SWM technology for efficient water management in universities: the case of PUMAGUA, UNAM, Mexico City

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Summary

Mexico faces a number of water challenges including water quality, access and inefficient management of water. On a smaller scale, Mexico's largest university (and indeed the largest university in Latin America), the National Autonomous University of Mexico (UNAM) also faces these challenges in its campuses. To address these challenges, UNAM launched the Program for Management, Use, and Reuse of Water (PUMAGUA) in 2008 with the aim of implementing the efficient management of water at the campuses of UNAM. The three key objectives of PUMAGUA were to: 1) reduce potable water consumption by 50% through improved practices and leak detection, 2) improve the quality of drinking water and treated wastewater in accordance to Mexican regulations and 3) promote participation of the entire UNAM community in the efficient use of water. Prior to PUMAGUA, UNAM faced up to 50% water loss through leakages in the university pipelines, irregularities in drinking water disinfection, treated wastewater did not comply with regulation, and there were no continuous capacity development activities or communication campaigns to save and conserve water.

Since PUMAGUA was initiated in 2008, it has achieved a reduction of 25% in water supply in the University City campus (CU), despite a population increase of more than 37% from 2008 to 2018. Drinking water and treated wastewater are now both of excellent quality. PUMAGUA has also enhanced the responsible use of water by key actors, as well as the participation of students and lecturers in generating proposals to solve water problems. In addition, it has carried out workshops addressed to maintenance staff and gardeners to enhance water saving actions.

In order to produce these results, PUMAGUA has made use of Smart Water Management (SWM) technology, in particular, remote water consumption measurement and water quality assessment tools. The Program created UNAM's Observatory of Water, a digital real-time platform that includes water quantity and quality data, and social participation, in order to respond promptly to any eventuality and to actively interact with the university community. In addition to the implementation of the program at UNAM, PUMAGUA has extended its activities to trial smart water projects in other university campuses and also in low-income housing in Mexico City.

Throughout the PUMAGUA program we have learned several lessons, including 1) smart water management can build trust in water users (in our case, in the university community); 2) smart technology still requires a lot of time and effort to manage and maintain, especially in the beginning stages of a project; and 3) as technology changes so quickly, it is essential to have the financial resources to afford the acquisition of technology upgrades, as well as the human capabilities to manage the updates. As a result of sharing our results and lessons from the PUMAGUA program we hope that other programs will be able to leapfrog some of the challenges we have faced, and also can achieve some of the successes we have accomplished.

Moving forward, our intentions are to update the SWM technology, particularly, regarding water consumption measurement. We will also try to use this kind of technology for other purposes, such as measuring soil moisture, in order to determine the need for watering gardens.

PUMAGUA has become a model for water management and use and has been extended to other universities, institutions, and localities. The use of SWM technology has been of the utmost importance to achieve this.

1. Background

This section highlights some of the challenges Mexico, and on a smaller scale UNAM, faces in regards to water management to provide the context for the PUMAGUA case study.

Water resources in Mexico

Country: Mexico
Population: 128,000,000
Annual rainfall: 1,500 billion cubic meters; 779 mm per year
Renewable water resource: 470 million cubic meters (3.67 m^3/annum/capita, one of the lowest in Latin America)
Climate: Highly varied (includes tropical, semi-arid, desert, temperate, humid subtropical and Mediterranean)

1.1 Water challenges in Mexico

To understand PUMAGUA, it is necessary to review the challenges that confront Mexico as a whole. Mexico's annual rainfall varies greatly across regions and seasons, with heavy rainfall occurring in summer (from May to October), while the rest of the year is relatively dry (CONAGUA, 2014). There are two distinct regions in Mexico: 1) the centre and the north region (which when combined occupy two thirds of the country), is very dry with rainfalls ranging from 200mm/year in Baja California to 600-1000mm/year at the south of the Altiplano Central; and 2) the southeast region, which is very humid with rainfall of over 3,500 mm/year. On average each year, Mexico receives 1.5 billion cubic meters of rainfall. Despite this, approximately 72% of rainfall is lost through evapotranspiration, with only 22% flowing into rivers and 6% infiltrating into and recharging aquifers. Considering the exports to and imports from neighbouring countries, Mexico receives an annual average of approximately 470 million cubic metres of renewable water resources (CONAGUA, 2014), making it a country with low natural water availability, one of the lowest in Latin America (SEMARNAT, 2012). In addition, high population density in some parts of the country causes an intense pressure on water resources. Such is the case of the region where Mexico City and the University City of UNAM are located (Figure 1).

