumping in a year, and this volume was saved in only one of the four areas with this pressure control. See Figure 9 below.

Volume saved 2020 Y 2021		
District	Control period	m^3 saved
Campos Elíseos	16 months	88,421
Cereso Estalal	15 months	363,056
Rastro municipal	16 months	4,196
Riberas del Bravo	12,5 months	1,047,370
Summary	16 months	**1,503,043 m^3**

Figure 9. Volume saved in four districts between 2020 and 2021.

Now we are planning more pressure control projects in the city in zones where we estimate we can get better savings (see Figure 10).

Figure 10. Classification of districts; at present in green, to start soon in blue, short-term period in red and long-term period in pink.



In addition to the water savings, we gained important energy savings and reductions on the rate of broken pipes. In the last stage of this project, a double control bypass was implemented, integrated by a pressure regulating valve (PRV) with sustaining valve, which both allowed the volume of water to migrate from one district to the other, depending on the demand and it allowed us to shut off a deep well with an approximate flow rate of 30 lps.
Currently, 40 more districts in the rest of the city are in progress with a kind of pressure control system which obviously reduces NRW (see Figure 10). Our challenge is that in 4 more years, 90% of the city will be implementing some or all four pillars of the IWA related to NRW reduction. This could mean an overall efficiency of the city in the range of 70%.

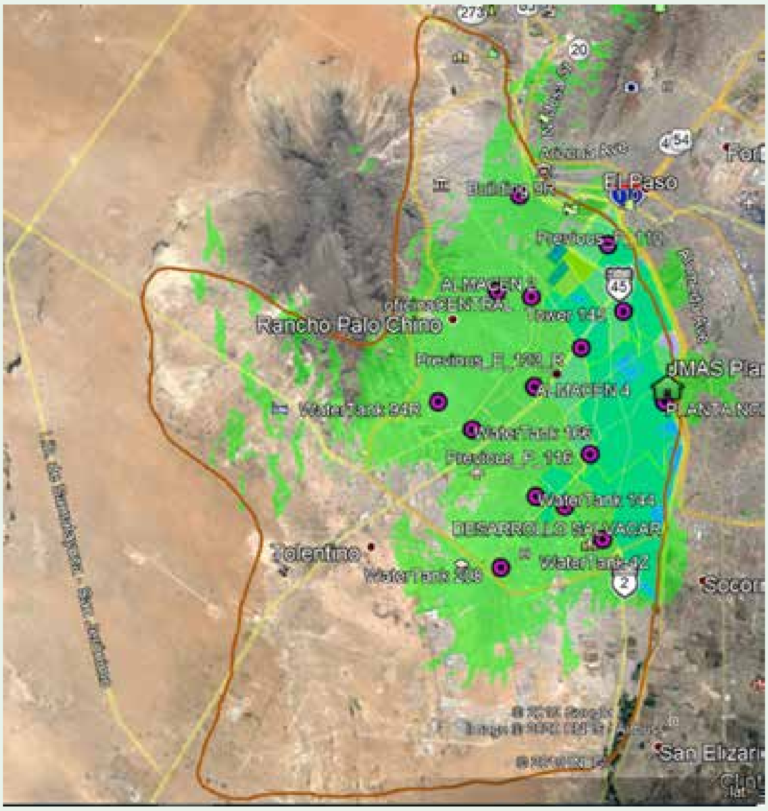
With this small but powerful smart network, we started the third stage of network. Now, we have received more than 70,000 hourly daily readings. We already own 40+ millions of hourly readings that allowed us to understand better the consumption of few users that represented a critical portion of the consumption and incremented our incomes.

Technical and non-technical requirements for the implementation of the smart water technologies

The technical requirements of the components were very well defined with the consultant company that specified the solution and the internal team appointed to get a successful story. Meter installation requirements were of issue because we were not very precise, and it had negative consequences. Issues related to the RF transmission were critical because our meters are installed underground in a pit with a metallic lid, reducing the distance to read.

Ciudad Juarez has very flat conditions, so the RF propagation study allowed us to cover around 70% of our served area with only 14 Radio gateway base stations. Thus, we could read in the second stage, 3,215 spread meters in a big area but still covered for the RF signals. This was considered a good reading for most of our biggest consumers.

Figure 11. Propagation study for the RF stage two with Sensus Flexnet network; municipality limits in red, estimated RF coverage in green

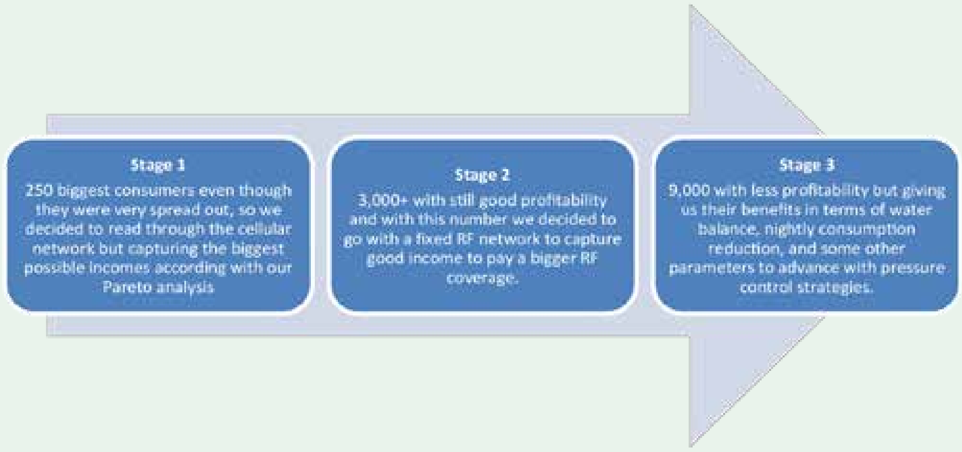


How we got funds to implement this ambitious project of Integrated Water Resources Management (IWRM)

To determine if we could get internal funds which would allow us to avoid external credits that carry both an additional cost and take a long time to get, we analyzed the associated cost of the infrastructure to see whether we could get enough income coming from the additional invoicing because of the better meter registration. We developed an excel file with historical readings of the mechanical meters which correspond to three years before using this technology; consumption was calculated month-by-month. Our initial estimation of registration was 10% because of the replacement of the old mechanical meters for new and very accurate electronic smart meters.

We analyzed the return of investment from different points of view, for every diameter, every tariff block that we call 'Grupo tarifario', and for every specific type of user that we call 'Giro'. Based on the historic consumption and potential increment, we determined an estimated return of investment of each of the consumer groups to calculate the internal financial support needed

Figure 12. Three stages of the implementation of the smart metering project



At the time of writing this report, we have 7,000+ smart meters throughout our three communication networks:

- The first 250 meters of stage 1 that we still are reading through cellular communication.
- 3,000+ meters of stage 2 read by a Sensus fixed RF smart network called Flexnet.
- 4,000+ meters read by Kamstrup Fixed RF network called Ready; project currently in progress of 9,000 corresponding to stage 3.

Main practical issues we found implementing this smart water project

There have been some practical and theoretical differences and issues found, some of which were positive findings.

Some positive findings

We thought we were going to find more obstacles from our users because their billing increased; however, as we went to the biggest consumers, they understood the critical issues of water conservation and accepted this technology. In some of the cases, they celebrated us for modernizing the meter infrastructure.

Other groups of consumers, however, like commerce or big residential consumers, complained about the consumption increments a month after this technology was installed. When we demonstrated the real consumption with hourly readings, however, they changed their attitude and promised to save water to avoid that additional increment.
We did not really have obstacles from the public, and this was mainly because we were widely announcing the project beforehand. We did an internal presentation to the utility labor union, as well as hosted some dinners to announce this project with chambers, Maquiladoras Organization, and more.

From the moment we started, we thought we were going to face internal obstacles, such as with our labor union, for instance, but we did not. Once they understood the project, asked what the benefits of implementing this technology were, we were able to explain how the meter-readings of big consumers would improve their working conditions; we assigned them more supervision tasks.

Another further advantage was the approach of several vendors in the market, giving us technical presentations and offering to test equipment and sell new technology as automatic valves, leak detection equipment, pressure control, etc.

The technology challenge was surpassed with certain difficulty. Ciudad Juarez has a high technological environment as there are more than 400 manufacturing facilities ('maquiladora industry'), many of which are involved in the high technology industry. There are good universities located here, as well as some research centers. Thus, you can find open-minded and educated people who are eager to learn. This environment proved very favorable for our project.

Some findings gave us valuable learnings

We thought at the beginning of this project that the RF propagation studies were not necessary, and we pushed back against vendors requesting about RF collector location. However, after some RF Studies of different vendors, we could verify how critical the geography is of where you are going to implement the project. As a result, we have had good experiences with RF communications.

We also thought that due to Ciudad Juarez's conditions and their underground meters and metallic lid over the register, it would reduce the RF reading performance. This proved to be a critical issue. Thus, we are changing our specs for future installation, changing lids to ruggedized plastic lids instead of metal.

Now we know the network performance depends not only on the smart meter, but rather, several factors are involved. These include whether the RF module is inside the meter or not; the RF power transmission inside the meters; the power of the RF collector and the height and gain of their antennas; the material of the lid covering meters in case they are installed in pits underground; and the geography of the city (among other factors). In Figure 13 we show the monitoring of the networks we had while writing this report.

Figure 13. Effectiveness and efficiency of the several couples'Smart meters<-> Smart Network'

As shown in Figure 13 above, the green line corresponds to the couples integrated by 'Aichi Tokei' electromagnetic meters with an Flexnet RF module where the antenna was outside the pit and they are read by Flexnet smart network. By contrast, the orange line refers to Sensus meters with a RF module located inside the meter reporting the reading through the same Flexnet network. In other words, the same network and same power of RF modules offer different performance depending on the meter antenna that is under or over the metallic lid. We have not had any experience with meters installed in pits underground with plastic lids over the registers. Still, we estimate the performance will be similar to those where the meter has an RF module with an external antenna. Hence, chances are our internal standards will change to plastic lids in future deployments and new accounts where we plan RF connectivity.

Summary of our results at this moment

Something especially important is that we implemented an MDM software customized to us through the consultant company with the purpose to read different meters with different networks. Now we are reading 5 couples in the networks:

- 60+ Arad ultrasonic meters Octave model (Ratio 400) with cellular gateways.
- 3,200+ Sensus water meters electromagnetic type model Iperl European version (Ratio 800) through the Flexnet network.
- 120+ Aichi Tokei electromagnetic meters model SU, through the Sensus Flexnet network.
- One Ultrasonic Badger meter e-series model is still under testing reading through LTE Cat-M network.
- 4,000+ Kamstrup meters model Flow IQ 2200 read by their network named ReadyAMI.

We have tested other brands or models of meters, like Omnimeter and Ally from Sensus company, gateways for sensors like the model Smart gateway of Sensus, and all reporting readings through Sensus Flexnet smart network.

Now we can say our smart network depends neither on one brand of meters nor on a specific RF network, vendors do not influence us, we specify our conditions, invite several vendors to explain our operations and requirements to receive the readings with a specific data format that we can interpret and add to our databases.

Regarding the RF licenses, we already have spectrums bands licensed to our utility in the next bands: Two bandwidth (one up and one down) on the 900 Mhz. range for Flexnet network, and a couple more in the 400 Mhz. range for Kamstrup network. We have a good spectrum availability to have a reliable smart water network infrastructure.

Challenges

After this positive experience, we plan to keep advancing with smart metering installations on profitable accounts. We have our master plan of district metering (DM) for water balances and pressure control based on the internal consumption.

We are planning to incorporate an online software module in our current platform to be aligned with the NRW concepts using the International Water Association (IWA) water audit methodology. We plan to follow and make the necessary adjustments for our master plan up to 2024 for an optimization related to a better metering and water distribution management.

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Heredia (Costa Rica)

Innovative technology for drinking water sediment collection: scaling from big to small cities in Costa Rica

Laura Benegas and Adolfo Rojas

Heredia (Costa Rica)

Abstract

Urban watersheds are almost universally subject to degradation driven by changes in flow and sediment inputs from the streams. In urban watersheds (cities), sediment sources from channel erosion is a common response to altered urban flow conditions. To analyze how the sediment yield is managed in a large city in Costa Rica, defining the potential to scale its experience to smaller rural cities, we present an innovative technology implemented in a drinking water system. After the analysis of a preliminary operational cycle, we found that the Sediment Dynamic Multivortex (SDM) removes 76% of turbidity. To scale such innovative technologies, from big to small Costa Rican cities, we define several considerations. Particularly for the municipality of Turrialba, some ongoing steps are needed. For instance, experiences in the implementation of best watershed management practices related to field visits, exchange of knowledge, general diagnostic of local needs on drinking water systems are already in place. On the other hand, the current technology implementer (ESPH), together with technology designer Lucas Electrohidraulica (LE), has the potential to contribute through lesson learning, data sharing, and technical assistance, as well as through overall support of the upscaling of its watershed management experience–particularly in the case of ESPH regarding their water resource protection fee. The intellectual property of the innovation belongs to Lucas Electrohidraulica S.A. The equipment was developed by the industrial diver, Pablo Gonzalez Lucas, and the engineer, Gustavo Tellez.

Introduction

Four in five urbanites in large cities, around 1.21 billion people, primarily depend on surface water sources (McDonald et al, 2014). 80% of GDP is produced in cities globally, and there will be major economic repercussions if water security is not guaranteed (UNESCO, 2019). Thus, ensuring urban water security is an urgent challenge that may threaten the food of humanity, as well as economic, ecological, and national security if not properly addressed (Jimenez -Cisneros et al, 2014; Gerlak et al, 2018).

Urban water security reflects the dynamic capacity of the water system and water stakeholders in safeguarding sustainable and equitable access to adequate quantities of water with acceptable quality that is continuously physically and legally available to meet water demand at an affordable cost. In order to sustain livelihoods, human well-being and socio-economic development, it's necessary to ensure protection against water-borne pollution and water-related disasters, as well as preserve ecosystems in a climate of peace and political stability (UN-Water, 2013; Aboelnga, 2019).

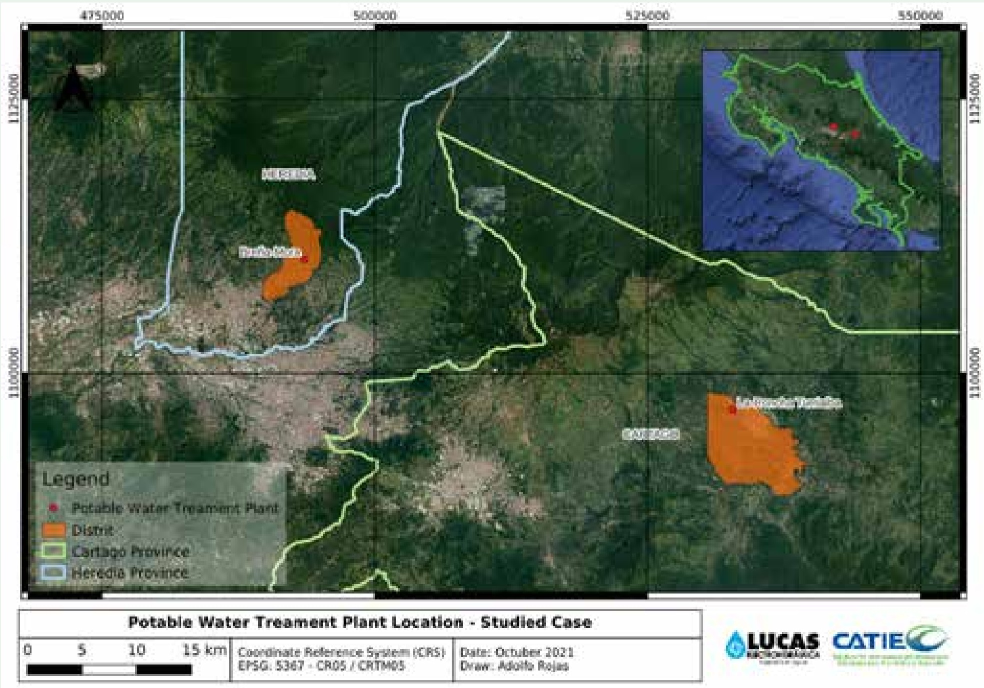
Streams with urban watersheds are almost universally subject to degradation, largely driven by changes in flow and sediment inputs from the watershed (Rusell et al, 2017). A major and widely documented sediment source is channel erosion, which is a common response to altered urban flow conditions (Chin, 2006).

Impacts of anthropogenic activities in water quality, with agricultural land uses (Ahearn et al, 2005) and population density (Holland et al, 2005) has been widely reported, altogether affecting sediment and nutrient loading

(McDonald et al, 2016). From a study of urban source watersheds for 309 large cities (population > 750,000), in the period between 1900-2005, it was concluded that watershed degradation has impacted treatment costs for 29% of cities globally, with operation and maintenance costs for impacted cities increasing on average by 53 ± 5%. Replacement capital costs are also increasing by 44 ± 14%, which leads to increases in water-treatment costs with real quantitative cost for hundreds of millions of citizens (McDonald et al, 2016).

Our case study seeks to analyze how the sediment yield is managed in the third largest city in Costa Rica, Heredia (World population review, 2021). Additionally, we explored the possibilities to scale the technological approach of such city in a small rural city, in Turrialba. Figure 1 shows the DWTP location in Breña Mora, part of the Enterprise of Public Services (ESPH) in Heredia, and the aqueduct of the small city to scale the technology, La Roncha, Turrialba, Costa Rica.

Figure 1. Location of the drinking water treatment plant, Breña Mora, Heredia and the small city to scale the technology, Turrialba, Costa Rica.



In Costa Rica, drinking water services are managed by the following operators: (1) Costar Rican institute of aqueducts and sewerage (AyA) serving 48% of the population; (2) Associations administering communal water supply and sewerage systems (ASADAS) serving around 26% of the population; (3) Municipalities serving 14% of the population, and the Enterprise of Public Services of Heredia (ESPH) serving 4% of the population; and (4) Rural Aqueduct Administration Committees (CAAR), covering around 6% of the population (Mora and Portuguez, 2020).

ESPH is an autonomous company that provides multiple public services and was incorporated under a private law. This company provides water, sewage, and electricity services to the province of Heredia. In Turrialba, the municipal aqueduct serves 20% of the population of Turrialba's canton. The remaining population is served by ASADAS and CAAR.

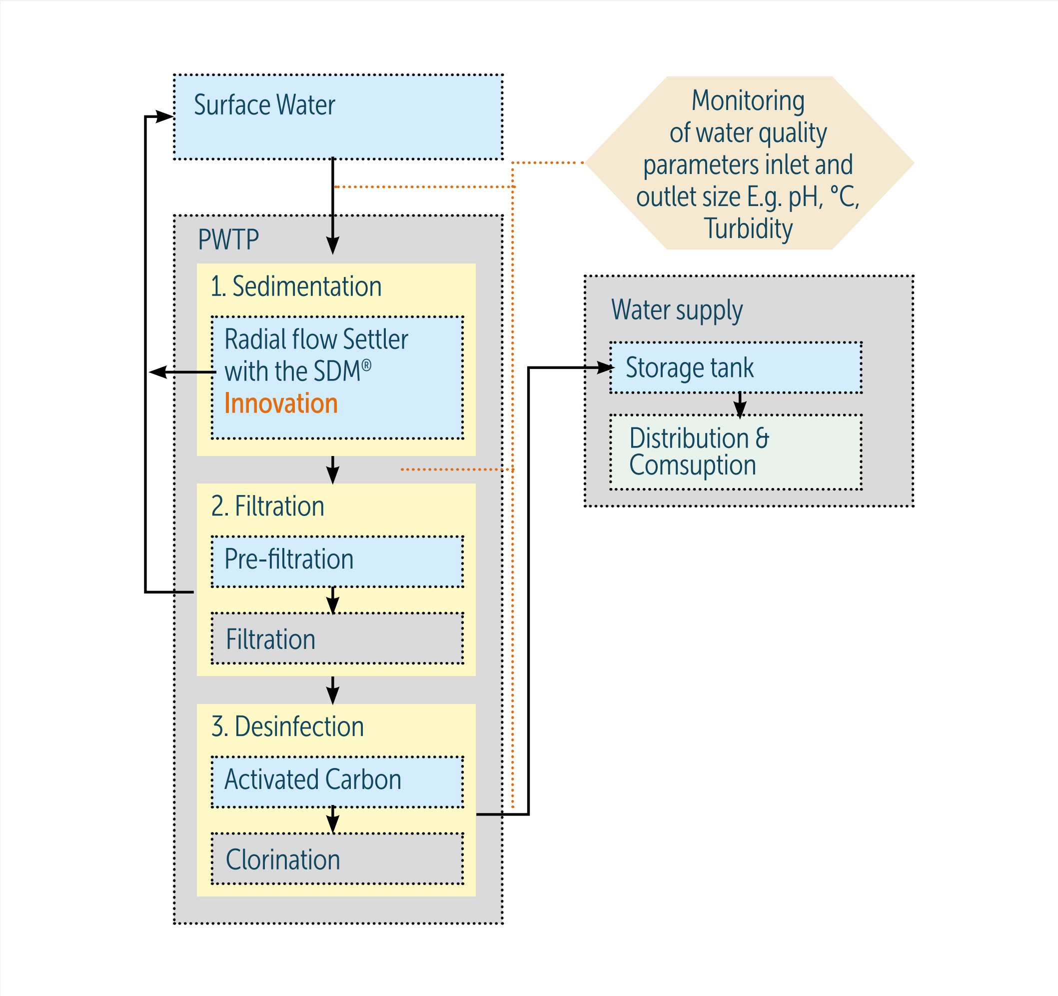
It is important to mention that in Costa Rica, 4.6% of the population with access to water supply is served from surface water resources, and according to the national inventory of water sources in 2015, 5.53 % of water resources corresponds to surface water. From these surficial water sources, 86.4% corresponds to rural cities or rural aqueducts (Mora Alvarado et al., 2016).