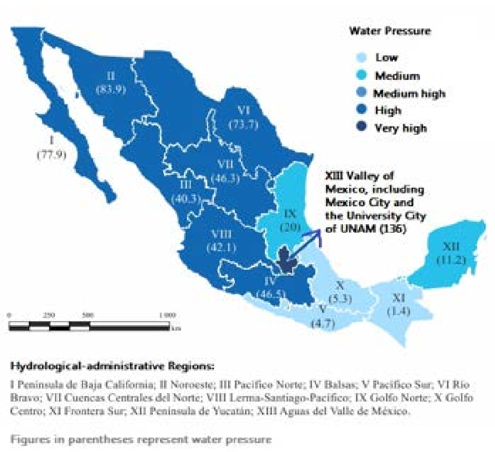

Figure 1. Water pressure map for the thirteen hydrological administrative regions of Mexico, showing Mexico City as one of the regions with the highest water pressure in Mexico.
Source: CONAGUA. Atlas del Agua, 2016

1.1.1 Drinking water services in Mexico

According to the National Commission of Water (CONAGUA) in 2015, 92% of the population of Mexico had access to drinking water (96% in urban areas and 82% in rural areas). Nonetheless, Mexicans have become the leading per capita consumers of bottled water in the world, each using between 215 and 234 litres of bottled water per year (Pacheco-Vega, 2017). Approximately 80% consume bottled water instead of tap water paying considerably more per litre than if they were to drink potable tap water. With water utilities providing more than 200 times the water in volume than that provided by purchased bottled water, for a lower cost. Low-income households spend more money on bottled water due to the water access being lower in poorer areas[1] (Torregrosa, 2012).

One of the main issues for water utilities in Mexico is the inefficiency of network operations. González Villarreal et al. (2015) found that at least one quarter of households do not receive water daily. Between 30 and 50% of water is lost through leaks in Mexican cities (Capella, 2015).

In 2008, per capita average piped water consumption volume of water in Mexico City was measured by Capella-Vizcaino et al. (2008) who showed that while average water consumption is 184 litres/person per day, consumption volumes in different areas of the city range from less than 125 litres to over 475 litres/person per day (see Figure 2).

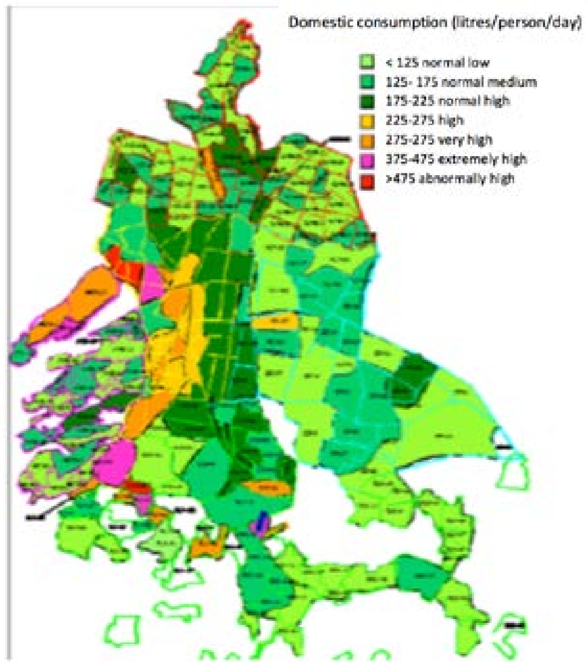

Figure 2. Water consumption volumes in Mexico City.
Source: Capella-Vizcaino et. al, 2008