According to INEC (2011), the central canton of Turrialba has a total population of 69,616, and 91.6% of that population has access to a supply of drinking water. The "La Roncha Turrialba" aqueduct is an important part of the municipal drinking water system, serving around 1000 connections. It has been affected by sediment load at recurrent occasions. Figure 2 shows the water catchment of La Roncha, Turrialba's aqueduct.

Figure 2. La Roncha, Turrilaba's aqueduct water catchment

The Breña Mora drinking water treatment plant (DWTP), owned by the Enterprise of Public Services of Heredia (ESPH by its Spanish acronym), was designed, and built by Lucas Electrohidraulica (LE) company in 2018. The Breña Mora DWTP takes surface water and has a design which encompass a flow capacity of 40 l/seg up to 60 l/seg. The DWTP mainly serve 2 of 10 cantons of Heredia with 3000 connections of water for a population of approximately 12,000 people. This represents 4.64% of the total population supplied by ESPH (Mora Alvarado et al., 2016). This DWTP has an innovation technology patented by LE Company –Sediment Dynamic Multivortex (SDM) into the settler of sediment phase. Figure 3 shows the site conditions and the grey infrastructure of the water catchment of Breña Mora DWTP, as well as the flow diagram of water treatment in Breña Mora Aqueduct. The innovation adding to the Smart Water Cities paradigm is the "Sediment Dynamic Multivortex (SDM)" which is located in the sediment phase into the sediment chamber of the settler.

Figure 3. Drinking water treatment plant diagram (source: DWTP drawings by LE)



The Breña Mora DWTP has three main phases: (1) Quality and quantity of raw water; (2) Coagulation-flocculation process and sedimentation; and (3) Filter and disinfection system: Pre-filter, multigranular filter, activated carbon filter, and chlorination.

This DWTP differs from other systems by settler characteristics, which correspond to a wake vortex turbulence technology. The wake vortex is defined as turbulence which is gendered by the passage of the water through the corrugated sheet. In Figure 4, we can observe the sediment collected in the corrugated sheet.

Figure 4. Sediment collection on the SDM
The flow direction in the picture is from left to right (source: ESPH - Breña Mora).

LE's experience led them to observe that working with slightly turbulent flow with the SDM reduces the side of the settler and makes it more versatile, cheaper, and shallow, requiring less area than conventional technology, reducing costs, and increasing flow rates where it can operate properly. Thanks to the versatility and low cost of the technology, it can be implemented in rural cities such as Turrialba. The DWTP has a designed radial flow settler with SDM with 8 meter of diameter in the sediment chamber (see Figures 5 and 6).

Figure 5. Breña Mora PWTP - Radial flow settlers with SDM (source: LE and ESPH)

Figure 6. Full view of Breña Mora PWTP - Radial flow settlers with SDM (source: LE)

The Breña Mora DWTP has an automated system for monitoring water quality parameters that allow for precise control at real time of water supply quality with its corresponding user interfaces in the control room.

Background and context for implementing the smart water technology

The implementing process of this technology in Heredia started with a need. The Mayor of the Municipality of Santo Domingo in Heredia established communication with the developers of this technology with the goal of improving water quality in Santa Elena, an area with 5 surficial water intakes which was affected by heavy rain and runoff generation reducing water quality for a period of 4 to 6 hours (such as altered apparent color and increasing turbidity). As a response, in 2006, LE Company started gradually to improve the aqueduct system of this municipality with water intake modification to filter elements of more than 1 mm in size, and then, developing the clarifier, testing it with a pilot in Santa Elena's water treatment plant with very good results. Then, in 2018, having hear of such experiences, the ESPH also acquired the technology for some of its water treatment plants–after a tailored adjustment and further improvements of the technology meet to its particular needs.

The technology complies with national and international regulations regarding the discharge of the sludge that is separated from the water and regarding the quality of the water that is distributed. The design of the structure and materials of the tank where the SDM settler is contained was built under the American Water Works Association (AWWA) standard.

From a wider perspective, Costa Rica has a National Drinking Water Policy for the period 2017-2030, where one of the guidelines is the rational use of drinking water. It states that water supply sources must be used efficiently with appropriate infrastructure and technologies to ensure their sustainability. In addition, the 2008 National Integrated Water Resources Management Plan, still in force, has as one of its guiding principles, the promotion of efficient water use, as expressed in the more recently elaborated National Drinking Water Policy. Both the national water policy and the national integrated water resource management plan are actively being updated.

Although current policy and planning instruments in Costa Rica recognize the importance of infrastructure and appropriate technologies, this is not reflected in the facilitation or specific incentives for the development and implementation of innovative technological solutions, such as the Sediment Dynamic Multivortex-SDM, to ensure the potability of water, which is presented in this case study.

In the case of the ESPH, there is a very particular situation that makes it a recipient and pioneer in the use of this technology. It has an Integrated Management System that includes all activities and processes related to the commercialization and provision of potable water distribution services, together with the other public services they provide (electricity, wastewater treatment, and communications). Since 1999, ESPH has been a pioneer in promoting incentives for the protection of water resources. It became the first aqueduct who charged a "water tariff" for the protection of water resources. In addition, ESPH is investing in the efficiency of its water purification plants. According to the head of Potabilization Management of ESPH, the plants they have been building are an example at the national level, due to the type of technology and because of the space where the project is developed, which, unlike older technologies, occupy less area (María José Calvo, head of Potabilization Management at ESPH, personal communication).

Challenge addressed

There are three main challenges identified in this study. The first challenge is to ensure the provision of safe drinking water; the second has to do with financial issues; and the third, with capacity building.

Provision of safe drinking water

The operational part of our water security concept involves three dimensions: (1) the level of system function (i.e., supply services); (2) risks to these services; and (3) robustness of system functioning (Krueger et al, 2019), which reinforces the need to develop and implement innovative solutions for drinking water treatment plants. It is in this third dimension that the "Sediment Dynamic Multivortex (SDM)" technology provides a feasible response, particularly in a context where water sources come from surficial water prone to high sediment load produced because of extreme rainfall events.

Figure 7. Breña Mora's water catchment

Financial issues providing drinking water

A typical 250 million liter per day (MLD) no-filtration WTP (Water Treatment Plant) might cost $104 million in capital costs to build, plus $1.7 million per year in O&M (Operation & Maintenance) costs, for a total annual cost of $8.5 million. This cost is 20% lower than a so-called conventional filtration plant, which uses sand or gravel filtration. On the other hand, an advanced filtration plant, such as one using membrane filtration, would have 2.1-fold greater annualized costs than a conventional filtration plant (McDonald et al, 2016).

Although the technology proposed in our study was applied to a small city (around 12,000 people) compared with the large cities studied by McDonald, et al. (2016), we can classify our reported technology as an "hybrid" between advanced filtration if we consider the disruptive technology supporting the DWTP, and a conventional system if we consider the relative lower cost associated with this technology (600,000,000 Costa Rican colones or 970,000 USD approximately for the whole DWTP, where the SDM technology represents around 6-10% of this cost). Although this technology has a lower cost than traditional systems, it is constantly improving and adapting functionally to the user's needs. The developers have the flexibility to identify specific needs for different contexts, adjusting the equipment to the new conditions. Therefore, financial issues could be overcome when technology is individually tailored.

Capacity building

A gradual changing from centralized to fully automated operation is currently ongoing within DWTP with consequences like increase in efficiency and a better and more stable water quality. Nevertheless, such automated treatment plants require sophisticated operator care (Trussell, 2000), but could also be linked with online process optimization. Online measured water quality data would feed models that predict the development of process parameters. As a result, the treatment processes would be adjusted to prevent the violation of operational windows of water quality parameters, saving costs and emissions by reducing the use of chemicals and energy (Worm, et al, 2010). This automated operation is also part of the innovation provided by the "water smart technology" we are reporting in this case study. The system used in our case is the Supervisory Control and Data Acquisition (SCADA). One of the associated benefits of this automation is a reduction in the chlorination process, which is a treatment requested by the Costa Rican regulations (Reglamento para la calidad del Agua Potable, No 38924-S).

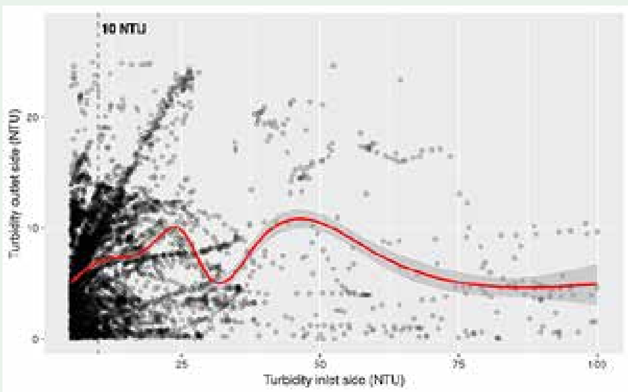
Brief exploration and data analyses for Breña Mora DWTP

We did a basic exploration data analysis (EDA) of our recently installed innovative technology. A total of 878,495 observations for the turbidity variable is reported here, given that turbidity is one of the most revealing variables to account for in the efficiency of sediment removal for this technology. The observations of turbidity were stratified into three groups: settler inlet side, settler outlet side, and final filter outlet. For all our analyses, we used R software Version 4.1.0 (R Core Team, 2020).

Covariation of turbidity between inlet to outlet side

The type of co-variation between the variables of turbidity of the settler at inlet and outlet side is not linear. This co-variation is important because it will allow to approximate the expected value of turbidity in the outlet related to values at the inlet. The spline is shown with the fitting curve–see the red line in Figure 8. Under 10 NTU turbidity settler at inlet side, the co-variation between variables looks linear even up to 25 NTU. For settler turbidity inlet side, the average estimate of % remotion of turbidity (RT) to over 10 NTU is 76.3%. The SDM's designer informed that the value of RT is the expected value according to the results in other installed systems. Nevertheless, the SDM has not been optimized yet, so the results could be improving.

Figure 8. Turbidity over 10 NTU only for inlet and outlet side from settler.



The intensity of the dot's color represents the concentration of observations (the darker the dots, the higher the concentration). It is noted that the highest concentration of observations dots is under 25 NTU inlet side and 15 NTU outlet side, approximately.

Expected performance on Turrialba city of SDM

Currently, the Municipality of Turrialba (MT) has only annual records of turbidity, with values less than 5 NTU in non-rainy events and does not have records of turbidity data on rain events; however, they have proof of sediment problems. However, according to Figure 8 and the turbidity records of "La Roncha", the expected value of outlet side for a settler with SDM technology can be close or lower to 10 NTU in rain events.

The MT report an average flow of 13.25 l/seg and minimum flow of 10.92 l/seg. Thus, and based on LE's criteria, the design of settler requires adaptation in dimensions by the location and flows. Final required adaptations can be defined in preliminary studies, commonly performed for any project.

Policy implications, recommendations, or next steps

To scale the innovative technology presented here, from big (related to Costa Rican context) to small cities, several considerations should be taken. Particularly for the municipality of Turrialba, first steps related to field visits, exchange of experience, and general diagnostics of local needs for drinking water systems are already in place. Adaptation of the technology will be the second step, also in progress based on this report, where our partner and developer of this technology is starting with simulations, numerical assessment, and optimization of the first and second version of the device (Sediment Dynamic Multivortex (SDM). The third step involves data sharing together with municipal commitments, which is also in place. Policy recommendation goes in two directions: (1) for the ESPH, which already operates the technology, we suggest the permanent update of potential water sources based in projections of urban water demand, as well as renewed efforts to work in integrated watershed management to prevent and reduce the potential sediment load affecting its DWTP. Outstanding efforts are already ongoing with ESPH collaborating in the first water fund in Costa Rica (www.aguatica.org), and previous to this initiative, the pioneering effort of the ESPH implementing a water tariff to be used in best watershed management practices is an example that currently is up scaled at a national level (Public Utilities Regulatory Authority-ARESEP by its Spanish acronym) and its tariff for the protection of water resources); (2) for the MT (Municipality of Turrialba), which is the potential recipient for the adaptation of the technology, we suggest to continue updating the baseline for the DWTP, particularly with data gathering. In addition, to prioritize and reorganize the municipal budget towards the inclusion of this adapted technology and to analyze globally the opportunities and projections of urban water demand to improve, increase, and redesign its DWTP. Finally, the MT should also consider implementing schemes of water tariff or similar mechanisms to obtain resources for integrated watershed management to prevent sediment load and contamination as well, which overall, for both ESPH and MT will represent a reduction in water treatment to guarantee the water security under a Smart Water Cities approach.

It is important to notice the non-technical elements which facilitate implementation of this technology. One such aspects is the capacity of the "innovator"–in this case, Lucas Electrohidraulica–to constantly improve and adapt their technologies using the data produced by previous developments (drinking water treatment plants) as an input for this continuous process of innovative development. Another aspect is the flexibility, which is a key value to overcoming limiting factors like financial issues, again, adapting the technology to the financial capacities of the users, and the constant ability for observation, investigation, and overall, innovation with their own effort to invest with the goal to cover the necessity of drinking water operators to achieve sustainable standards of water quality for water security. A third important aspect is the local conscience on the importance of the integrated water resource management present in both ESPH and the Municipality of Turrialba. This characteristic of local stakeholders set the bases for innovation and allocation of resources to implement promising technologies to move towards Smart Water Cities.

Acknowledgements

Our deep acknowledgement to the Enterprise of Public Services of Heredia (ESPH) for the support in sharing its data and for its practical experience, to Pablo Gonzales Lucas and Gustavo Tellez by Lucas Electrohidrahulica for data sharing and technical guidance, and to the Municipalidad of Turrialba for data sharing, and altogether for their interest and commitment with smart cities initiatives.

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Hong Kong (China)

Smart technologies, actionable data, and domestic water consumption in Hong Kong: Potentials and constraints

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Abstract

With the domestic sector becoming the dominant user of water in many global cities since the turn of the millennium, water planners have accordingly shifted their attention to households in strategizing long-term water conservation projects. Smart technologies, at the same time, have made progress in leaps and bounds. Emerging technologies have enabled the HKU Water Centre to build a Smart Water Auditing system which makes use of a set of judiciously selected and integrated technologies to build an IoT-based Smart Meter Analyser to collect, analyse, and communicate to ordinary people through an easy-to-read visual format, some real-time, ultra-fine-grained actionable data to induce them to embrace habit-changing, positive water conservation behaviour. In addition, the Smart Meter Analyser shows the potential to help transform, at low cost, a city's conventional mechanical water meters into fully functional smart meters that could transmit high-resolution digitized water consumption data to a cloud-base processing center for policy analysis. The major hurdles that might block the way towards making use of such actionable data to suppress domestic water consumption would stem mostly from the usual institutional constraints, including political ineptness, bureaucratic inertia, and resistance to adopting innovations that are inherently disruptive to established practices.

Introduction

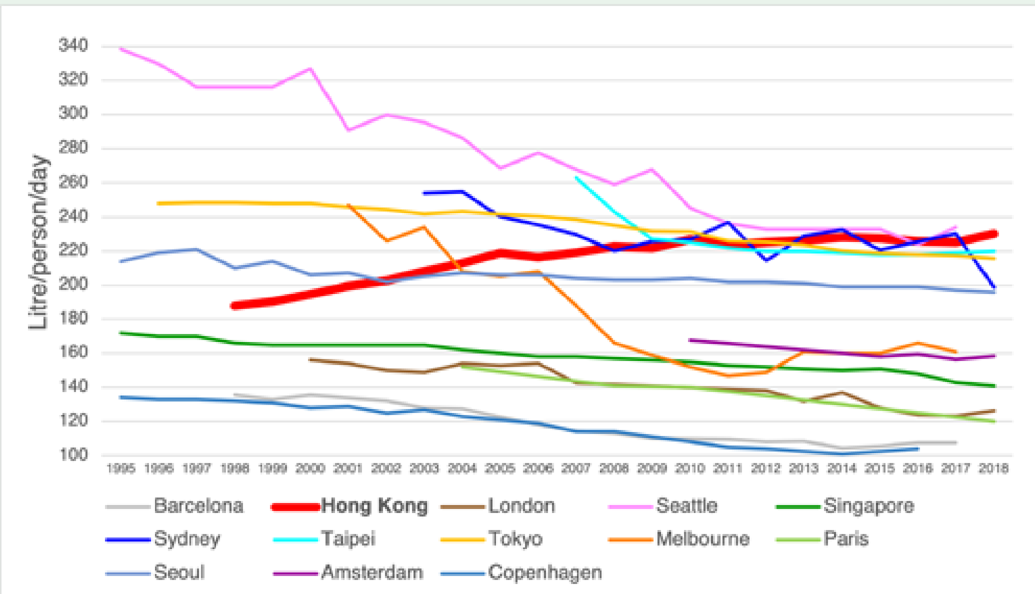
An inherently water resources-short city, Hong Kong's water agency nevertheless has been able to provide a 24/7/365 water supply since the early 1980s—resulting, paradoxically, in a perception of water abundance among the populace. This un-interrupted municipal service, spanning four decades, is made possible by a combination of factors, both institutional and structural. A conventional, inter-basin transfer engineering scheme brings surface water from the East River, a tributary of the Pearl River, through an 83-km aqueduct, into the Special Administrative Region (SAR) since the 1960s (Lee & Moss, 2014). This water infrastructure was the product of a 1960s-era political negotiation between London and Beijing, at the former's behest, albeit reluctantly (Lee, 2013). Since the turn of the millennium, both the quality and quantity of this imported water have been guaranteed by formal agreements signed between the Guangdong provincial government (the seller) and the Hong Kong SAR government (the buyer). Triannual negotiations between these two parties, conducted since the noughts, determine the quantity and the price of this imported water. One unexpected, but highly consequential outcome of these tacitly contentious negotiations is an over-supply of East River's water for Hong Kong.

Compounding the repercussions of an over-provision of imported water on Hong Kong people's water psyche is the deleterious effect of an egregiously under-priced tap-water. Water tariff levels have been frozen since 1995-96, a by-product of political impasse of those times that have remained unresolved today (Lee & Nickum, 2015). Nowadays, household water bills, on average, recover only 37.8 percent of the actual unit production cost of water, according to a recent study (Zhao, et al., 2019). Consequently, pricing, a tool commonly used in other jurisdictions to induce water conservation behaviour, is a blunted policy instrument in Hong Kong. In addition, the magnitude of over-supply has been exacerbated by a drastic drop in overall demand, caused principally by deindustrialization that started around the late 1980s. The drop in industrial demand also means that the domestic sector now accounts for more than half of the city's total demand. Domestic water consumption thus has begun to draw water managers' attention when they formulate the latest batch of water conservation measures.

Amidst all these changes in the water economy, the Hong Kong government has signed onto the global sustainability agenda, if belatedly (Sustainable Development Unit, 2005). This commitment has slowly found its way into the water sector, resulting in a recently promulgated pledge to reduce overall per capita water consumption by 10 percent by 2030, referencing 2016 as the base year to combat climate change (The Hong Kong SAR Government, 2017). With the city's overall demand stabilising and perhaps plateauing soon, concerned decision-makers must have vetted such a modest target and concluded that it is technically achievable. One statistic, however, has stood out as a cause for concern for policymakers because it has defied a global trend and has not shown any signs of reversing itself any time soon.

As shown in Figure 1, while cities around the world have registered a steady, if gradual, decline in per capita domestic water consumption level over the course of the past twenty-plus years, Hong Kong has wandered into the opposite direction. The continuous upward drift in per capita domestic water use, if unchecked, could jeopardize, if not derail, the policy agenda on water conservation. The question of how to tame and trim domestic water consumption has therefore taken on a certain degree of policy imperative. This shift of focus onto domestic water consumption to driving the overall policy agenda of water conservation has provided the impetus for this policy-oriented research project.

Figure 1. Per capita domestic water consumption in Hong Kong and selected cities



The formulation of an effective water conservation strategy and an evaluation of its efficacy after it has been implemented is predicated on an accurate, complete, and nuanced understanding of how much water people are using, when they use it, and for what purposes at home. Such information, however, has never been collected in Hong Kong. That is, water planners have been doing their job with only a partial picture of domestic water consumption. They have been deprived of a nuanced understanding of household-level water use because they did not have the tools to collect requisite data that could be disaggregated into end-use types at that micro scale. Past attempts to measure the percentage distribution of domestic water consumption by end-use types have been faulted for producing unreliable results because the reported figures were subject to the vagaries of study participants' self-reporting skills.

The per capita domestic water consumption figures for Hong Kong, as shown in Figure 1, contain two components: potable water and water for toilet flushing. The reported figures for the former are fairly accurate because potable water supplied to almost all the households is metered. However, the fact that 85 percent of the households are using seawater for toilet flushing (with the other 15 percent using freshwater) complicates the picture for meaningful cross-city comparison purposes. This is because the published statistics on seawater provision do not differentiate between the domestic and the non-domestic.

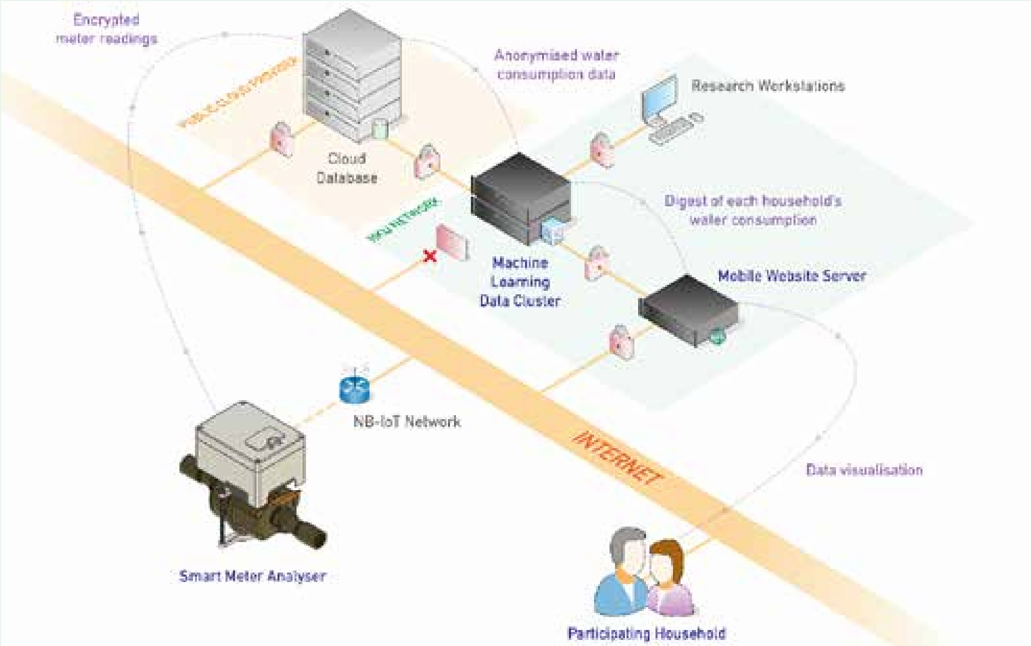
To fill the above-identified knowledge gaps, the project's research design is purposefully formulated to integrate a select set of Internet-of-Things (IoT)-based smart technologies—comprising Big Data, AI, and Machine Learning—to create a Smart Water Auditing (SWA) system to collect, analyze, and report ultra-high resolution data on domestic water consumption. The SWA system will enable us to (i) produce an accurate, complete, and nuanced depiction of how, when, and how much, water is being used at home; and (ii) design, test, and evaluate the efficacy of a near-real-time feedback mechanism to induce and instil water conservation habits on the users of the system. In a nutshell, our team has assembled a judiciously selected set of smart technologies to enable us to produce actionable data, easily visualised on a mobile device, that will impact domestic water consumption behaviour.

Creating a Smart Water Auditing system

The Smart Water Auditing system is comprised of three major components:

- A self-built, non-intrusive clamp-on Artificial Intelligence analyzer module, which we can affix onto a conventional mechanical water meter within minutes and transform the latter into a water meter capable of performing smart functions;
- Machine Learning algorithms, such as support-vector machines and artificial neural networks which could disaggregate total household water consumption data into specific end-uses: showering, washing machine, kitchen-tap, and basin-tap; and
- A mobile website through which users could login to view the break-down, by end-use type of their day-to-day water consumption data.

Figure 2. A Schematic Illustration of the Smart Water Auditing system



The SWA system is an output of a five-year research project initiated by the HKU Water Centre, with seed-funding provided by the Water Supplies Department (WSD) of the Hong Kong SAR Government. Begun in late 2019, the project team has developed an IoT-based Tap Sensor for collecting tap-based water consumption data to train a Machine Learning model to disaggregate water end-uses. A scalable data collection architecture was created to collect tap-based consumption data from 21 households in Hong Kong since early 2021. As of today, over two hundred thousand annotated end-use-activity profiles have been captured by Tap Sensors with data resolution set at a 1-second interval, coupled with a 2ml accuracy level. This first-of-its-kind tap-based data collection exercise will provide indispensable ground-truth information for the Smart Water Auditing project as well as the global research community working on this topic because this set of original, annotated data will help improve the accuracy and the generalizability of residential water end-use classification models significantly (Gourmelon et al., 2021). The team has also modified the engineering design of the Smart Tap Sensor and turned it into the First-Generation Smart Meter that is capable of recording per-second household-level water consumption data. The data resolution specifications of the Smart Meter, set at a 1-second interval, have proven to be sufficient for meeting the data requirements for the disaggregation of end-uses by Machine Learning algorithms.

The First-Generation Smart Meter, nevertheless, has a major weakness: The in-line installation of such a Smart Meter involves plumbing works and, hence, temporary suspension of water supply for an entire apartment—resulting in nuisances for water customers and incurring prohibitively expensive project costs. Subsequently, the HKU Water Centre decided to bypass these operational difficulties and developed a Second-Generation Smart Meter, which is a non-invasive, portable AI analyzer module. We call it the Smart Meter Analyzer (SMAN) (see Figure 3).

Figure 3. A Smart Tap Sensor (top-left); an in-line Smart Meter (top-right); and a Smart Meter Analyzer prototype (bottom)

The Second-Generation clamp-on Smart Meter, SMAN, leverages on the city's mature metering program (more than 99 percent of water customers are metered). By incorporating the most recent advances made in edge computing, computer vision, and networking technologies, SMAN can adapt to any WSD-issued mechanical water meter and turn it into a smart meter. Ultra-high resolution water consumption profiles (100 ml, at 5-second interval) could be constructed via SMAN. The Project Team plans to test and roll out a fully functional SMAN module to collect fine-grained water consumption data from 300 randomly selected households from 2022-2024. These water consumption profiles, with time sampling resolutions comparable to those of international best practices, will be classified and disaggregated into specific end-uses by a Machine Learning model. Narrow-band IoT (NB-IoT), a form of Low-Power Wide-Area Network (LPWAN) technology, is used to transmit encrypted digitized water meter readings from a range of urban settings in Hong Kong—including tightly packed high-rise buildings in densely populated districts as well as remote sites that are poorly covered by conventional telecommunication infrastructures—to the Project's secure cloud server. Data are then disaggregated into categorized water end-use information.

While a team of engineers are building the hardware and the software components of the Smart Water Auditing system, a team of social scientists have merged a constellation of pertinent social science concepts—such as the notion of environmental ethics, as well as ideas on behavioural and cognitive psychology that are embedded in feedback intervention theory and goal-setting theory—into constructing an intuitively enticing feedback platform of the SWA system. Users, through this platform, will be able to view real-time detailed information on how much, and how, water has been used at home via their mobile devices (see Figure 4). The bedrock premise of this feedback platform: real-time feedback on water consumption could serve as a powerful nudging tool to help responsible users of the Smart Water Auditing system by empowering them to experiment with and embrace habit-changing water conservation practices. Users can benchmark their own water consumption level with the study's overall averages, for instance. More importantly, users can set their own water conservation targets and measure the progress they are making towards achieving those targets. The platform will also push notifications on practical water-saving tips that are customized to fit with each user's unique water consumption profile.

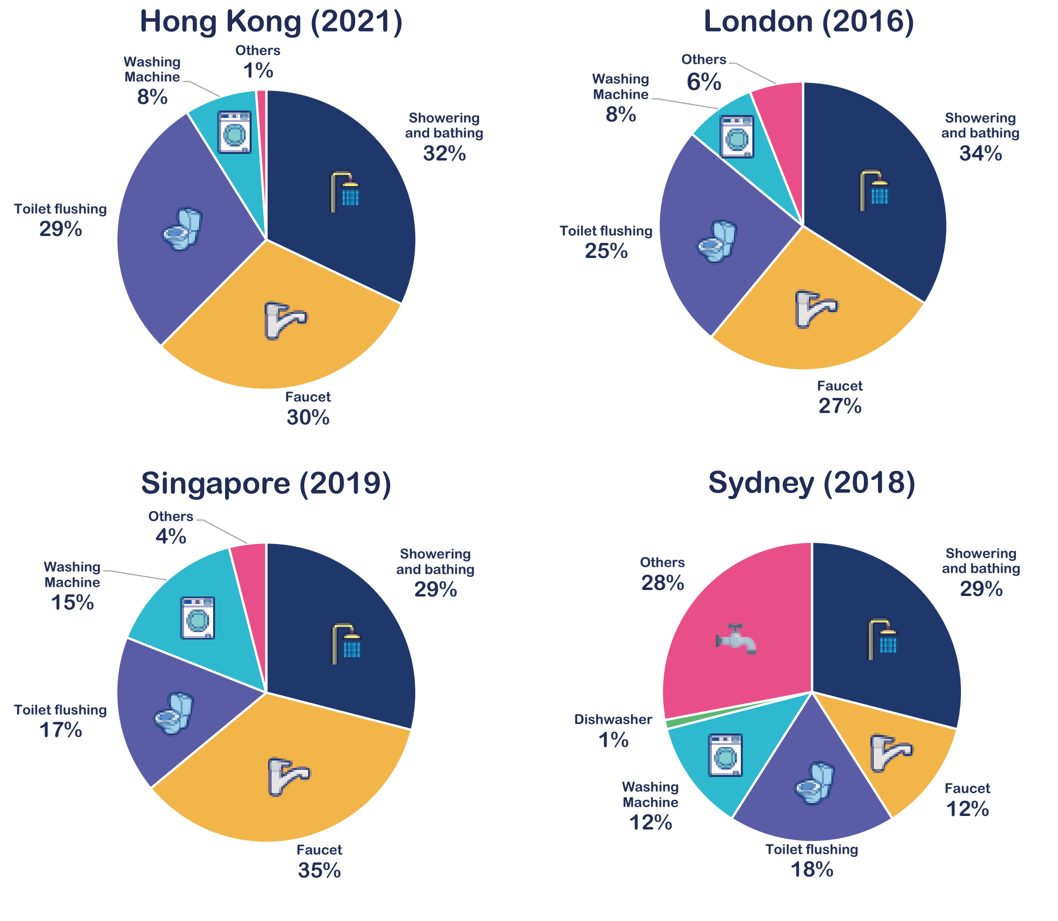
Figure 4. A mobile website for providing feedback on water use to the users

Potentials of and constraints to the Smart Water Auditing system

In other parts of the world, water utilities have conducted smart water metering projects to collect data to help them monitor water losses, forecast water demand, explore water restriction policies at times of water supply interruptions, and formulate demand management strategies to identify and reduce peak demands (Di Mauro et al., 2020; Pesantez et al., 2020; Rahim et al., 2020; Ramos et al., 2019). While these researchers have made use of smart technologies to generate and report near-real-time data on domestic water consumption, the HKU Water Centre is the first to collect empirically gathered ground-truth data, at 1-second interval, in multiple households continuously for up to three months for the training of generalizable Machine Learning models.

The Smart Water Auditing project, by producing actionable data to induce positive behaviour on domestic water conservation, aptly demonstrates that recent technological advancements have enlarged the boundary of policy imaginations by allowing researchers and policymakers to conduct analysis at unprecedentedly granular levels. In converging IoT, AI and data analytics in this project, we have begun to produce the first set of policy-centred actionable data for Hong Kong on household-level water consumption. Water utilities could make use of such data to formulate, calibrate, and evaluate household-level water conservation measures to reach city-level water conservation goals. The early findings of the SWA project are shown in Figure 5, juxtaposing Hong Kong's data—which are the first-of-its-kind ever empirically derived for the city, with those of Singapore.

Figure 5. Domestic water end-use distribution in Hong Kong (2021), London (2016), Singapore (2019), and Sydney (2018)



Moreover, the Smart Water Auditing system has shown its potential to help expedite the digitization of a city's urban water management system in a cost-effective manner. For instance, in Hong Kong, WSD has installed over three million mechanical water meters, which are single-purpose devices (for billing) that measure the quantity of water consumption of tap-water customers over a 4-month billing cycle. The financial costs and technical difficulties in retrofitting the conduit system in old buildings to accommodate the cabling network of AMR outstations are the major hurdles that stand in the way of the implementation of a city-wide AMR scheme. Subsequently, tap-water customers residing in these buildings could not enjoy AMR's beneficial features, such as alarms on leakage and timely notifications on over-consumption.

The almost universal metering coverage achieved in Hong Kong, nonetheless, has set the stage for the city to easily transform its domestic water supply network into a digitised, smart system. The clamp-on SMAN could serve as a low-cost alternative to commercial smart meters that require costly in-line installation. The minimal efforts required to install a SMAN module means that it could be rolled out rapidly to digitize and modernize a city's water metering system. Coupled with the application of related, emerging smart technologies, it is now plausible for Hong Kong's long-term water planning exercise to transition to a truly real-time, data-driven, evidence-based policy-making process.

In the first two years of the project, the Project Team has spent much time trying to resolve technical issues that are commonly encountered in the early stages of any practice-oriented research projects. In our case, one salient technical challenge pertained to optimizing the power requirements of several types of emerging IoT technologies, each with its own specifications, when we integrated them to create a new device. We have learnt that such technical hiccups, with engineers' usual traits of persistence, ingenuity, and patience, are surmountable—given time and sustained financial support.

On reflection, we surmise that the major constraints that might block the realization of our vision of the production of actionable data to facilitate domestic water conservation in Hong Kong stem primarily from institutions. First, for a real-time, data-driven, water conservation-centred feedback mechanism to work on targeted users, the charging principles that have underpinned the city's water tariff regime since the early 1980s will need to be restored and strenuously enforced. That is, at a minimum, customers will need to pay for the full cost of water production and provision. Otherwise, both the knowledge effect and the nudge effect of the feedback platform will be heavily discounted, if not totally discarded.

Secondly, instead of soft targets, the Water Supplies Department should be assigned hard targets and given a chance to demonstrate its resolve, commitment, and professionalism. Up until the current moment, water conservation campaigns conducted under the aegis of WSD do not include any targets. For instance, the 'Let's Save 10L Water' campaign, launched in 2014, did not come with a target attainment date. Inevitably, over time, viewed from the public's perspective, these words were equated with a sloganeering project, and no discernible outcome could be attributed to its implementation.

Thirdly, to align itself fully with the conservation-inspired zeitgeist of the global water community, Hong Kong's water agency will need to re-define its remit to embrace a broadened agenda that goes beyond its singular objective of achieving a 99.9% reliability in provisioning water supply for its customers. Instead of such a narrow focus, WSD should aim at pursuing a larger set of KPIs that bind its functions and operations and to fulfilling some larger, and admittedly challenging, but rewarding, societal aspirations such as decarbonization and ultimately, net zero carbon. Such a structural, and fundamental, shift in agency priorities is, of course, a tall order for any government in any parts of the world that are deeply entrenched in decades-old mind-set. The impetus to reforming outdated practices could only emanate from the city's top echelon of decision-makers, whose attention has, unfortunately, been distracted by a string of more immediate and contentious political and social urgencies in recent times.

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Mumbai (India)

Metering Mumbai: Lessons from AMR technology use in Mumbai's water supply network

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Mumbai (India)

Abstract

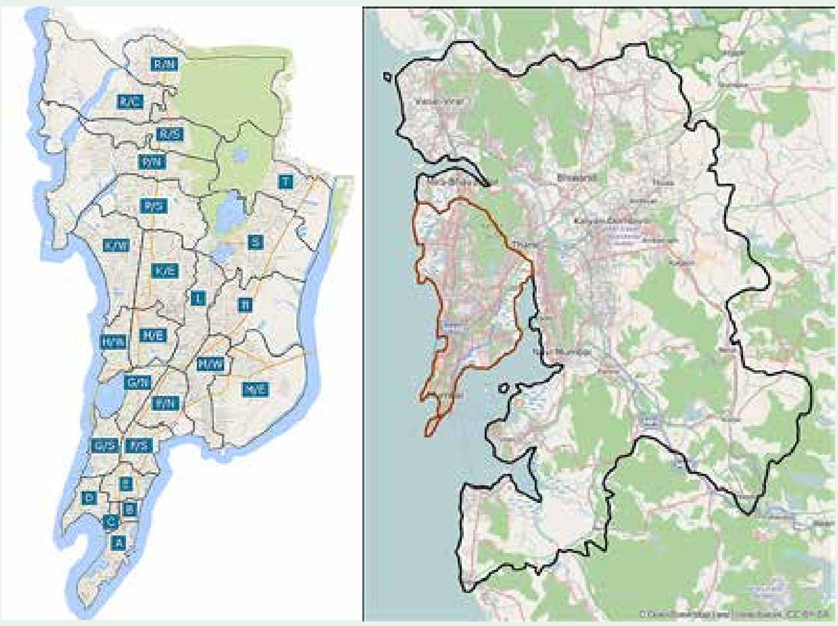
Mumbai city (India) faces an immense challenge of managing water supply needs to it's over 18 million consumers. In 2009, the municipality initiated a pilot application of Automated Meter Reading (AMR) technology to improve revenue collection and in the long-term demand management. At the time, most of Mumbai's water meters were non-functional, affecting cost recovering and water management. This chapter examines the pilot phase of the city's AMR project. Comparison of consumption data pre and post AMR illustrate the improvements in billing accuracy. However, public opposition, financial, physical, and technical constraints were faced during the project. This early example of smart water technology in India is further discussed in relation to more recent policy developments, such as India's smart cities mission. This chapter explains why the lessons from Mumbai are still relevant today and highlights the need for simultaneous investments in institutional capacity to realize the full potential of smart water technologies.

Overview of Mumbai City

Mumbai, capital of Maharashtra, is the seventh largest megacity in the world (United Nations, Department, 2018). It has a tropical, wet and dry climate with a distinct monsoon season (June to September) during which it receives heavy rainfall and can experience major flooding events.