1.1.2 Water quality in Mexico

With regards to drinking water quality, in 2008 Mexico ranked 59th out of 92 countries, below countries such as Bangladesh, Egypt, and Kenya (Carr and Rickwood, 2008). While the water utility of Mexico City states that tap water complies with regulation in most of the city, Romero Sanchez (2015) has shown that 12% of inhabitants (approximately 1 million people) do not receive good quality water. According to Romero-Lankao (2010) even when water quality is allegedly monitored on a continuous basis, it is doubtful that this monitoring is effective,

1 Some areas in Mexico have limited access to tap water due to the rationing of water by the water utilities

particularly in central areas of the lake system and in some areas of its aquifers. This is because aquifers are polluted with bacteria, faecal matter and sulfates, among others, due to over-exploitation, subsidence, fractures, lack of access to sanitation by some sectors, and lack of maintenance of domestic installations, such as water tanks. There are no accurate data on the health implications of poor water quality in some areas of the Metropolitan Area of Mexico City. Nevertheless, 30% of intestinal related diseases in Mexico are related to the quality of water, and diarrhoeal diseases are the fourth most common cause of child mortality in Mexico City.

Bottled water use in Mexico

According to González Villarreal et al. (2015), Mexicans buy bottled water mostly due to the belief that tap water is not safe. A study by the Interamerican Development Bank (2011) in Mexico City found that the reason 81% of interviewees buy bottled water is a lack of trust in tap water, despite 88% of them stating they had never fallen ill after drinking it.

With the purpose of encouraging tap water consumption whilst reducing bottled water and consumption, in 2013, the Legislative Assembly of Mexico City modified the Law of Education of Mexico City to require the government to install water fountains in primary and secondary schools (ALDF, 2013). At the national level, in 2016 the Ministry of Public Education modified the Law of Physical Educative Infrastructure in order to obligate public schools to provide sufficient drinking water for students, and to install water fountains, according to guidelines established by the Ministry of Health in collaboration with the Ministry of Education (DOF, 2016).

Water uses in Mexico

Irrigated agriculture is by far the main water user in Mexico, consuming about 76% of this resource in a very inefficient way (CONAGUA, 2016b). According to Almazan Cisneros (2003), about 38% is lost in piping and 40% in application. Around 65% of water for agriculture comes from surface bodies and 35% from aquifers (CONAGUA, 2016a).
Domestic use is the second water consumer in Mexico, using 14.5% of water for consumptive uses. About 64% of it comes from surface bodies, and 36% from aquifers. From 2005 to 2014 there was an increase of over 12% in the volume of water allocated to this use (CONAGUA, 2016a).
While the national average pressure for water is 19% (more than 40% is considered as high), in the southern states of the country, water pressure for water is low, while in the northern ones it is high. The administrative hydrological region (a division established by CONAGUA) where Mexico City is located, pressure for water is the highest in the country (nearly 140%, Figure 2) (CONAGUA, 2016b).

1.2 PUMAGUA at the University City, UNAM

University City (CU), UNAM, Mexico City

Population: 185,000 people
Land size: 700 hectares
• 240 ha ‘Pedregal de San Angel’ Ecological Reserve
• 150 ha of gardens
• 300 ha covered by ~400 buildings
Water supply in 2008: 100 litres/second (8,640m^3/day)

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The National Autonomous University of Mexico (UNAM) in Mexico City is the largest university in Mexico and Latin America (see Figure 3). Its main purpose is to serve the country, to train professionals, to organize and carry out research, with the key focus on national conditions and problems and in disseminating the benefits to the country (National Autonomous University of Mexico, 2017). After the IV World Water Forum in Mexico City in 2006, the University created the Water Network of UNAM, with the participation of 26 schools and institutes of UNAM. Yet while UNAM was conducting research on water quality challenges elsewhere throughout Mexico, they did not have a water management system in place for their own university premises. As the main campus, City University (CU), alone houses 185,000 students, academics and other staff and is 700 hectares in size. The ‘Program for Management, Use, and Reuse of Water at UNAM’ (PUMAGUA) was established, in 2008 with an interdisciplinary team assembled to implement an integral program of management, use and reuse in UNAM’s campuses, with the participation of the community.

The autonomy of UNAM with regards to the Mexican government gives it the faculties of (1) self-regulation, that is, to regulate its internal relationships; (2) self-academic organization, which means that it decides its academic, research and culture dissemination plans and programs; (3) administrative self-management, in other words, to freely administrate the economic resources assigned by the legislative power (González-Pérez and Guadarrama-López, 2009).

1.2.1 Water supply at University City (CU), UNAM

The Directorate of Works at UNAM is responsible for operating the water services within UNAM’s campuses, in the case of CU. UNAM has a concession of the three wells by the National Commission of Water, and as a result of this concession, UNAM is not required to pay for the supply and use of water. This is of particular importance, as unlike many other smart water management projects recovered costs via reduced water consumption was not feasible in this project.

Figure 3. Location of the University City (CU for its acronym in Spanish) in Mexico City.
Source: PUMAGUA, 2012

Mexican water regulations relevant to PUMAGUA, UNAM

The following regulations were set out by the Mexican government to improve water quality in Mexico:
• Official Mexican Norms (NOM): NOM-127-SSA1-1994 (2000) for drinking water quality
• NOM-003-SEMARNAT-1997 for quality of treated wastewater
• NOM-230-SSA1-2002 for water sampling procedures
• NOM-179-SSA1-1998 for sample size requirements and sampling frequency

1.3 Water conditions at the CU when PUMAGUA was launched

Soon after PUMAGUA was launched, the team realized that, in addition to calculating the water balance, it was fundamental to assess drinking water and treated wastewater quality in order to determine compliance with Mexican regulations and to improve water safety. In addition, community participation was believed to be of the utmost importance, as the team understood that technical improvements both in water quality and in water saving would need the community's support in order to be lasting. Therefore PUMAGUA was organised into three main areas: Water Balance, Water Quality, and Communication and Participation, with three key objectives.

1.3.1 PUMAGUA's objectives:

1. To reduce potable water consumption by 50% through improved practices and leak detection;
2. To improve the quality of drinking water and treated wastewater in accordance to Mexican regulations; and
3. To promote participation of the entire UNAM community in the efficient use of water.

PUMAGUA started in the main CU campus as a pilot case in order to create a model of water management that could be exported to other campuses of UNAM, to other universities, and to other localities in the country. UNAM has six campuses throughout the country, seventeen schools in the Metropolitan Area in Mexico City, as well as research institutes and schools in 20 states of Mexico, the United States, Canada, Spain and China. In addition to the pilot case, some SWM were also implemented in other campuses of UNAM[2].

1.3.2 PUMAGUA Management

PUMAGUA comprises different members of the University: (1) The interdisciplinary team; (2) the staff of the Direction of Works; and (3) the authorities of each institute, school, and administrative office.

1. The team has had a different number of participants in the lifetime of PUMAGUA. For instance, in 2010, there were 50 participants (see organisation chart, Figure 4), while in 2017, the group is made up of 10 persons, due to budget restrictions.
   The mission of the team is to assess water management conditions (water quality, water quantity and social participation) and to issue recommendations to improve them.

2 In addition to the pilot program, water meters were placed in Facultad de Estudios Superiores Aragón (Mexico City) and in Juriquilla campus (in the State of Querétaro). Other actions not related with SWM included installing drinking water disinfection system in Facultad de Estudios Superiores Acatlán (State of Mexico) and a toilet infrastructure upgrade in Facultad de Estudios Superiores Iztacala, and Zaragoza (both in Mexico City).