Historically, Mumbai consisted of separate islands connected through land reclamation projects. Over time, Mumbai city expanded to the northern suburban areas to form the peninsula area of Greater Mumbai (437.71 sq km) (MCGM & EMI, 2011). Today, Greater Mumbai comprises of three regions: the island city, the eastern, and the western suburban areas (Z´erah, 2009) (see Figure 1).

Figure 1. Administrative wards in Greater Mumbai (L), Map of Greater Mumbai & Mumbai Metropolitan Region. (Source: Disaster Management Department, 2017; Chakraborty et al., 2015)



Between 1991-2002, Mumbai's population grew by 28%, especially in the eastern and western suburbs. Urban expansion also gave rise to satellite cities which together comprises the Mumbai Metropolitan region (Hust & Mann, 2005; Z´erah, 2009) (see Figure 1). Today, Mumbai's population is estimated to be 21 million and is projected to become the 4th most populous city globally by 2030 with 29 million people (Department of Economic & Social Affairs, Population Division, 2015; HT Correspondent, UN, 2014). Lack of affordable housing and high real estate prices in Mumbai force residents who cannot afford formal housing to live in slums. Estimates of Mumbai's slum population is between 41% and 55% of the total population (Desai, 2014).

Water Supply in Mumbai

The Municipal Corporation of Greater Mumbai (MCGM), established in 1882, is the public authority responsible for urban services including water supply. Its functions and operations are based on the Mumbai Municipal Corporation Act (1888).

The organizational structure of the municipality consists of a deliberative and administrative wing. The deliberative wing is headed by the mayor and includes the standing committee comprised of elected municipal councilors (BMC, 2019a). The city is divided into 24 administrative wards, each governed by an assistant commissioner or ward officer. Water supply services are managed by the hydraulic engineering department (BMC, 2016b). At the ward level, this department is responsible for day-to-day functions, including water supply, maintenance, metering, revenue collection, and customer complaints.

Water supply is sourced from several rain-fed reservoirs, some within city limits, others over 100km away. A gravity-based system transports water to Mumbai via nearly 4,000km of pipelines (BMC, 2016b; Desai, 2014). Groundwater from 3,950 dug wells and 2,514 bore wells serves as a supplementary source for all other purposes besides drinking and domestic uses (Gupta, 2013).

A majority of the MCGM's water users are domestic. Water supply provisions for domestic users differ for residents living in apartments, private dwellings, or in slums. For apartment and private dwellers, it ranges between 240-250 litres/ per capita per day. Meanwhile, slum residents receive stand post connections (Desai, 2014). Some residents live informally on pavements, under bridges, near railway tracks, etc. They represent the most marginalized population, are excluded from municipal supply, and are forced to beg for water from other areas or through illegal connections (Bapat & Agarwal, 2003).

Currently (as of 2021), Mumbai receives 3,850 million litres per day (MLD) although water demand is estimated at 4,200 MLD. Demand is furthermore projected to reach 6,000 MLD by 2041 (CDEM, n.d.). Therefore, in order to meet the current and projected future water demand, a series of additional water supply projects, infrastructure improvements, such as refurbishing old infrastructure, water auditing, and construction new underground tunnels is underway (Gupta, 2013; Pardeshi, 2020; Purohit, 2012). A 200MLD desalination plant is also envisioned in the near future (Cheif Engineer, 2021; Upadhyay, 2020)

Water management issues in Mumbai

When smart water technology was first considered in Mumbai back in 2005, it faced a number of challenges. There was a water supply deficit of approximately 850MLD (Itron SmartMedia, 2011). As a consequence, water supply was intermittent, ranging from two to four hours per day to 24 hours in some zones (Desai, 2014; MCGM, n.d.-c). The city's ageing water supply infrastructure was also in dire need of refurbishment. Mumbai regularly faced incidents of leakages, pipe bursts, and water losses upwards of 20% (Desai, 2012; Desai & Raj, 2012; Nallathiga, 2006). Thus, there was a need to reduce network losses to meet future demand.

Water meters allow for revenue generation of both water supply and sewerage. At the time, accurate estimations of water consumption were constrained by a lack of metering capacity. The city had approximately 300,000 water meters. The policy was to charge users based on a metered supply, yet 50% of domestic meters and 20% of bulk meters were damaged or non-functional (Desai, 2012).

Figure 2. Examples of meter reading issues (clockwise from top left): Meter buried under footpath, enclosed in cement, broken meter, readings not accessible (Gomes, 2012; Itron India, 2009)

Furthermore, users were charge based on average (rather than on actual consumption) and water bills were not generated in time, resulting in outstanding dues of approximately $70 million (INR 525 crores) (Sharma, 2011). Part of the billing problem was due to manual meter readings. Mechanical water meters were used to generate consumer bills. The increase in mechanical meters due to population growth, high housing density, poor meter installation, and water logging in the monsoons made meter reading extremely challenging (see Figure 2). Manual readings require manpower and runs the risk of human error or meter tampering.

The metering problem also made it difficult for the MCGM to allocate water supply between the city and suburban areas. A study shows how south Mumbai (city area) was receiving the highest per capita water supply despite having the lowest population, leaving the more populated suburban areas with less water (Desai & Raj, 2012). Thus, there was a pressing need to replace non-functional meters and improve the efficiency of meter reading.

Automated meter reading technology

Automated Meter Reading (AMR) is a type of smart water technology. They allow for remote collection of meter readings through radio frequencies, removing the need for physically accessing meters. AMR technology offers a range of benefits for water utilities including:

- Faster, more frequent meter readings to calculate changing consumption patterns.
- Leakage and water theft detection helps reduce non-revenue water.
- Improved billing accuracy.
- Awareness of resource use. In Ann Arbor, Michigan, users track consumption in real-time and calculate which activities can help lower consumption.
- Two-way (remote) meter management if meter readings are transmitted to a smart grid. (source: Hope et al., 2011; McCormick & Welser, 2009; Quraishi & Siegert, 2011)

AMR project in Mumbai [1]

In 2005, the MCGM initiated its AMR technology project. Mumbai was the first Indian city to invest in AMR at the time, although Delhi, Navi Mumbai, Pune, Hyderabad etc., were also conducting similar AMR projects. The municipality financed 100% of the project[2] and used a public-private partnership model.

AMR devices from three-meter manufacturers (Itron, Arad, and Chetas) were purchased and tested as per recommendations of a technical evaluation committee. Three contractors were hired in September 2008 to supply, install, read, and maintain meters. An eight-month feasibility pilot study began in 2009, where approximately 6,082 mechanical meters were upgraded to AMR (see Figure 3).

Figure 3. Installed AMR meters in Mumbai (Gomes, 2012)

Quarterly readings were taken using handheld devices and submitted to the MCGM (see Figure 4). Up to 8 meters could be read simultaneously, eliminating the need for physically accessing meters unless a problem was detected. Readings identified tampered, broken, and poorly installed meters. Tests to verify reading accuracy and investigate meter display errors, group readings, and 180-day readings were also conducted. The pilot study highlighted technical differences between the three types of AMR devices. AMR meters transmitted readings to the devices through radio frequency. The location of the meter could also be recorded on the device using GPS.

1. Information in this section is based on interviews and analysis in 2012 by the author. For more details, refer to Chapter 3,4, and 5 in (Gomes, 2012).
2. Total project cost was budgeted as $107 million (INR800 crore), however, incurred costs were $34 million (INR257 crore) as of 2012 (Controller and Auditor General of India, 2013)

Figure 4. System Architecture: Software with data transfer to billing department (L); Meter reading device (M); water meter with radio module (R) (Itron India, 2009).

A work order for 129,000 AMR meters was issued in August 2009. Installation in the full-scale phase began in July 2010, following meter modifications, performance, life testing, and site clearances from local wards. Initially, 300,000 AMR devices were ordered in this phase, but it was later scaled back to 129,744 meters. Contracts specified 1-2 years for AMR installation depending on the location and an additional 5 years for reading and maintenance.

Table 1. Overview of AMR project

Location	Pilot Study (No. of AMR meters)	Full-scale project (No. of AMR meters)
City	2,053	20,383
Western Suburbs	2,022	65,754
Eastern Suburbs	2,007	43,607
Total (No.)	6,082	129,744

Evaluation of Mumbai's AMR technology pilot project

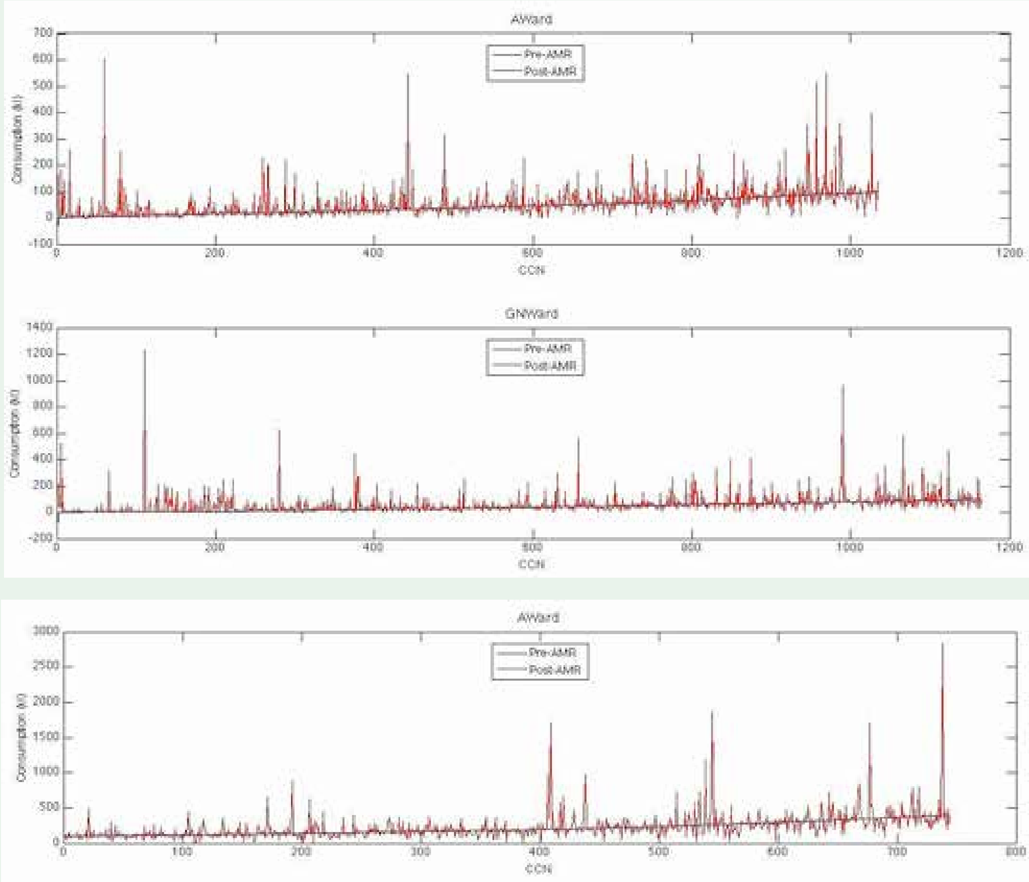
Project objectives

In the short term, the AMR project was expected to improve billing accuracy and customer transparency, improve meter reading, earlier detection of meter tampering, and help achieve universal metering and 100% volumetric billing. Long term, it would help with demand management, awareness of water use, equitable water distribution, billing lifecycle reforms, and water audits.

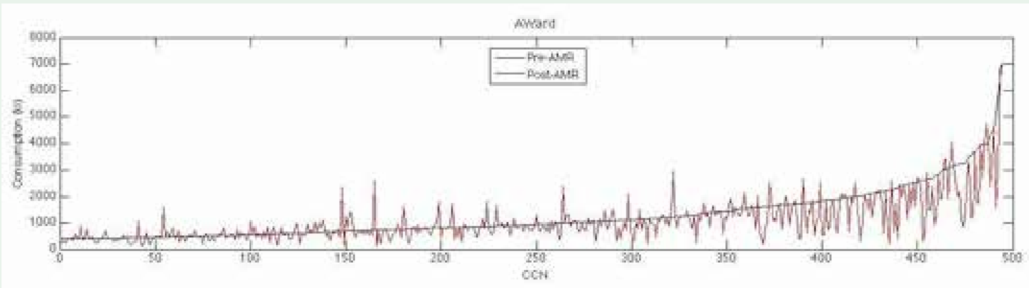
Impact of AMR on billing accuracy

Water consumption data of users from two municipal wards (A, GN) in Mumbai were compared pre- and post- AMR installation as part of a study conducted in 2012 by the author. A statistically significant difference ($p<0.05$) post-AMR installation was found in low consumption users (0-100kilo litres) in both wards A (n=1036) and GN (n=1164) (see Figure 5). For low consumption users, AMR technology improved billing accuracy. The change in average consumption pre- and post- AMR is quantified as 30% and 47% in wards A and GN respectively. Similar statistically significant results are also observed post-AMR in the 100-400kl range in ward A (n=743).

Figure 5. Pre- and post- AMR comparison in 0-100kl range in wards A (Top) and GN (Middle); 100-400kl range in ward A (Bottom) (Gomes, 2012).

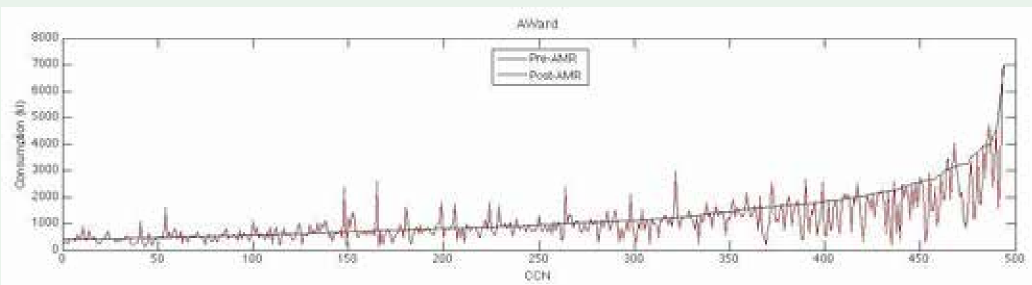


Comparison of consumption data in the highest consumption range (>400kl), shows a statistically significant result in ward A (n=495) (see Figure 6).



Here, consumption values decreased post-AMR, suggesting that consumers were over-charged pre-AMR. It was discovered that bills of some commercial users were two to five times more post AMR, revealing the inaccuracies of average billing. Results in GN ward in the 100-400kL and >400kl range were not statistically significant.

Figure 6. Pre and post AMR comparison in ward A for >400kl range



Cost barriers
The high cost of AMR meters made it a financially unsustainable for the MCGM. Typically, the cost of new meters is recovered from the consumer via a meter rent charge, which was $0.20/month (INR15) in 2012. AMR meters would increase the meter rent charge to $2.68/month (INR200) and is expected to receive public opposition. This partly shaped the decision to replace the rest of Mumbai's meters with new mechanical meters.

Implementation challenges
One of the main causes for project delays was the discrepancies in consumer data from the wards. Records of meter size and ownership, meter numbers, water connections, and consumer addresses were found to be incorrect during installation which slowed down the process. As many as 40-50 data discrepancies were identified in certain wards. There were also physical hurdles in locating meter sites and identifying connections.

Some areas also reported stolen or tampered AMR meters. Copper and other materials is typically sold from stolen meters by thefts. In response, the municipality decided against installing costly AMR technology near slums, installed tamper proof safety covers, and began charging consumers $16 (INR 1,200) to replace tampered meters (Mahamulkar, 2011; Mhaske, 2010).

Contractors were expected to submit meter readings as per the MCGM's billing cycles. However, readings were not submitted on time, thus causing delays in the generation of water bills to consumers. In some cases, this was due to inadequate training of staff, hardware, and software issues in local wards.

Public response to AMR technology
The project also faced public opposition during installation over fears of increasing water bills (Shukla, 2010). Yet, as this analysis shows, domestic users could be paying less after AMR, as bills appeared to overestimate water consumption. A higher number of complaints were also reported after AMR, with users requesting refunds for overestimated water bills.

The sharing of information between service providers and customers could also be improved. Prior to AMR installation, the MCGM issued a notice to users which did not mention specifics about the project, AMR technology, or potential long-term benefits for the consumer, such as, billing accuracy, for example.

Lessons from Mumbai's AMR technology pilot project

The primary objective for using AMR was to achieve 100% metering in Mumbai as well as achieve volumetric, accurate billing of consumers. This basic functionality of AMR (i.e. automated readings using hand held devices) appeared to improve billing accuracy in some wards.

However, the project's success was limited. A 2012 audit revealed that only 82,857 meters had been installed with 46,918 meters lying unused. Given the delays in supply and installation of the meters, the initial goal to install 300,000 meters was revised (Controller and Auditor General of India, 2013).

Despite this study's findings in billing accuracy after AMR, it appears that approximately 44% of water bills in Mumbai continue to be estimated due to non-functional meters (Express News Service, 2018). A follow-up study of AMR maintenance since installation could help identify whether current billing issues stem from the installed AMR meters or pre-existing mechanical meters.

AMR was expected to make meter readings more efficient and minimize human error and manual tampering, thus improving transparency and accountability towards the consumer. However, audits of meter readings in nine wards found that 30% of reading were recoded as 'non-acceptable'. (Controller and Auditor General of India, 2013). Further research is needed to examine underlying causes. Moreover, heavy rainfall and lightening also affected readings. Thus, if manual meter reading in monsoons is one of the concerns, then AMR does not appear to resolve this problem.

This case study highlights the value of pilot applications of smart water technology. In Mumbai, it uncovered new technical, social, financial, and institutional issues. This suggests a need for attention to other governance related aspects in addition to technology. Service providers must be able to adapt the technology to their context. For example, the MCGM could have explored several options to address the issue of cost recovery of AMR meters. Further analysis of consumption data for example, might indicate which user groups are cost effective candidates for AMR technology. However, analyzing consumer data in this way is associated with privacy concerns and thus, could not be included in the study. Alternatively, the MCGM could have sourced designs for a locally made, more economical option. This will help make technological investments financially viable in the long-term.

In Mumbai, public participation during the project could have helped generate support for AMR and its associated costs. Better communication might help consumers realize the added, long-term benefits of AMR in identifying leaks, creating water demand maps etc. which ultimately improves water supply services for the consumer. However, public acceptance of smart water technologies is difficult without access to information. Local councillors interviewed during the study were in favor of improving citizen awareness on water related projects through the media, public banners, etc. Many smart meter technologies are also accessible to citizens through apps or websites. In Valencia, for example, access to water consumption data was found to positively impact water conservation behaviour (Cominola et al., 2021). In cities where poor water supply has eroded local confidence in service providers, technology can be used to share consumption, maintenance, and water quality data to improve transparency and re-establish trust.

Policy developments for smart (water) technology in Indian cities

There has been a growing interest in smart technologies in Indian cities stimulated by municipal strategic goals as well as national level programs. Early applications of smart water technologies were sporadic and motivated by different factors. In Mumbai, for example, the literature highlights two smart water technology proposals. The MCGM has initiated several large-scale projects since 2007. The Sujal Mumbai Abhiyan program (2007) intended to map Mumbai's water infrastructure and leak detection (Desai, 2012). This was followed by the AMR project in 2009. The AMR pilot and other water reforms at this time were guided by the recommendations in the pivotal Chitale committee report in 1994. This study, commissioned by the state government of Maharashtra, was undertaken following the water crisis in 1992. It recommended a number of measures for Mumbai city until 2021 pertaining to water supply augmentation, alternative sources, leak prevention, water recycling, management, and citizen participation (Desai, 2012). Success of these projects, however, is limited due to implementation issues (Singh, 2016).

Another early smart technology proposal in 2007 was examined by Anand (2020). This strategy was to install prepaid meters in new slum settlement areas (set up after 2000) as a way of extending water supply services to unrecognized residents. The decision to explore this technology was motivated by discussions at a stakeholder consultation meeting in 2007, with international experts from Johannesburg who had previously applied it in Soweto. However, faced with strong opposition from activists and hesitation from hydraulic engineers in Mumbai, the proposal was withdrawn. Activists learned about the shortcomings from their South African counterparts and feared it would lead to the privatization of water services. Meanwhile, engineers were concerned about the long-term issues if poorly managed prepaid meters cut off water supply, not to mention their cost. Only later in 2014, following a ruling by the Mumbai high court, was this proposal revisited as a way of extending water services for all slum residents in some form. However, 5 years on, Anand (2020) finds that none have been installed as scepticism from local engineers continues.