Figure 4. Organisation chart of interdisciplinary permanent group of PUMAGUA in 2010

2. Separate from the PUMAGUA group, the Direction of Works is responsible for planning and undertaking construction at UNAM, as well as operating, refurbishing, maintaining, and conserving all buildings, gardens, equipment and electromechanical installations. The area of Conservation of this office collaborates with PUMAGUA with the purpose of operating the distribution network more efficiently and particularly to detect and repair leaks. It also operates the drinking water disinfection system (Sodium Hypochlorite 13%), as well as the wastewater treatment plant.

3. The authorities of institutes, schools, and administrative offices participate in PUMAGUA by implementing actions suggested by the Program: installation of real-time water meters, drinking water fountains, and of bathroom water saving appliances (i.e. taps, toilets and shower heads); leak detection and repairing, substitution of high water consumption gardens for low consumption native vegetation, dissemination of water saving information, attendance to PUMAGUA's workshops.

2. Water challenge

Prior to the PUMAGUA program, there was not a clear understanding of the water problems at UNAM, as previously no diagnosis had been conducted. Thus there was a need to better understand the water system and the initial PUMAGUA diagnosis revealed the depth of the challenge, as outlined below. The first activity of PUMAGUA, in 2008, was a diagnosis of the water system at the University City focusing on three core issues: water quantity, water quality, and social participation.
A summary of the findings is listed below, and this section explains it in more detail.

- Absence of updated hydro-sanitary information
- Absence of water consumption measurement in buildings
- Water losses in distribution network above 50%
- Noncompliance of Mexican standards of quality of drinking water and treated wastewater
- Three treatment plants needing refurbishment
- 26 integrated anaerobic bio-reactor plants needing removal

- Absence of a program that incited participation of university schools, institutes, and offices in responsible water management and use
- Lack of knowledge about the water management system among CU's community
- Reluctance of academics for water conservation measures that could imply some level of compromise
- Highest willingness to participate found among students
- No specific irrigation method and water saving was not found as an objective of this activity.

2.1 Water quantity

To assess the volume of water used on site, the Directorate of Works analysed the information available on the hydro-sanitary infrastructure (i.e. the water distribution and wastewater collection networks), and measured drinking water supply and leaks using water meters.

A lack of hydro-sanitary information was immediately detected, including the layout of the distribution network. The only blueprints available were on paper as there was no online system available to upload them to (see Figure 5). Consequently surveys took place in order to determine the pipeline routes and to draft and digitalize hydro-sanitary blueprints. A total of 54 km of drinking water pipelines were identified. It was also found that there was no water consumption measurement within the buildings. None of the water meters installed in the past were working when the diagnosis took place.

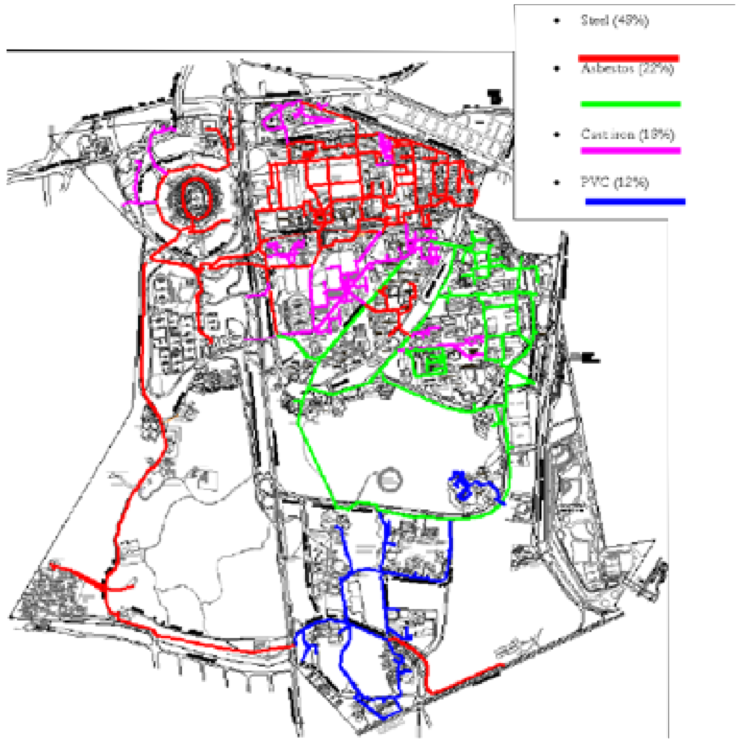

Figure 5. Digitalized water supply network of the University City of UNAM. Pipeline colours correspond to different materials: steel, asbestos, cast iron, and PVC.
Source: PUMAGUA, 2012

Thirty percent of a sample of toilets and faucets were not working properly. After the assessment, a full inventory of infrastructure was created. The water system identified is briefly described below in Box 5.

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Water infrastructure prior to SWM implementation

Drinking water infrastructure:
- 3 wells, with an average extraction of 100 l/s
- 3 storage tanks with a capacity of 12,000 m^3
- 54 km of pipelines

Wastewater infrastructure:
- 18 km of sewage pipelines
- 1.8 km of rainwater drainage
- 3 treatment plants and 26 small, integrated anaerobic bio-reactor plants.
- 13 cisterns of treated wastewater for irrigation of the university gardens

Pressure modelling and sectorisation:
Pressures in the distribution network were modelled using the software EPANET, and five hydraulic sectors were defined in order to facilitate leak detection (Figure 6).

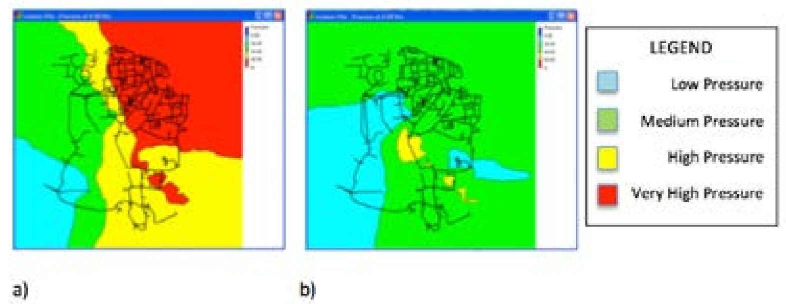

Figure 6. Simulation of the distribution network of the University City of UNAM a) without pressure control, and b) with pressure control
(PUMAGUA, 2012)

According to measurements performed by PUMAGUA, over 50% of water extracted from the wells was lost through leaks and operation wastes (for instance, 5000 liters were lost per day in a laboratory that did not have water recirculation or cooling). Figure 7 shows the water balance in 2008.

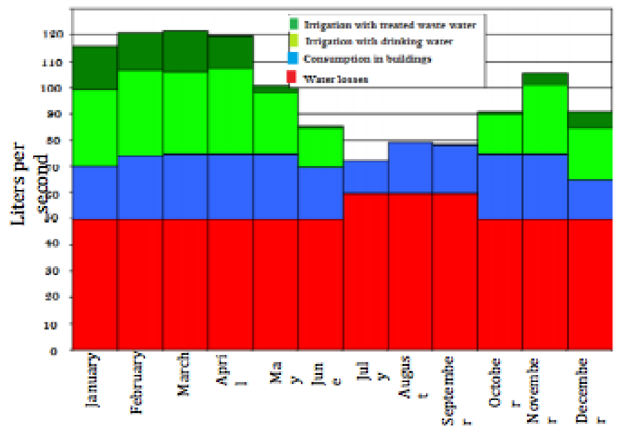

Figure 7. Water uses of University City, in 2008, according to which water losses were over 50% of water supply.
Source PUMAGUA, 2008

2.2 Water quality

Water quality at CU was analyzed both before and after disinfection in order to (1) determine if there were pollution threats in the groundwater and (2) to determine if the disinfection system worked properly. Periodical sampling of ground water was performed from 2008 to 2010. This allowed the identification of potential health hazards, such as the sporadic occurrence of Total Coliforms and Faecal Coliforms. The water quality analysis showed nitrate levels were close to the established limits in national regulations (NOM-127-SSA1-2000: 10 mg/L nitrates).