At the national level, India has also witnessed a top-town push for smart city development through the evolution of national level schemes aimed at urban development. Prasad & Alizadeh (2020) explain the evolution of these policies from infrastructure-focused to market-based. Technology here was seen to draw international investors. In particular, the Jawaharlal Nehru National Urban Renewal mission (JNNURM) and subsequent Smart cities mission (SCM)–both implemented through the Ministry of Housing and Urban Affairs–have played a major role in promoting and funding the development of smart cities.

The JNNURM targeted the rejuvenation of cities and towns across India between 2005 and 2015 (Ministry of Housing and Urban Affairs, 2021). Its goal was to fast-track reforms in urban infrastructure and service delivery to the urban poor (Roy, 2016). It was implemented in two phases. In the 2nd phase of this mission (2012 onwards), the concept of 'smart cities' was put forth. It promoted the use of Information Technology (IT) in projects which included water supply and sewerage (Sethi, 2012).

Smart city development in India was initially associated with greenfield cities where technological instruments was used to attract foreign investments, technology firms, and private real estate companies (Roy, 2016). In 2014, the smart cities concept was reframed for urban development. The smart cities mission, launched in 2015, includes both greenfield, brownfield, and pan city development projects. This 5-year mission aims to help establish 100 smart cities and towns in India. This conceptualization of smart cities refers to the long-term aspirational goals for urban services for its citizens, developed incrementally over time. Here, technology is integrated within the goal of developing institutional, physical, social, or economic infrastructure in a more efficient way for creating liveable, inclusive, and sustainable cities (Aijaz, 2021; Prasad & Alizadeh, 2020).

Dholera city in Gujarat was the first such smart city in India under this mission, developed in the Delhi-Mumbai industrial corridor. It was here that a SCADA (Supervisory Control and Data Acquisition) based smart water technology was used to manage waterlogging and wastewater problems. This smart city project, which began in 2012, has 3 phases, each 10 years in duration (Bang et al., 2020). Since then, several smart water technology projects have been selected by the mission. They include sanitation (Jabalpur, Kochi, Pune, and Coimbatore cities), preservation of nature water bodies (11 of 20 proposal studies), climate and disaster management (Ahmedabad, Bhubaneshwar and Vishakapatnam) projects (Prasad & Alizadeh, 2020). In total, 100 cities and towns were selected between 2015-2018 for technology-aided infrastructure projects across urban sectors. These projects are co-funded by governments at different levels and must also acquire external funding from financial intermediaries, multilateral organizations, and the private sector, etc.(Aijaz, 2021).

Both the JNNURM and SCM have faced criticisms. Evaluations of the JNNURM reveals limited impact due to lack of participatory planning, coordination between citizens and government, and the absence of suitable monitoring mechanisms–concerns that Roy (2016) argues were not considered in the follow up SCM. Recent assessments of the SCM shows only 50% project completion due to slow financial roll out and difficulties faced by states and union governments in mobilizing necessary funds (Aijaz, 2021). Prasad & Alizadeh's (2020) review of 20 proposals in the SCM furthermore, highlights the gaps in prioritization of environmental dimensions at the policy level compared to other dimensions. Although they argue that smart governance is the core of such projects in India, the failure to consider this dimension in smart city policies is concerning given the growing environmental issues in Indian cities. The location of some greenfield smart cities, for example, raise concerns about sustainability (Roy, 2016).

Aside from criticism from researchers and advocacy groups, local politics have also influenced participation in the mission. Conditions, such as the setup of a separate overseeing body known as 'Special Purpose Vehicles', was opposed by politicians in Mumbai and Navi Mumbai for fear that it would dilute the powers of the municipal authorities (Aijaz, 2021). Similarly, cost recovery is recovered from services charges such as water taxes in New Town was opposed for fears of inequitable development by the state of West Bengal (Aijaz, 2021; Housing & Land Rights Network, 2018).

Re-defining the role of smart technology for India's urban context

This chapter set out to examine an early smart water technology project in Mumbai, India. The pilot project reveals a variety of governance issues associated during the implementation of AMR technology. Ten years later, the insights from this pilot study continues to be relevant as India pursues its mission of creating 100 smart cities. In this concluding section, I reflect on the insights from India in a larger discussion of smart cities.

Historically, smart technologies, and in particular, smart water technologies like AMR, were adopted and tested in Europe and North American cities. More recently, they have emerged in developing countries, as demonstrated by the examples from India. These contexts very significant and must be considered in the application of smart technology projects (Prasad & Alizadeh, 2020). For example, cities in developing countries continue to face the challenge of meeting basic urban needs like water supply and addressing critical issues like poverty or climate change. Here, smart technology investments must be embedded in addressing these more fundamental issues instead of detracting resources away from them (Backhouse et al., 2020). A review of smart cities in South Africa (South African Cities Network, 2020) further highlights the role of the informal urban economy in these contexts and less mature IT and data management capabilities–both of which need to influence the design and success of smart technology projects. In India, ICT enabled urban services, for example, runs the risk of marginalizing large sections of the population who are unable to access them due to their socio-economic background or informality in living and employment situations (Roy, 2016). Meanwhile, Cheong et al. (2016) signals practical issues of power breakdowns that smart technology projects also need to take into account.

The review of smart technology applications in India gives importance to the role of governance. In some cities, particularly in the developing context, addressing institutional gaps is required before technological investments are made. Ideally, investments in institutions and technology should go hand in hand; however, the reality is that institutional capacity often lags behind technological advancements (Grey & Sadoff, 2007). Governments must prioritize and incentivize investments in institutional reforms (van de Meene et al., 2011). However, the capacity for institutional change depends on the socio-political conditions.

Moving forward, the adoption of smart technology in less developed regions and cities should be given more attention to by scholars. Smart technology use in India remains under-researched, especially when it comes to the governance of these projects. As a result, our understanding of the governance needed to support technological reforms is limited. Similarly, as the smart cities mission program wraps up in India, a need for monitoring and for evaluating projects in the long term is important. Here, Prasad & Alizadeh (2020) suggest assessing the proposals and vision statements of the smart cities in terms of addressing environmental challenges and economic opportunities from policy to implementation at the operational level.

Finally, recent utilization of smart water technologies in less developed contexts, calls for a need to revisit the original conceptualization of a smart city. Defining and evaluating smart cities through a purely technological lens ignores the socio-political motivations and processes that influences them (Roy, 2016). For example, in Indian smart cities mission, the focus is on smart governance; yet, critics point out the pitfalls of adopting a technocratic approach to governance. This is reflected also in the issues of funding, human resource capacity, citizen participation, and sustainability that appear to have impacted the success of this mission (Gulati, 2021). Prasad & Alizadeh (2020) argue for a contextualized definition to reflect the different urban realities and technology use in policy and practice. Instead, Roy (2016) suggests not viewing technology as the goal but as the means to improve the conditions for the most marginalized in order for smart cities to be inclusive.

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7.

Nakuru (Kenya)

Sponge City Nakuru

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Nakuru (Kenya)

Abstract

Rapid urbanization and population growth in Kenya's cities and towns creates a situation in which basic services and facilities often fall behind. Water supply and provision falls short due to dwindling resources. Flooding becomes a major issue due to insufficient stormwater management and buffer capacity. In a Sponge City, we aim to overcome these issues by deploying natural principles of water recharge, retention, and reuse in a built environment. This case-study of Nakuru presented in this article, focuses on three neighborhoods in cities with majority low-income households. It describes the formulation of the Sponge City building blocks in which the social engagement process is crucial. A 'mapathon', a combination of data collection tools, with google earth mapping and story-telling, was conducted to thoroughly understand the perspective from the residents, getting a real on-the-ground view and feel. It proved essential to build skills, commitment, and contribution. This case-study showcases that a sponge city must build upon locals and that the social engagement process with diverse multi-level stakeholders is at the backbone of a successful sponge city.

Key words: Sponge city, Sponge city, urban resilience, urban flooding, urban planning, urban water management, mapathon

Introduction

Globally, more people live in urban areas than in rural areas, with 55 % of the world's population residing in urban areas in 2018. In 1950, 30 % of the world's population was urban, and by 2050, 68 % of the world's population is projected to be urban (United Nations, 2018). This growth is the result of major economic and social transformations. Coupled with extreme weather events and prolonged drought periods, water supply and provision especially in urban areas becomes more and more challenging. While natural resources are depleting, the pressure on these very resources is increasing.

Rapid urbanization is difficult to accommodate in terms of basic services, facilities, and infrastructure, thus leading to the creation and sprawling of large informal settlements and slums where inhabitants often self-organize to compensate low public investment. These areas usually suffer from overcrowding, low employment, poor transport infrastructures, poor housing conditions, limited access to healthcare and education, and a lack of sanitation and waste management systems–hence generalized insalubrity (United Nations, 2018). As such, they are at great risk of entering the vicious circle of under-development and extreme poverty.

Kenya is one of these countries in SSA with rapid urbanization. It is expected to become a predominately urban country by 2033, with half of its population living in urban centers (World Bank, 2011). The growing urban centers all over the country are growing, especially in Arid and Semi-Arid Lands (ASALs) which are facing some pressing issues, including insufficient urban water provision, excess stormwater and flooding, and low quality of water. Each have a debilitating effect on the quality of life in many ways. For example, flooding destroys properties, leads to traffic congestion, and displaces people in affected areas.

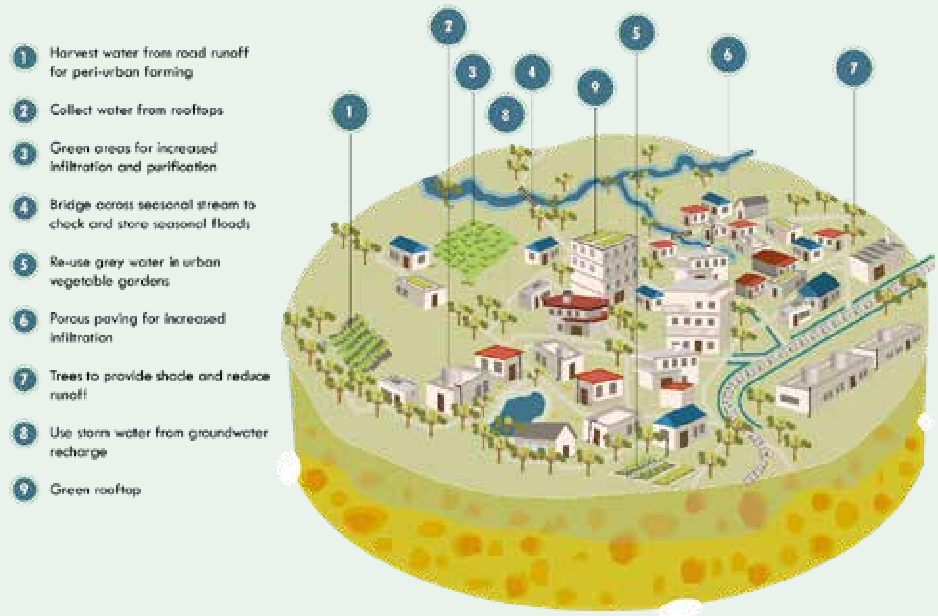
Sponge City seeks to provide a holistic solution to the myriad of pressing needs through the key principle of buffering extremes of high intensity short rainfall and long drought periods.

In the current planning paradigm, the idea is to drain out all the excess stormwater as quickly as possible. While in the dry season, water is supplied from an outside source, for instance, from a dam. However, a link between both stormwater management and water supply is often not made. This link is urgently needed, as current water supplies cannot meet the demand, while in the future, the gap between demand and supply is likely to grow bigger. Furthermore, quickly draining water out of the system creates high risk of flooding and erosion.

The Sponge City concept therefore takes a completely different approach and builds on the principle to buffer extremes. A sponge can soak up the water, retain it over time, and release it slowly in time of need. The real innovation of a Sponge City is not in single measures to be implemented, but in finding the right alchemy in which the measures are integrated in the urban landscape according to context and needs. Normally excess water, resulting from heavy downpours, is managed following the old paradigm of disposing water as quickly as possible. This approach implies a strong focus only on drainage lines to make water go out of the system. Nevertheless, this also implies that drains need to be oversized, with roaring costs, and that water that could be used otherwise is lost very quickly. The Sponge City concept aims at reverting this paradigm.

A sponge city can be described as a city "that can hold, clean, and drain water in a natural way, taking on an ecological approach" (O'Meara, 2015). Even though the context is substantially different, the concept is already being piloted in 16 cities in China, as a way to use landscape-based measures in order to address both water shortages and urban flooding. This entails the widespread adoption of water buffering techniques. The aim is to create an urban landscape that will function as a sponge. Sponge cities are thus characterized by natural retention, recharge, and reuse (3R).

Figure 1. Overview of Sponge City Interventions



These cities can save water resources, as well as protect and improve the urban ecological environment. It is a form of development that aims at providing a natural buffer for storm water runoff, and furthermore, provide for drainage, water harvesting, and storage facilities. In an urban environment, where concrete, stone, and asphalt are prohibiting water to infiltrate naturally into the ground, we integrate green infrastructure, such as recharge pits, bio-swales, and green roofs, to ensure water can be sustained within the town or city (see Figure 1). Annex 1 provides additional measures with short explanations.

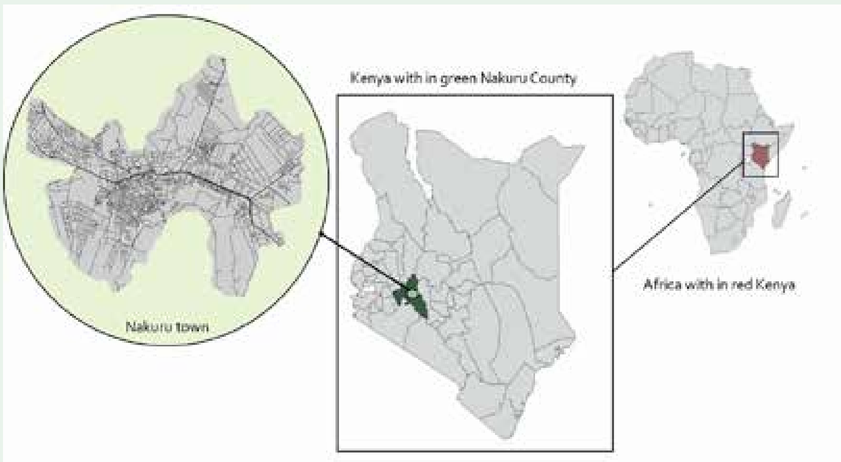
The sponge city concept results in sets of interventions that the environment and the residents will benefit from, either directly or indirectly. The interventions aim to (i) improve the water quality and quantity in a city, coupled with flood protection, and safeguarding of property and infrastructure; (ii) contribute to the restoration of degraded/abandoned landscapes and water sources, while also increasing economic goods and services such as urban farming through the utilization of the harvested stormwater; and (iii) increase urban community awareness on environmental issues, such as climate change and waste management and their well-being.

This paper presents the case-study of Nakuru City in Kenya, Africa. It elaborates on the main challenges, the sponge approach, the proposed solutions, the main findings and lessons, and finally policy implications and recommendations. We demonstrate an exemplary solution of a current Smart Water City project, thus contributing to an improved understanding of how fast-growing cities can transform into sponge cities and towns. We hope that more and more cities take this important step of becoming a sponge city or town.

Characteristics of Nakuru City

Nakuru is the 4th largest city of Kenya (population of 533,800, 2019 census) and is located at the bottom of the Great Rift Valley, just south of the equator, approximately 160 km from the capital city Nairobi. Nakuru County is one of the fastest growing areas in East Africa, expected to grow from 2 million in 2019 to 5.4 million in 2050, with an annual population growth of about 3.1%. According to a UN study released in 2011, Nakuru is Africa's fastest-growing city and the fourth in the world[1].

Figure 2. The location of Nakuru city in Nakuru County, Kenya, and Africa



1. www.wsup.com/content/uploads/2019/08/Sanitation_Nakuru_final.pdf

Figure 3. The location of the case-study areas London, Free Area, and Kaptembwo in Nakuru Town

Nakuru town is soon to be officially registered as a city and is strategically positioned to serve its hinterland, as it is centrally located with developed transport corridors to other centres. It has a relatively well-developed urban infrastructure which has enabled it to play a major and effective role in the region. The town is also a center for various retail businesses that provide goods and services to the manufacturing and agricultural sectors proliferate in the Rift valley of Kenya. According to a study by MajiData in 2011[2], Nakuru city has 49 low-income areas, comprising 57% of the population. These low-income areas are less served with water and sanitation services and highly affected by floods during rainy season. Figure 3 shows the low-income density in the three project areas: London, Kaptembwo, and Free Area in Nakuru city. The areas have several partitions which are commonly denoted as 'urban slums', and overall, the low-income density is higher compared to Nakuru city overall.

Nakuru town is facing increasing threats to its water supply, largely because groundwater sources are dwindling, while it provides 90% of the total water supply. Currently only 45,000m^3/d of water is available against a demand of 70,000m^3/d[3]. The demand for water is expected to rise significantly, with the demand for water reaching 191,000m^3/d in 2050 to serve the estimated population. The aquifers, rivers, and storm water drains in Nakuru city also feed Lake Nakuru. This lake sustains rich biodiversity, including pink flamingos that feed on algae blooms and has been designated a Wetland of International Importance by the Ramsar Convention[4].

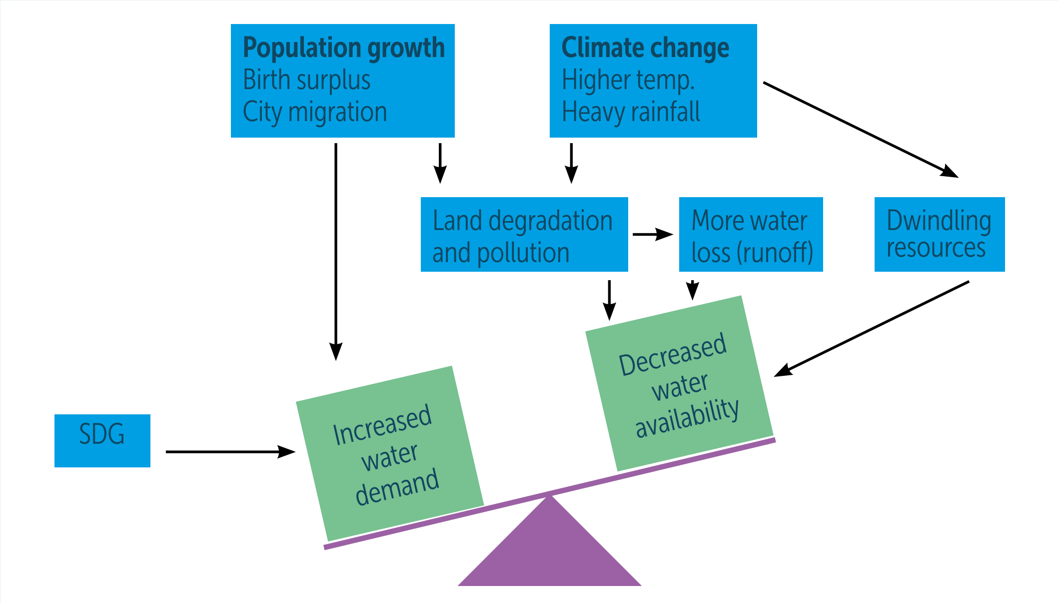
2. MajiData. (2011). MAJIDATA. majidata.go.ke
3. www.oagkenya.go.ke/getmedia/2b8dde69-743d-45c0-8329-bb6d352558e8/water-nakuru-water-and-sanitation-services-co-ltd2015-2016;.aspx?disposition=attachment
4. A Ramsar site is a wetland site designated to be of international importance under the Ramsar Convention. The Convention on Wetlands, known as the Ramsar Convention, is an intergovernmental environmental treaty established in 1971 by UNESCO, which came into force in 1975. It provides for national action and international cooperation regarding the conservation of wetlands and wise sustainable use of their resources.