Water quality after disinfection with chlorine was also determined. Samples were sent to an external certified laboratory for the analysis of the 41 parameters comprised in the Mexican drinking water standard. All parameters complied with the standard, except for free residual chlorine (FRC), which is fundamental to prevent the growth of microbiological organisms. FRC was found to be below its minimum ´permissible' limits Figure 8 shows free residual chlorine concentration in one of UNAM's buildings.

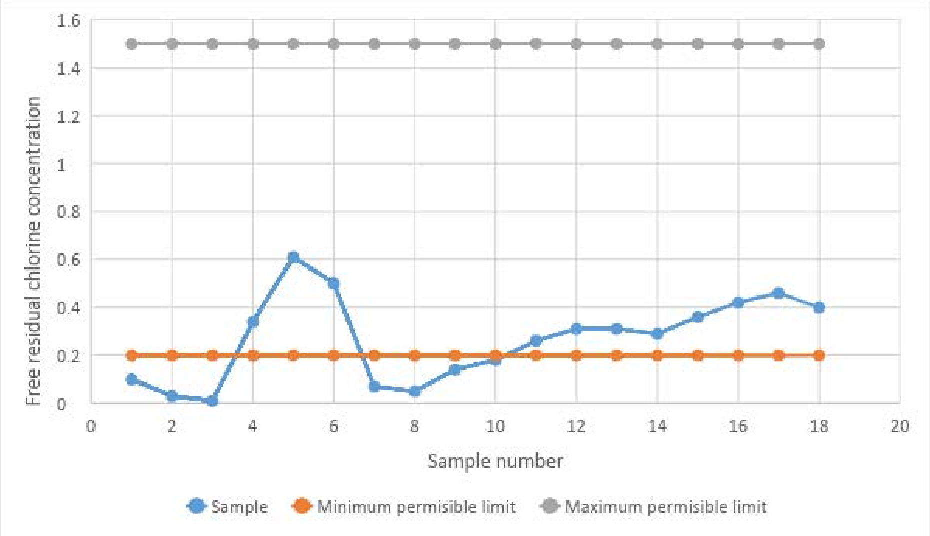

Figure 8. Concentration of free residual chlorine in 18 samples of disinfected water at Universum Museum, University City, UNAM, in 2008.
Source: PUMAGUA, 2008

To assess the water quality on site, an in-situ water sampling program was also carried out, assessing the water quality in the water wells, the distribution system, and the drinking water tanks (Orta de Velásquez et al. 2013). The sampling points were selected based on Mexican Standards, empirical criteria and the application of probabilistic systematic sampling. Initially 20 sampling sites were established to cover the five hydraulic regions; and testing was performed monthly. Concentrations of FC, TC, and free residual chlorine (FRC) in water were assessed. Figure 9 shows the FRC and coliform bacterial densities obtained in 2012.