Key urban water challenges addressed

At this moment, the predictions for Nakuru County clearly show shortage of water supply continuing to form an issue, while with the estimated population growth this shortage is likely to get bigger, especially for the town. This is not a stand-alone issue, as indicated in Figure 4.

This paragraph will first discuss the problems in clusters, after which underlying systemic issues are elaborated on as well.

Figure 4. Bigger pictures of interconnected issues



First, Nakuru is both fast growing and fast sprawling, which is a big challenge for urban planning, water supply, and sanitation. Water demand is already higher than supply and recent data indicate that resources in Nakuru city area are overexploited. Amongst others, this is due to minimized direct recharge in the city, particularly due to abundance of hard surfaces, allowing little infiltration. Moreover, these hard surfaces promote extreme runoff, resulting in floods which is another major issue in Nakuru city. As one person put it: “Why do we look at the water flow past us in floods when it rains, only to chase it afterwards with donkeys when the rains have stopped?” Especially in low-income areas (London, Kaptembwo, and Free Area), connected water supplies cannot meet the demands: 71% of low-income population experiences insufficient water supply, while 29% is not connected at all. Buying additional water is difficult for the population due to high price levels. Second, due to climate change extremes, such as long drought periods coupled with high runoff due to urban sprawl, existing groundwater sources are dwindling. While the existing groundwater sources contain high levels of fluoride, making it unfit for drinking. Third, the town faces a myriad of technical issues: Lack of green spaces, blocked drainages, flooding, insufficient sanitation facilities, and poor solid waste management. Fourth, the town faces a myriad of governance and financial issues, such as a lack of timely spatial planning, ad hoc solving of issues in silos, insufficient investment capital, reliance on big dams, loads of well-written policy documents, but little concrete action on the ground and a lack of accountability.

Finally, there are several underlying systematic gaps at play which hamper sustainable urban water management. Firstly, government programs tend to focus on large-scale interventions that are not connected to each other, taking a long time to establish, and are often not as successful as planned. Secondly, a common perception occurs that the solution should come from 'the others' (the community members look to the county government, the county government looks to the national government and donors, and utilities wait for interventions from donors, the national government and other agencies). Along with that, there is often no clear problem holder; the problem affects us all and needs to be solved by all. This leads to lack of agency in solving the problem. Thirdly, there is a focus on tangible short-term issues like fighting COVID-19, rather than long-term threats, like climate change. Fourthly, water harvesting and sanitation structures are mostly organized on individual basis rather than at a community level. Lastly, some vulnerable groups are left behind in planning and catering for Water, Sanitation, and Hygiene (WASH) services, whereby provision of services through youth and women to combat poor livelihoods and high unemployment are not yet enabled.

Innovative Smart Water technology solutions proposed

Despite the difficulties which the described issues bring with them, these challenges also provide huge opportunities in multiple ways, the sponge city concept is designed to utilize the opportunities, through (1) deploying tailored natural 3R methods and integrate this into a built environment; (2) focussing on low-cost, high-impact solutions that can be implemented by a wide range of stakeholders; (3) integrating green infrastructure in urban planning and design; and (4) creating a strong social movement through intensive engagement of multi-level stakeholders.

Figure 5. A range of aspects to consider when developing a Sponge Town

A Sponge City for instance provides the opportunity to create urban green spaces, which both contribute to water management as well as to recreation. In summary, a Sponge City means improved water management, improved safety, longevity of infrastructure, and beautification of cities. The overall aim is to create a better living place, one that is vibrant, green, and attractive.

In the case-study, we (i.e. the project team consisting of Nakuru County Government, NAWASSCO, VEI, and MetaMeta) selected three areas, London, Free Area, and Kaptembwo, (see Figure 6 and Table 1) in Nakuru that are linked to each other topographically and have a large share of low-income population–a total population of 105,608 people. We conducted a formulation phase for Sponge Town Nakuru's preparation, aiming to leverage ideas and solutions that are created by the people living in the town itself. Our aim is to organize the building blocks with which the residents, private sector, and governments can build their own sponge city.

Figure 6. Low-income density of estates/villages within the study areas

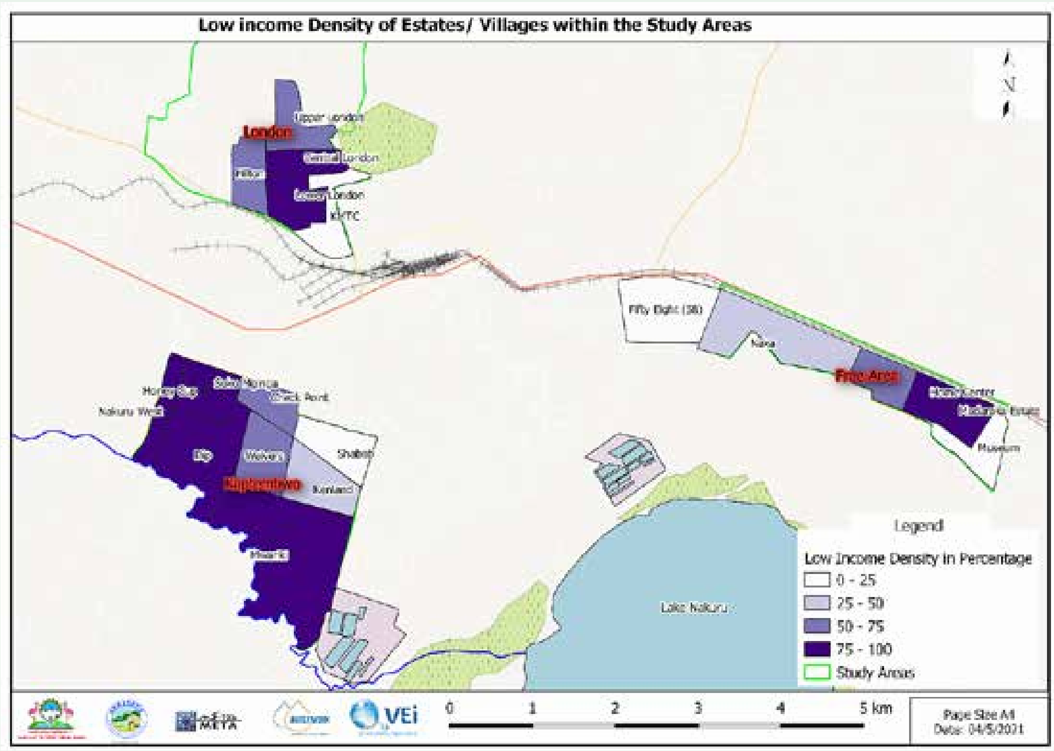


Table 1. Study Areas Characteristics

	Free Area	Kaptembwo	London	Total	Average
Population Size	46,004	43,521	16,083	105,608	
Number of HHs	14,469	15,351	4923	34,743	
avg. HH size	3.18	2.84	3.27		3.09
Population of low income	21,137	36,695	3,133	60,965	
% low-income	45.95	84.32	19.48		49.91

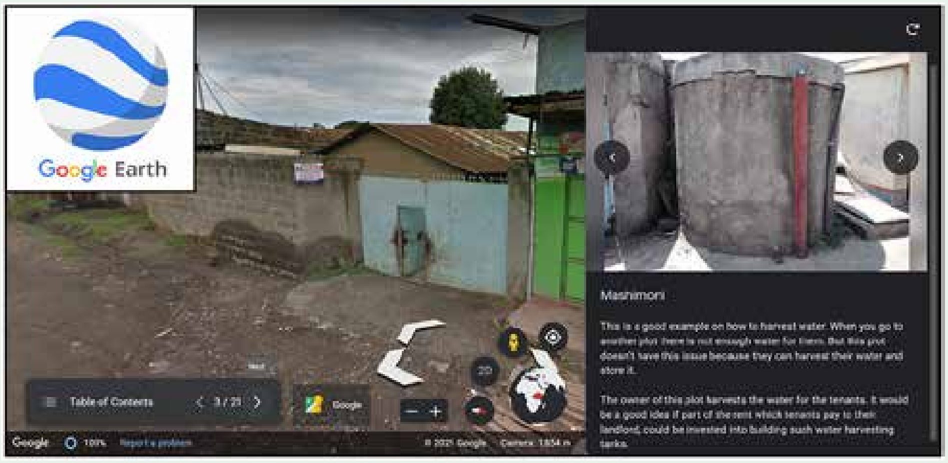
The 'mapathon' as a tool for community engagement

During the formulation phase, we have connected to many target stakeholders (180 in the baseline survey, approx. 150 through FGDs with community target groups and SMEs, 24 in the citizen Mapathon, 45 in the exchange visit and 20 in government meetings).

Figure 7. Mapathon as a tool for community engagement

Each has shared various ideas, as well as explained its own role to play and their contribution to make. In Nakuru, we used new tools to improve the inclusion of the 'voice of the resident' in urban planning. We did this through a mapathon, an event where residents are trained on digital skills to collect, share, and monitor data. These residents took us along on a journey through their neighborhoods. They made us look through their eyes, and better yet, they captured their stories and ideas in such a way that we could share it with other key stakeholders and decision makers who may not have the time or the ability to travel to their neighborhoods, but who do make major decisions which influence the quality of life in these neighborhoods. We used two platforms through which local knowledge and outer space can be connected: Google Earth combined with Kobo Toolbox.

Flooding and water shortage particularly occur in the low-income areas in the wards Kaptembwo, Free Area, and London. We had detailed discussions with residents from these areas on the two topics and the concept of 'sponge city' – applying 3R (retention, recharge, reuse) in the city to reduce these issues. These discussions were held with several community groups who were formed by residents to create change in their neighborhood and included residents from different backgrounds, abilities, age groups, and gender. The discussions include an introduction of the sponge city concept, brainstorm sessions, and planning sessions using maps of the areas. After these discussions, the residents traversed their neighborhoods in small groups armed with their phones and tablets to share what specific issues related to flooding and water shortage occur. However, while it is often easy to find what is wrong, it is more challenging to find out what to do to alleviate the problems. Therefore, when reporting on the issue, the ward residents also came up with potential solutions. These stories and ideas were collected through an app called, KoBo Toolbox, in which each story includes a GPS point and can be reported through photos, videos, and/or text. These information points were then transferred to Google Earth, resulting in a dynamic and visual map. Google Earth is known by many as an interactive map of the world that enables zooming in and out of areas which can be observed through highly detailed satellite images. However, the platform also includes a feature to make your own 'project'. This project creation tool is very user friendly and was used by the residents to turn their collected KoBo Toolbox data points into a cohesive story. They selected the most relevant pictures and videos and added descriptions. The viewer of this story can now click on 'next' and in doing so follow the residents on their walk through their neighborhoods, zooming in and out of areas with major issues and areas with great opportunities for improvements.



The result of this 3-day mapathon is a digital story where you can see the neighborhoods through the eyes of the residents. Through pictures, videos, and stories residents show us issues, good examples, and new solutions. You can join them on a journey through their neigbhorhoods by clicking here[5].

Technical and non-technical requirements for the implementation of the smart water technologies

The aim of our formulation phase is to prepare all stakeholders to transform Nakuru into Africa's first Sponge City by creating a critical mass of local support, investments, knowledge, partnerships, innovation, and commitment that will make a Sponge City and keep it running. The innovation does not lie in one single measure, rather the added value of a Sponge City lies in the holistic approach with a key role for residents, businesses, and authorities. The main lessons and findings include the following:

For the success of a Sponge City, social engagement is crucial. It is essential to include, engage, and work together with diverse and multi-level stakeholders. Each person has something to bring to the table, and it is vital to facilitate constructive discussions and collaborations between these different stakeholders. The social engagement process is as important as the technical solutions. Sponge city involves community in the entire process to ensure technologies are most appropriate to their particular settings, and that they are informed on the available options and the consequences of these choices on the long-term–in terms of maintenance, safety, and environmental impact. In this way, we respond to direct demand of communities in the delivery of facilities.

5. earth.google.com/web/data=Mj8KPQo7CiExNGJSR01mdkJ5RjhyYXFrSTVmTXphbm5HM FBKTFpWdGsSFgoUMDMxQTA2Rjk1RTE5N0I4OUZENTY

Figure 8. Snapshots from Nakuru Town where residents developed ideas and/or solutions

Furthermore, key stakeholders must be strengthened regarding their capacity to make informed technological choices. Hereby, it is important to strike a balance between necessary safety and quality standards on the one hand and local resources and management capacity on the other hand. Pay attention as well to strengthen the production, construction, and maintenance capacities of local providers as to be capable to respond to demands, opportunities, and ideas from consumers and investors. Sponge city service delivery will be simple, affordable, and adequate, linked to what is practiced and available. This is done by ensuring that constructions blend in with the local building style, using locally available materials and skills, meeting the need of women, children, the elderly, and handicapped.

We use a rights-based approach. Through local lobbying, advocacy, and budget tracking, communities will be empowered to express their needs and demands to the authorities for adequate budget allocation and use. Civil society organizations will be supported to translate needs and demands at grass roots level into advocacy messages to influence county government policies and budget allocations, as well as function as watchdog to hold responsible authorities accountable.

Financing is required to provide and sustain Sponge City investments at city, private, public, community, and business level. Market forces must be recognized and appropriately considered, so that small enterprises have the opportunity to flourish when properly addressing water and sanitation in a locally regulated business sector. The main financial principle of a sponge city is Local Finance First. We work towards models in which investment costs are covered as much as possible through local funding sources (consumers, the public sector, private investors, through household contributions, recurrent tax revenue, fee systems, decentralized funds, and loans from local finance institutions, like banks).

Local/regional government must be at the forefront and take charge of the interventions, enabling to leverage on existing policies and institutions.

In Nakuru, the County is upfront in improving the enabling environment by opening opportunities for communities and private sector players to engage and improve the resilience of the city. The County recently assented The Nakuru County Water and Sanitation Services Bill, 2020, which seeks to provide a legal framework to guide water and sanitation service providers. In the bill, Sponge City is explicitly mentioned as intervention towards water sustainability and safety. Furthermore, an Integrated Water, Sanitation, Faecal Sludge and Wastewater Master Plan for Nakuru County is being developed. In addition, the County has passed 3 water bills, among them The Nakuru County Climate Change Bill (2020).

Policy implications and recommendations or next steps

It is not easy to foresee how a city or city will evolve, especially not a fast-growing one in Kenya which often evolves very organically. Therefore, we don't want to get lost in future-blueprints; rather, we ensure the building blocks are future-proof. In order to do so, we must develop progressive legislations that create an enabling environment (e.g. water sensitive construction permits and installing Community Environmental Volunteers) and that make large scale public interventions possible (e.g. blended finance, green taxes).

A second recommendation is to put the residents of the town or city in the driver's seat. They are the ones living there; they will feel the change day-by-day and are always 'on-site' to make a change. Through a process of intensive and inclusive social engagement, we lay the foundation for sustained commitment and contributions.

A third recommendation is to focus on low-cost technologies, with high impact, which can be provided by local businesses and skilled people. When you source from within, a town or city can also be developed economically.

Lastly, we encourage you to be creative in engaging people and making it fun; this opens both doors and minds. The mapathon is an example of an inspiring tool in the project that ensured collaboration, ownership, and valuable input from the participants straight from the start. Next, it can be used to track the progress of the project, to monitor the project, and evaluate it, especially if the participants have their own smartphones. This can be done continuously to see where the project needs to be tweaked and identify where things are not working out as planned. Finally, it is a great method for reporting. It is often more enjoyable and engaging to travel through a google earth story than to get stranded in a 10,000-word report.

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Acronyms

3R – Retention, Recharge and Reuse
ASAL – Arid and Semi-Arid Land
FGD – Focus Group Discussion
HH - Household
NAWASSCO – Nakuru Water and Sanitation Services Limited
SDG – Sustainable Development Goal
SME – Small and Medium Enterprise
SSA – Sub Saharan Africa
WASH – Water, Sanitation and Hygiene

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Summarized inventory of sponge city techniques

Measure	
Rooftop water harvesting	Traditional system to harvest runoff water, mostly for domestic use.
Recreational wetlands	Develop a water retention and storage site in combination with a recreational park.
Urban farming	Enhance growing of vegetables in a small, efficient garden, with the water harvested from the roof, or from the compound. Possibly in combination with grey water reuse.
Groundwater / wellfield recharge	Deploy tube-well recharge to augment groundwater sources, especially those already in use, but with low yield.
Sand dams and sub-surface dams	Barriers in sandy seasonal streams are a simple way to augment the amount of water stored in the sand, which can be harvested through simple wells and scoop holes.
Bioswales (bunds)	Can be used to trap sheet runoff and augment infiltration.
Raingardens	As alternative or in conjunction to rooftop water harvesting, the water can be used to nurture homestead/school gardens.
Road drifts	Low causeway can become a simple way to recharge shallow groundwater while decreasing road damage.
Culverts	Culverts orientation, number and design commonly define drainage patterns and can be therefore engineered to channel water to recharge/retention areas.
Irish bridges	Irish bridges can be turned into multi-functional infrastructures where they double up as sand dams, storing sand, thus storing water and acting as a buffer against floods.
Small reservoirs	Multipurpose small reservoirs can retain water to be used during the dry season. Special care must be paid to water quality.
Recharge basins	Storm water can be retained in permeable basins that help to recharge shallow groundwater and to buffer peak discharge.
Permeable paving	Permeable paving with cobble stones is functional in decreasing peak runoff and in increasing infiltration.
Water from roads	Roads divert and concentrate big volumes of runoff water. The road surface and the adjoining drains can be used to redirect water for recharge or for productive uses.
Roadside planting	Storm water can be diverted to trees, strategically planted along roads.

New York City (USA)

New York City: A Smart Water City case study

Alan Cohn and John Brock

New York City (USA)

Abstract

New York City faces a variety of urban water challenges that require innovative solutions. As New York City's water and wastewater utility, the Department of Environmental Protection (DEP) holds the critical mission of enriching the environment and protecting public health for New Yorkers by providing high quality drinking water, managing wastewater and stormwater, and reducing air, noise, and hazardous materials pollution. Longstanding challenges and stressors, including budgetary pressures, make it more difficult for DEP to balance regulatory requirements with the growing need to invest in climate resiliency and sustainability, while also maintaining customer affordability. Innovative water technology solutions that consider all aspects of water management are necessary for DEP to optimize resources and achieve multiple objectives.

Introduction

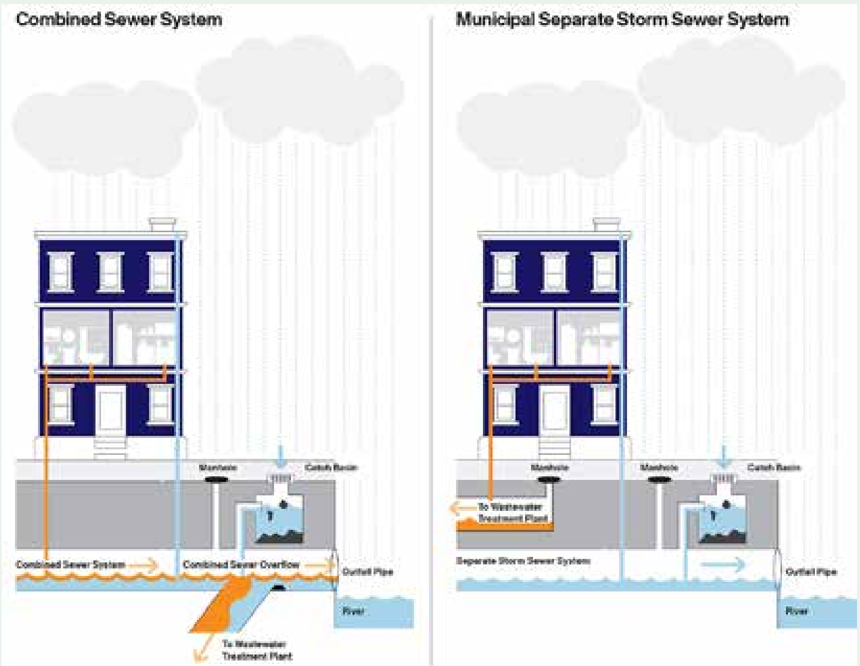
New York City's water supply system is comprised of 19 reservoirs and three controlled lakes spread across a watershed that spans over 5,000-square kilometers (see Figure 1). Today, DEP delivers approximately 3.8 billion liters of high-quality drinking water to more than eight million NYC residents, visitors, and commuters, as well as to one million upstate customers. Throughout its history, New York City's ability to provide a reliable source of water for its citizens has allowed it to grow and develop into a great urban center.

Figure 1. New York City's Water Supply System

New York City's wastewater treatment system consists of over 9,500 kilometers of sewer pipes, 135,000 sewer catch basins, 495 permitted outfalls, and over 90 pumping stations that transport wastewater to one of the city's 14 wastewater resource recovery facilities located throughout the five boroughs. DEP treats approximately 5 billion liters of wastewater per day.

Like many older cities, New York City is partially served by a combined sewer system in which pipes accept a combination of sewage and stormwater flows. The combined sewer system serves approximately 60 percent of New York City by land area. In dry weather, practically all of New York City's sewage is treated. During rainfall, however, the added volume of stormwater can exceed the capacity of the sewer system. This can result in untreated overflows from relief structures that are designed to protect the biological treatment process in treatment plants and to prevent sewage backups and flooding. This is what is known as combined sewer overflow (see Figure 2), or CSO, and can have effects on water quality and the recreational use of local water bodies.

Figure 2. Combined Sewer Overflow During Wet Weather



In many regions, including the Northeast United States, a higher percentage of total annual rainfall is occurring in the form of heavy downpours. Climate projections suggest that annual precipitation in New York City will likely continue to increase (NYC Panel on Climate Change, 2015). DEP's current stormwater programs have been successfully managing the rainfall events for which they are designed. However, typical stormwater infrastructure is not designed to manage heavy downpours, mainly due to space constraints. As New York City continues to experience increases in the frequency of heavy rainfall events which exceed the capacity of current stormwater infrastructure systems, increases in combined sewer overflows and flooding may also occur.

Additionally, as New York City continues to grapple with the consequences of climate change, opportunities to ensure the resiliency and reliability of our water supply system must continue to be identified. Reducing water demand benefits the water supply system and New York City at large by increasing flexibility in operations, reducing our energy footprint and greenhouse gas emissions (from treating less drinking water and wastewater), and keeping water bills affordable. DEP is the lead agency not only for delivering drinking water, but for ensuring its sustainable use by optimizing existing resources and maximizing co-benefits with a holistic, One Water approach.

Characteristics of the city

Location: Northeast United States
Size: 784 square kilometers
Density: 70,000 people per square kilometer (NYC Department of City Planning, 2021)
Socio-Economic development:

- GDP: $1.7 trillion, GDP per capita: $71,084 (Bureau of Economic Analysis, 2017)
- Life Expectancy: 81.3 (NYC Department of Health and Mental Hygiene, 2018)
- New York Literacy Rate: 77.9% (World Population Review, 2021)
- Unemployment Rate: 10.6% (NYS Department of Labor, 2021)
- Speed of urbanization: 2.7% increase from April 2010 – July 2018 (NYC Department of City Planning, 2018)

Key urban water challenges

Water supply

The New York City watershed is in portions of the Hudson Valley and Catskill Mountains with areas that are as far as 200 kilometers north of New York City (see Figure 1). Since 2009, average daily demand has been below the 1960s drought-of-record (when demand was approximately 4 billion gallons per day) with demand in 2020 hitting a 60+ year low, due in part to the COVID-19 pandemic and associated closures. While New York City is considered water-rich, DEP has actively been seeking ways to reduce drinking water demand and to prepare for a major infrastructure improvement project to repair leaks in one of the city's largest water distribution tunnels. In addition to providing a critical buffer prior to and during repair work, lower demand will also help optimize reservoir water levels during times of drought, offset energy and greenhouse gas emissions associated with pumping and treatment, and reduce flows to the sanitary and combined sewer systems (NYC Department of Environmental Protection, 2021).

Harbor water quality

As stormwater flows, it sweeps up pollutants such as oils, chemicals, sediments, pathogens, and trash. During wet weather, these pollutants can flow into the city's waterbodies and greatly impair water quality. DEP oversees a broad citywide effort to better manage stormwater to improve the health of our local waterbodies and prevent flooding. Since 1909, the city has monitored the waterbodies of New York Harbor through its Harbor Survey Program which collects water quality data and tracks progress of improvements efforts. Investing in new infrastructure, while also pioneering advancements in wastewater treatment, water reuse, and resource recovery is critical for the continued improvement of the city's waterbodies. Over the last several decades, the city has invested more than $45 billion in the construction and upgrade of critical wastewater and drainage infrastructure to improve the health of our city's vital ecosystems. In recent years, the city has committed an additional $10.6 billion to continue the legacy of innovation and investment to usher in a new era of environmental protection for its waterbodies. Today, New York Harbor is cleaner than it has been at any other time in the last 100 years, but more work is needed (NYC Department of Environmental Protection, 2018).

Climate resiliency

New York City experiences combined sewer overflows with each moderate rainfall and flooding during heavy rain events. Extreme rainfall events are becoming more frequent and disruptive in New York City and beyond. According to The National Climate Assessment, which summarizes current and future impacts of climate change on the United States, the heaviest 1 percent of daily rainfalls increased by 70 percent in the Northeast United States between 1958 and 2012. Climate projections suggest that this trend will continue, and that New York City will likely experience increased precipitation in the future. The New York City Panel on Climate Change (NPCC) anticipates that by the end of the century, the city could experience as much as 25 percent more annual rainfall than today and 1.5 times as many days with more than one inch of rain (NYC Panel on Climate Change, 2015).

Climate change will affect water resources in New York City from the upstate watershed to New York Harbor. It will demand an innovative response by the city's water managers, planners, and regulators to meet stringent water quality standard requirements while advancing the city's sustainability and resiliency objectives. As the largest municipal water utility in the United States, in a city with over 830 kilometers of at-risk coastline and approximately 5,000 square kilometers of watershed protecting drinking water, DEP must find new ways to maximize investments by incorporating the latest climate science, affordability, population, and water demand projections, tightening regulations and associated uncertainty into our planning.

Innovative smart water technology solutions

New York City Water Demand Management Program

DEP's Water Demand Management Plan identifies six key strategies for managing water demand in New York City and details specific initiatives to be implemented through 2023. Since the release of the plan in 2013, DEP has invested over $50 million to achieve water savings of over 60 million liters per day (MLD) and continues to make progress towards achieving the program's 75 MLD water savings goal.

DEP utilizes automatic meter reading technology (AMR) to track water consumption and progress across the Demand Management Program. In 2009, DEP launched its AMR program and largely completed that effort in 2012. DEP has installed approximately 829,000 AMR transmitters, representing 99% of DEP's AMR installation target. As DEP moved to AMR, meter readings changed from four times a year to at least four times a day and often, hourly. This has allowed DEP to establish citywide water consumption trends, identify opportunities for conservation, detect leaks, and track the progress of water conservation programs. AMR also allows customers whose accounts have been upgraded for AMR to access details of their water usage through DEP's website.

As part of the Demand Management Program, DEP established partnerships with fellow city agencies to ensure that water is used as efficiently as possible in city-owned facilities. These programs and partnerships have allowed DEP to advance smart water technologies, such as water reuse. Water reuse reclaims water from a variety of sources and treats and reuses it for beneficial purposes. This can provide alternatives to existing water supplies and be used to enhance water security, sustainability, and resilience. DEP has implemented several innovative water reuse projects with our municipal partners. DEP also established a Water Conservation and Reuse Grant pilot program as incentive to private properties. While the primary goal of this program is to conserve potable water, on-site water reuse also offers opportunities for achieving co-benefits and is an important part of DEP's One Water approach towards managing water resources. For example, water conservation and water reuse projects reduce flows to the sewer system and wastewater facilities, which can contribute to reductions in combined sewer overflows.

For example, DEP worked with the New York City Fire Department (FDNY) to install a new facility to recycle water used to test and calibrate the meters and equipment of the fleet's pumper truck rig. FDNY's vehicles need to be tested prior to being accepted into the fleet to make sure they are in working order and once a rig is in service, require testing and calibration once a year. These tests would typically use water that would then drain directly to the East River, or to catch basins connected to a sewer. To improve this process, the new water recovery facility creates a closed loop system, so that used water can be recovered and reused, instead of relying solely on potable water. This project is estimated to save over 110,000 liters of water per day.

DEP also supported a reuse project in partnership with Brooklyn Botanic Garden (BBG) by providing funding for a pump system as part of a stream restoration project that conserves water and reduces discharge to the combined sewer system. The stream restoration project, called Belle's Brook, reduces BBG's outdoor consumption for its water features from over 80 million liters per year to less than four million liters, a reduction of over 200,000 liters per day.

DEP is currently working with the Central Park Conservancy and Department of Parks and Recreation on the North End Recirculation Project in the iconic Central Park. This project is estimated to save over 3 MLD of potable water by recirculating stormwater rather than potable water between the park's northern waterbodies. In addition to the potable water reduction, other benefits include improved water quality in the park's northern waterbodies and combined sewer overflow reduction of over 10 million liters per year to the East River.

To promote additional measures on private properties, DEP is also offering the Water Conservation and Reuse Grant pilot program to offset capital costs for projects that save at least 3.7 million liters of water per year. As part of this program, DEP is supporting a first-of-its-kind, 1.5 MLD district-scale reuse system that not only reduces demand on New York City's potable water supply system, but also cuts flows to the combined system by an estimated 99 percent. Currently, DEP is seeking new and innovative ideas, technologies, and approaches for how stormwater can be successfully captured and treated to optimize benefits, reduce risks to public health, and promote co-benefits (NYC Department of Environmental Protection, 2021).

Wet weather management and climate resiliency

DEP has been committed to investments and policy changes for drainage improvements, green infrastructure, and on-site stormwater management, which have the added benefit of reducing the amount and slowing the rate of stormwater entering the city's sewer system. The 2010 Green Infrastructure Plan provided a detailed framework and implementation plan to meet the twin goals of better water quality in New York Harbor and a livable and sustainable New York City. Green Infrastructure diminishes the impacts of heavy rain events by capturing the rain runoff from normal rain events. The Plan launched the New York City Green Infrastructure Program, which has implemented over 10,000 green infrastructure practices, managing over 1,200 "greened acres" (approximately 3,500 cubic feet) which are constructed or currently in construction (NYC of Environmental Protection, 2020). Through the Program, DEP has formed important relationships with city agencies and expanded sustainable stormwater management principles to streets and public spaces. The Program has three primary implementation areas:

- **Right-of-Way (ROW) Green Infrastructure**: In 2012, DEP launched area-wide green infrastructure projects, in partnership with other city agencies, and has achieved most of the stormwater management through the installation of ROW practices such as rain gardens and infiltration basins.
- **Public Property Retrofits:** DEP, in partnership with other city agencies, is developing green infrastructure projects on almost 200 publicly owned properties.
- **Private Property Initiatives:** DEP's Green Infrastructure Grant Program offers funding for the design and construction of green roof retrofits on private property in New York City.

In addition to traditional green infrastructure, innovative drainage solutions, such as the Bluebelt Program, have also been developed. Bluebelts are ecologically rich and cost-effective drainage systems that naturally handle the runoff that falls on our streets and sidewalks by preserving natural drainage corridors including streams, ponds, and wetlands, and enhancing them to perform their functions of conveying, storing, and filtering runoff precipitation or stormwater. As New York City prepares for rising sea levels and heavier rains due to climate change, Bluebelts offer a natural and effective solution for stable and sound stormwater management. However, while Bluebelts are effective, they still do not address larger, extreme storm events and additional means are required to handle larger storm volumes.

In 2015, DEP partnered with the City of Copenhagen to share knowledge on innovative solutions that can prepare the New York for heavier and more frequent downpours or "cloudbursts" brought about by climate change. As part of this collaboration, DEP initiated the Cloudburst Resiliency Planning Study to assess risks, prioritize response, develop neighborhood-based solutions, and assign costs and benefits for managing cloudbursts. As a result of the Cloudburst Resiliency Planning Study two pilot projects were identified in the neighborhood of Southeast Queens, an area for which the city has committed $1.9 billion to build a comprehensive drainage system and alleviate flooding and to help demonstrate the feasibility of implementing the cloudburst approach.

One of these projects is located at the South Jamaica Houses, which is an 8-block public housing campus in South Jamaica, Queens, and is home to approximately 2,600 residents. This project will maximize stormwater capture for almost 6 cm of rainfall per hour. In addition to flood mitigation, another focus of this pilot is to show how cloudburst infrastructure can go beyond just managing stormwater and offer many co-benefits by reimagining the urban fabric of communities. This innovative approach utilizes interconnected, below- and above-ground rainwater conveyance and storage. Cloudburst projects aim to supplement ongoing sewer buildouts and act as a buffer for storms not captured by sewers due to the size of the storm, or the lack of fully built-out storm sewer infrastructure (see Figure 3). This would reduce flooding in areas where traditional infrastructure takes longer to implement and will alleviate chronic flooding of adjacent areas (NYC Department of Environmental Protection, 2017).

Figure 3. As part of the South Jamaica Houses cloudburst pilot project, an existing basketball court will be excavated to create underground water storage and repair the surface. The new "cloudburst" design will lower the basketball court, allowing it to fill with water during extreme rain, and will provide a new seating area for residents.

In 2021, New York City Released the Stormwater Resiliency Plan, which outlines the city's approach to managing the risk of extreme rain events. Truly holistic planning for rain-driven flooding involves consideration of both large storm events and the chronic worsening of average conditions. For this reason, the plan addresses emergency response procedures as well as accounting for increasing rainfall in standard design and long-term planning of stormwater infrastructure. The plan commits to four goals that optimize emergency response to extreme rainfall events and ensure that future city investments manage this climate risk:

1. Inform the public about flood vulnerability from extreme rain;
2. Update NYC's flash flood response procedures to prioritize response in vulnerable areas;
3. Advance policies that reduce urban flooding as well as research that informs future risks;
4. Leverage stormwater investments to help manage future flood risk from extreme rain and sea level rise. Future investments can alleviate flooding throughout the city.

For this plan, NYC performed a first-of-its-kind citywide analysis of rainfall-induced inland flooding. Modeling this type of flooding requires consideration of multiple urban flood drivers including the development of representative rainfall hyetographs (a graphical representation of the distribution of rainfall intensity over time), consideration of tidal conditions and climate change, and an understanding of localized sewer network capacity and overland drainage pathways. These components are complex individually, and when combined and considered on a city-wide scale, require detailed hydrologic and hydraulic (H&H) models to evaluate and predict flood risk. Through this modeling effort, New York City produced stormwater flood maps that depict areas of predicted rain-driven flooding to help New Yorkers understand and prepare for this risk. These maps will help individual New Yorkers understand risks related to extreme rainfall events and the city to prepare for future long-term investment and target that investment towards implementing innovative solutions in the most flood-prone areas.

New York City is working to improve water quality and address urban flooding through an integrated stormwater management approach that ensures long-term resiliency and reliability for communities. Interconnected networks of stormwater infrastructure that work together to convey, store, and filter stormwater can play an important role in mitigating flooding and improving water quality, as well as provide several co-benefits to communities (NYC Mayor's Office of Resiliency, 2021).

In addition to infrastructure solutions for managing stormwater, DEP offers innovative technologies to engage the community. In 2016, DEP launched the Wait... Program, which is a voluntary text messaging program that notifies participants when to use less water during a heavy rainstorm to reduce sewer overflow to waterways. Wait... engages an active environmental community and helps illustrate that individual actions can have an impact on waterbodies. During heavy rainstorms, the Wait... Program sends text notifications to participants informing them that sewers are at capacity and to wait to use water until after the rain. Participants then receive a second text alert notifying them that the rain has stopped, and they are clear to resume using water responsibly. After two successful pilot programs, DEP is currently in the process of developing a smart phone application for the Wait... program that will be deployed citywide.

Technical and non-technical requirements

CSO Consent Order: On March 8, 2012, the New York State Department of Environmental Conservation (DEC) and DEP signed a ground-breaking agreement to reduce CSOs using a hybrid green and gray infrastructure approach. As part of this agreement, DEP agreed to develop 10 waterbody-specific Long-Term Control Plans (LTCP) plus one citywide LTCP to reduce CSOs and improve water quality in NYC's waterbodies and waterbodies. The goal of each LTCP is to identify the appropriate CSO controls necessary to achieve waterbody-specific water quality standards, consistent with the Federal CSO Policy and the water quality goals of the Clean Water Act. As a result of this agreement, DEP is targeting to reduce CSOs by 6.32 billion liters per year by 2030.

Delaware Aqueduct Shutdown: DEP has monitored two leaking sections of the Delaware Aqueduct since the early 1990s, which release an estimated 75 million liters per day. The 137-kilometer-long Delaware Aqueduct, the longest tunnel in the world, typically conveys about half of New York City's drinking water each day from reservoirs in the Catskills. To make needed repairs, the aqueduct will need to be temporarily shut down to construct a bypass tunnel that will be connected to structurally sound portions of the existing Delaware Aqueduct to convey water around a leaking section of the tunnel. To offset water demand during this shutdown, DEP has targeted a 75 million liter per day reduction by 2023.

Local Law 172: In 2018, the New York City Council passed Local Law 172 which required the city to produce maps showing areas of the city most vulnerable to increased flooding due to the anticipated effects of climate change, and to publish a long-term plan to prevent or mitigate such increased flooding. Consistent with the Local Law, the 2021 Stormwater Resiliency Plan and maps will be updated at least every four years, and periodically as new modeling is available and as climate change projections are updated.

Policy implications

DEP has spent billions of dollars to create extra capacity through gray and green infrastructure but achieving the goals of a clean harbor and mitigating flooding is becoming more costly and impacting rates, which have increased 50 percent since 2010. While still affordable for most at 0.4 cents per liter, there is a disproportionate impact on low-income communities. This has led to a need for further innovation and promoting projects that offer multiple co-benefits, therefore helping the city to achieve multiple objectives and maximize every dollar of capital funding.

DEP has already established a powerful business case for innovative water technologies, such as green infrastructure and water reuse, by showing that they can help relieve pressure on water systems, reduce combined sewer overflows, save property owners money, and create green jobs. By considering the interconnectedness between all aspects of water management through a One Water approach, DEP is positioned to invest in the future of New York City by promoting affordability, climate resiliency, and sustainability for all its residents.

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Ningbo (China)

A Pilot Project of Smart Water City in Ningbo, China

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Ningbo (China)

Abstract

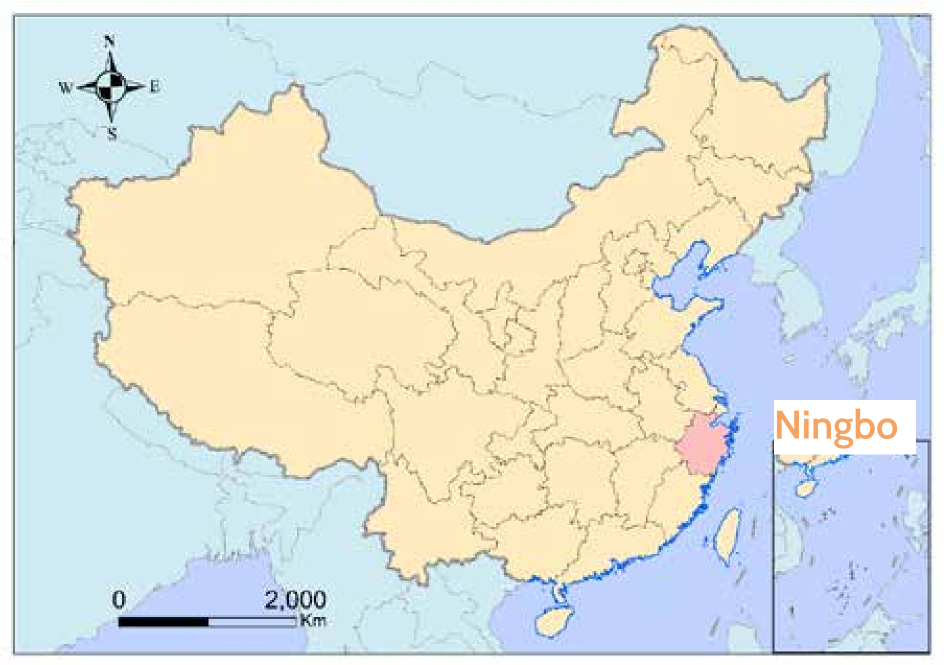
The global water crisis and challenges are well recognized around the world. As a result, there is an urgent need to fight against such mounting water pressures, and smart water technology enables water sector to transit towards a new paradigm that can help to address the degradation of water resources, water ecology, water environment, and water disaster in a coordinated way. Smart water innovation is firmly embedded in the transition of water resources management in Ningbo where lies in the coastal line of the East China's Zhejiang province and is more susceptible to typhoon flooding and coastal flooding. This paper gives a brief and general information on water status, Pilot Project of Smart Water City, and key elements for supporting the implementation of the Project. Although it addresses some challenges, such as it prohibits the progress Ningbo's smart water revolution, the paper also provides four aspects that may help the in a position and profound direction. Ningbo is actively embracing digitalization and intelligence in order to support the effective implementation of transforming and optimizing water, and the city is therefore advancing water security and sustainability in China.

Introduction

Smart water refers to a movement in the water industry involving emerging technology that helps to solve problems through automation, data gathering, and data analysis. Its application in water management potentially provides solutions for leak detection, efficient irrigation, energy efficiency, water quality, water quantity, water quantity, floods and more. The "smart water" has become a promising aspiration and provides a platform for more efficient technology use and more informed decision making (IWRA, 2017).

The development of intelligent technologies is becoming an area of increasing interest and shows a rapid growth in China. It is at the forefront to deal with both the existing and the upcoming urban challenges in many of coastal cities. Its continuous expansion and application provide strong technical support for water management and the smart principles have started integrating into many local, regional, and national strategies. The Ministry of Water Resources of China has paid great attention to the construction and development of a Smart Water City. The Ministry selected 3 pilot Smart Water Cities in March 2020. They include where Ningbo lies in the coastal line of the East China's Zhejiang province and in the South of the Yangtze River Delta (The Ministry of Water Resources, 2020) (see Figure 1).

Figure 1. Ningbo's Location in the Map of China (Source GIWP, 2021)



Ningbo has a territorial land area of 9,816 km^2, a territorial oceanic area of 9,758 km^2, and a total coastline of 1,562 km (OECAN EXPO, 2020). As of 2019, Ningbo has permanent residents of 8.5 million, and is considered to be the most developed economy in China with GDP of 1.2 trillion RMB ($173.69 billion) (The People's Government of Ningbo Municipality, 2020).

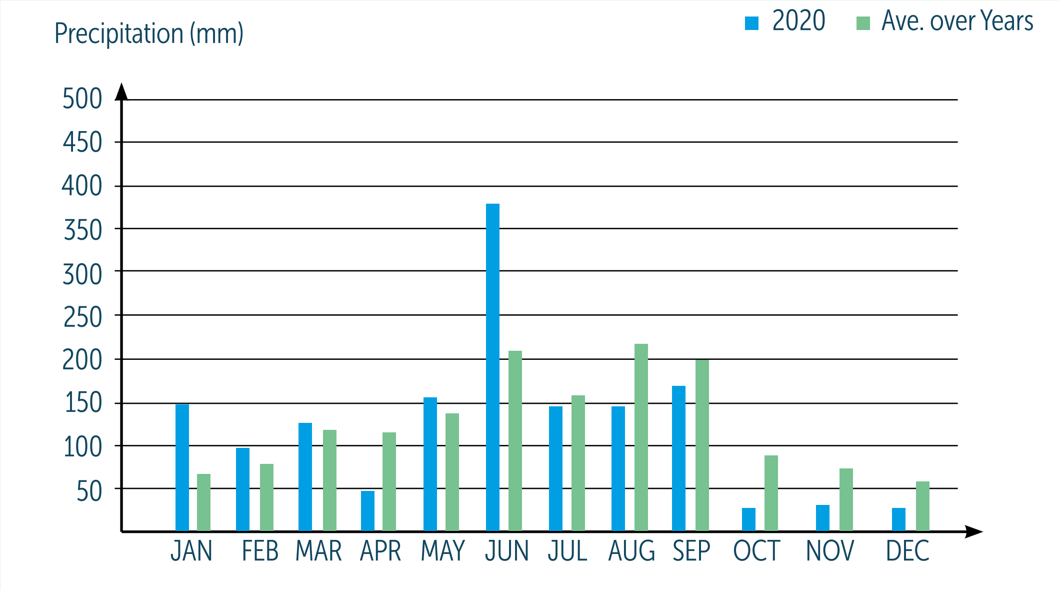
Ningbo is a local commercial center, a hub of a water-transportation network of coastal traffic and canals, and most importantly, it connects to the world as a port city. Among the 102 historical and cultural cities in China, Guangzhou, Quanzhou, and Ningbo are most famous for their deep involvement in the Silk Road on the Sea. There is a record that indicates communication between Ningbo and Japan and Korea and Southeast Asia in past centuries. Thus, Ningbo has been continuously promoting leading enterprises in the marine economic industry which will eventually contribute to the economic and social development of Ningbo (The People's Government of Ningbo Municipality, 2020).

Water status in Ningbo

In 2020, the total amount of water resources in Ningbo is 8.07 billion m^3, the total amount is 41.8% less than 2019 and 3.1% less than the average value. The total water supply is 2.101 billion m^3 including 2.059 billion m^3 of surface water, 41 million m^3 of sewage treatment and rainfall, and 0.1 million m^3 of groundwater. The total water use is 2.101 billion m^3 - an increase of 2.8% than 2019. It consists of 507 million m^3 of domestic water use, 1.536 billion m^3 of industrial water use, and 58 million m^3 of ecological water use, and the water use per capita is 246 m^3. However, the total water consumption[1] contributes to 54.2% (1.139 billion m^3) of the total water use (Ningbo Water Resource Bulletin of Year 2020, 2021).

1. Water consumption is the portion of water use that is lost into the atmosphere through evaporation or incorporated into a product or plant and is no longer available for reuse.

Figure 2. Monthly rainfall in Ningbo (Source Ningbo Water Resource Bulletin of Year 2020, 2021).



Ningbo enjoys a subtropical monsoon climate featuring high relative humidity but distinctive seasons. In 2020, the city receives an average annual rainfall of 1,507 mm but the spatial and temporal distribution of rainfall is extremely uneven (Figure 2), showing the rainfall is more in the North than in the South and is affected by the plum rains of the Asian monsoon in Summer (Ningbo Water Resource Bulletin of Year 2020, 2021).

Because of meteorological and geographical factors, Ningbo often experiences water-related disasters including typhoons, rainstorms, high tides, and floods, with complicated causing factors. Since 1950, there were forty-four typhoons have affected Ningbo, resulting in a total economic loss of more than 93 billion RMB (Tong et al., 2007). From 2000 to 2020, the Emergency Events Database (EM-DAT) reveals that an average of 10 typhoon-related tropical cyclones were registered in China per year, and China's southeast coastal cities (e.g., Ningbo) are more susceptible to typhoons that can lead to severe waterlogging and long-term and large-scale interruptions of traffic and power (Yao, et al., 2021). Also, according to Hanson et al. (2011), Ningbo was ranked one of the top 20 global port cities most prone to flooding risk during the typhoon season when tidal surges and intense rainfall events occur more frequently, and the risk of coastal flooding will rise by 2050 because of population growth, urbanization expansion and land subsidence.

Alongside with the development of the new generation of internet of things, cloud computing, big data, and other cutting-edge technologies, the People's Government of Ningbo Municipality aims to improve the integrated management of water resources and enhance the decision-making ability by addressing innovative smart water technology solutions. The city also strives for preparing prewarning protocols and setting up emergency plans of water crisis, such as storage of disaster relief materials, public promotion of typhoon prevention measures, timely release of early warning information, and relocation from inhospitable and dangerous areas; therefore, the government and the public can be highly aware of water-related disasters and take necessary precautionary actions (Yao, et al., 2021).

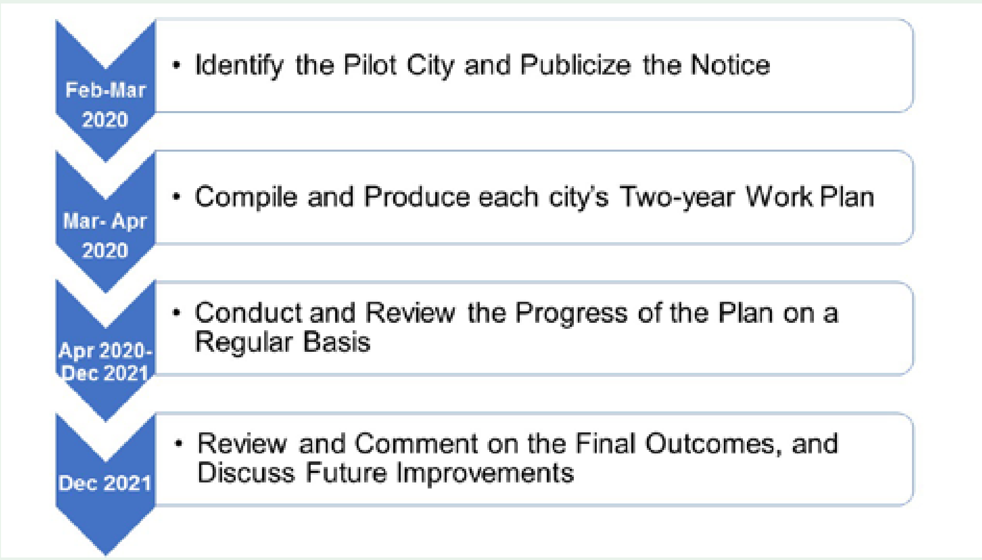
Pilot project of Smart Water City

General background

The rapid growth of smart water is the concrete reflection of invigorating the nation. It is the key approach of achieving the revolution of the water sector and is also the significant indication of high-quality development of water resources. In this context, the Ministry of Water Resources issued the Notice on the Implementation of the Pilot Project of Smart Water Management in March 2020. Shenzhen, Ningbo, and Suzhou were selected as the pilot city to conduct smart water technologies, such as sensors, Internet of things, smart meters, big data, 5G, video monitoring, GIS, remote sensing, satellite mapping, blockchain, and other data sharing tools to steer the development of smart water management that can be implemented to reduce current water management challenges and to strive for urban modernization.

The Notice clearly indicates timeframe and requirement for the pilot project (see Figure 3). It also proposes that as of the end of 2021, these pilot cities should produce cases of excellent application and typical solutions of smart water technologies that can be up-scaled and replicated in a broader range–therefore making continuous breakthroughs, promoting innovative collaboration, and fostering good and healthy growth of the smart water technologies in China (Ningbo Water Resources Bureau, 2020).

Figure 3. Timeframe of the Smart Water Project



Work plan for Ningbo

The project of smart water technology development

The aim of the project is to satisfy the intelligent needs of multidisciplinary fields and levels. It developed an overall framework of "One Cloud, One Network, One Center and Two Platforms" (1+1+1+2) that strives for information services, information security, information sharing, business collaboration, and intelligent application. One Cloud is a cloud platform that helps local government to arrange project-related affairs in a whole picture. One Network means real-time monitoring by developing an Internet of things for water resources. One Center refers to a smart water data center that aims to centralize the data for sharing and research. Two Platforms include an application support platform and an integrated application platform to enhance the analysis ability and refined management (Ningbo Water Resources Bureau, 2020).

The project seeks to make future advancement in the following five aspects: the construction of Internet of Things in water, the construction of data centers and a technical support platform, the construction of an integrated application platform of smart water technology, the construction of basic operation environment system, and the construction of regulatory system. In terms of reinforcement of digitalization, the above aspects have been incorporated and integrated in six key fields: flood and drought disaster prevention, river and lake management, water-related project management, water resources management, hydrological management, and public service. With the assistance of smart water technology, the project was designed to achieve the mechanism of wide consultation, joint contribution, and shared information between Ningbo and its subordinate counties (The Ministry of Water Resources, 2021).

In January 2021, Phase I of the project has officially put into operation. This phase has achieved remarkable results that have been widely recognized by the public and the government. It firstly strengthens the ability of preventing flood and drought disaster. The project has formed one flood risk map of the whole city and built an integrated management platform of flood risk at both the provincial and county level. Phase I effectively improves the real-time flood risk early warning function by simulating the flood process of rivers and develops the early warning function of mountain torrent disaster. Secondly, it enhances the ability of water resources management. The project integrates the data information of 50 reservoirs and 62 water supply plants in Ningbo and constructs an early warning analysis model of the supply and demand between reservoir and water supply plants. The model generates the water allocation scheme within 20 seconds, which can provide scientific support for urban network water supply and cross regional water diversion project. Thirdly, it increases the management ability of rivers and lakes. The project aims to classify the management of rivers and lakes at city, county, and township level, therefore having a holistic grasp the overall situation of rivers and lakes in Ningbo. The project relies on intelligent video analysis technology to carry out intelligent inspection of rivers within 3-5 minutes, and the problem can be automatically alarmed, which greatly improves the efficiency of river inspection. Last but not least, Phase I improves the ability of risk management and control because the information management facilitates the whole life cycle management of water-related projects through the perspective of planning, construction, quality supervision, operation, and safety production. It allows monitoring, review, evaluation, and assessment of the safety risk management and control (Information Center of the Ministry of Water Resources, 2021).

The People's Government of Ningbo Municipality takes Phase I as a good reference, and Phase II will add 400 new basic perception monitoring sites and further explore 10 intelligent smart water technology application scenarios to continuously focus on the key fields of water resources, upgrade the smart water technology, give full play to the project benefits, and strive to produce local, innovative, and emblematic achievements for Ningbo (Hydrological Information Annual Report of Year 2020 in Ningbo, 2021). Ningbo will complete the construction of pilot project of a Smart Water City by the end of December

2021 with high quality standard to achieve the overall goal of "visible, calculable, adjustable, and verifiable" (Information Center of the Ministry of Water Resources, 2021).

Application in key and prior fields

Ningbo is particularly focused on the monitoring, forecasting, and early warning of flood disaster by using the advanced information technology. It reflects the typical needs for Ningbo. Therefore, in Phase I, there are some applications with Ningbo's local characteristics that have been put into real practice.

First, is the application of dynamic flood risk map in water disaster prevention. By using the Internet, big data, cloud computing, and other advanced technologies, and integrating multi-source and multi-scale meteorological forecast results and models, a set of coastal city dynamic flood risk analysis, prediction, and early warning system has been developed. It includes basic information query, real-time flood risk assessment, dynamic flood risk analysis and many other functions. The system can accurately predict the occurrence area, time, and risk level of urban flood disaster 6-12 hours in advance, and therefore, it is responsible for accurate flood forecast, real-time disaster assessment, and rapid decision-making of the whole city.

The second application is the forecast and early warning of mountain torrent disaster. It refers to the real-time monitoring rainfall data and meteorological precise short-term and imminent rainfall forecast data, and combines advanced technologies such as meteorological radar, remote sensing, and dynamic early warning analysis to accurately predict the risk of mountain torrents 1-3 hours in advance. It effectively improves the timeliness and accuracy of mountain torrent early warning. The next step for this application is to add new functional modules such as sending out early warning information based on the big data of real-time population location, dynamic planning of mountain torrent evacuation and transfer route, etc. This application is one of the ten Best Practices that has been recognized by the Ministry of Water Resources.

The last application is the joint water dispatching operation management system of Ningbo's three main rivers (Yong, Fenghua, and Yao). These three rivers have a combined catchment area of approximately 800 km^2. The water resources must be carefully managed at the end of summer to ensure adequate supply for the winter months. Thus, this application uses advanced Internet of Things and automatic control technology, aiming to fulfill centralized monitoring, centralized control, centralized dispatching, and centralized management of water conservation projects alongside these three rivers to ensure the safe and reliable operation of these projects. As a result, it promotes the establishment of integrated management system that includes holistic information control, real-time operation monitoring, and whole process dispatching tracking.

Implementation requirements

Policy support

New water regulations and public policies are emerging worldwide in response to the new normal of a prolonged water crisis and resultant water shortages. Thereby, it is vital to incentivize the process automation and the use of digital technologies to improve water services. China has issued a series of policies to promote the transformation from "digital water" to "smart water ". In 2011, the No.1 document of the Decision on Accelerating the Reform and Development of Water Resources Management by the Communist Party of China Central Committee and the State Council has been announced. In 2015, the State Council has issued the Guidelines on Active Promotion of the "Internet +" Action. In 2016, the Ministry of Water Resources has formulated and published the 13th Five-Year Plan for Water Resources Informatization Development (Yan and Zhang, 2017). In 2020, the Ministry has then decided to issue the Notice on the Implementation of the Pilot Project of Smart Water Management to closely adhere to the governmental instructions. The chosen pilot case should also be problem-oriented and driven by demand. It should take local and regional characteristics and economic development into consideration. Most importantly, excellent cases can provide guidelines and solutions for upscaling applications in other regions in China.

Allocation of responsibility

It is important to create a governance body for the project to delegate the workload. Oversight board is at the top layer of the governance body structure and engages leadership within a project team. The board must discuss the mission, the direction, and the vision for the project and how smart water technologies could fit within and enhance that vision. Identifying priorities, outlining strategies, developing roadmaps, and allocating funding are critical steps in terms of the transition from the "digital" to "smart" era. In tandem, board members alike must then hold each other accountable, ensuring goals are met, resources are allocated, and the mission is fulfilled. The board has its working groups with different working priority. They are responsible for developing roadmaps, accelerating the delivery of the project, working on innovative thoughts with key partners, and ensuring the success of the project.

Communication and coordination

There is a need to strengthen the overall planning and coordination of the pilot project to form an interconnected layout for the whole city. The first is to establish a regular work meeting system. Members of the communication group or liaison officers of difference departments will attend the meeting. They shall have the opportunity to timely raise and solve problems encountered in the work. The second is to establish a top-down notification system. The city will regularly review and report the progress and operation of the pilot project, as well as oversee the implementation of the pilot project as planned.

Capacity building

First, we need to ensure funding sources. The pilot project can be viewed as a valuable opportunity to actively connect with major bureaus, such as Ningbo Municipal Bureau of Water Resources, Ningbo Municipal Bureau of Development and Reform, etc., and to increase the guaranteed level of smart water funds. Second, technical support should be ensured. Ningbo needs to produce corresponding norms for technical requirements, data resources, operation services, geographic information, etc., and they shall be fully implemented in construction and operation. Third, we should strengthen the publicity and interpretation of the relevant policies, regulations, and programs of smart water, so as to unify the understanding of the purpose, significance, and importance of the pilot project, and to fully mobilize the subjective initiative of the relevant personnel. Lastly, we should carry out the relevant technical training to improve the professional ability and technical skill, thus the project can come into effect smoothly and effectively.

Conclusions

To continuously raise the importance and prominence of smart water technology on flood and drought disaster prevention of pilot project phase I in Ningbo, Ningbo should continuously improve the following four aspects in a position and profound direction.

First is the overall strategic arrangement, including the arrangement for data resources, technical applications, and many other perspectives of Ningbo smart water projects. Second is the real-time online monitoring to improve the ability of information capture and perception. Third is the water resources data sharing. With the assistance of cloud computing, artificial intelligence, and other technologies, Ningbo smart water resources data center has been constructed and it can help to collect countless data, centralized sharing, and further explore the uses of the data. Lastly is the support of platforms that can take real applications as basic demand and enhance the analysis ability and refined management.

While the adoption of smart water solutions will seldom be a smooth journey, it contains many hurdles and barriers that slow, and at worst, prohibits the progress of pilot project. To comprehensively fulfil the requirements of smart water revolution, regulatory, technology, and organizational challenges must be addressed. First, there is a growing challenge of systems integration and interoperability. Second, the people play a key role in smart water transition; this relates to skill gaps, workforce transition, and change management. Third, with limited budgets, financing solutions without a clear value proposition can often pose a tough decision to whether deploy a smart water solution that can drive long-term efficiencies or not. Finally, continual advancements in smart water need to ensure cyber-security and customer data protection.

To fight against mounting global changes, the dawn of the smart water technology has demonstrated efficiency in mitigating pressures of scarcer and less reliable water resources, it is gaining momentum and becomes increasingly necessary to provide more reliable, qualified and secure water resources. Thus, by transiting towards a new paradigm for urban water management, we can help create a more sustainable world.

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