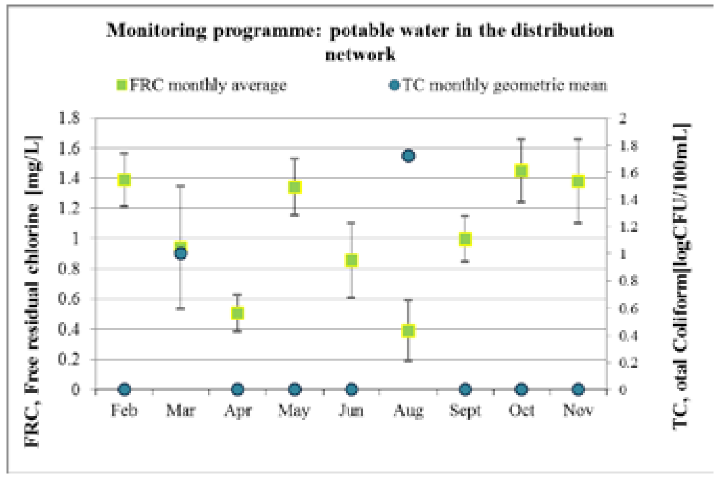

Figure 9. Free residual chlorine concentration and coliform bacterial densities in different points of the water supply network of the University City of UNAM throughout the year. Results display FRC intervals with a 95% confidence level.
Source: Orta de Velásquez et al. 2013

The main treatment plants and their effluents were also evaluated (Figure 10). The Direction of Works operates three wastewater treatment plants (WWTP) distributed around the campus. The team determined that water quality from the three plants did not comply with Mexican regulations. Consequently, the team recommended refurbishment of the three plants (PUMAGUA, 2008).

In 2008, there were also 26 small Integrated Anaerobic Bio-Reactor Plants (BRAIN, for its acronym in Spanish) spread throughout the campus. Due to lack of maintenance, water quality within BRAIN did not comply with Mexican regulations. Therefore, PUMAGUA suggested to close the 26 plants.

Figure 10. "Cerro del Agua", main Wastewater treatment plant of the University City, in 2008. It comprised:
a) Pre treatment: sand traps and screens for elimination of large solid particles; b) Flow meters: three flow meters parallel to each other; c) Secondary treatment: Activated sludge treatment, rotatory biological discs, and spray filter (all used within the same WWTP); d) Tertiary treatment: sand traps (filters) and disinfection.
(PUMAGUA 2012)

The distribution system of treated wastewater was also analysed. Within the campus water distribution system, treated water is pumped to cisterns from where water is distributed for the irrigation of gardens. Since 2008, the effluent's water quality has been analyzed every month with regards to FC, helminth eggs, fats, oil and greases, Biochemical Oxygen Demand, Chemical Oxygen Demand, and Total Suspended Solids. The PUMAGUA team assessed the physical and operative conditions of the plants and concluded that they were operating below design capacity, did not have adequate physical conditions and their effluent quality did not comply with Mexican regulations (Orta Velásquez et al. 2013).

Likewise, inspections of the storage cisterns revealed that most of them had inadequate physical conditions (lack of lid, leaks, rusted metal parts, etc.), as shown in Figure 11. It was deemed that the water stored in the cisterns did not comply with local regulations (Orta Velásquez et al. 2013).

Figure 11. Inadequate conditions of some storage cisterns located at the University City. (PUMAGUA, 2012)

2.3 Social participation

The initial PUMAGUA diagnosis of the water system at UNAM CU also revealed that there was no program within the University to encourage authorities of schools, institutes or administrative offices to implement actions to lower water consumption or water pollution inside buildings.

A stratified survey was developed in 2009 by the PUMAGUA team, in order to establish a baseline of CU's community who participate in responsible water management and use. The variables assessed were knowledge, beliefs, attitudes, practices, and preferred means of communication. The team believed that communication and training activities could be better designed if these variables were determined.

Face to face interviews were carried out applying a questionnaire to a sample of 1,480 people of different sectors (academics, students, administrative workers, laboratory staff, housing residents, and visitors), and special workshops took place for gardeners in order to determine their watering methods.

These were the main findings of these activities:

- There was limited knowledge of the water management system among all sectors.
- Less than half of interviewees noticed water waste in the campus.
- A significant portion of the participants (over 40%, particularly administrative staff) believed that UNAM's authorities did not care about water waste.
- Students were the only sector that specifically recognised their own responsibility in water waste.
- Academics were the sector with the least willingness to accept measures for water conservation that would require some level of compromise.
- Only one third of academics had been trained to adequately dispose of chemical residues in laboratories.
- Very few maintenance workers had received any sort of training regarding responsible water management.

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- Multiple watering methods were used, without detectable criteria and without the purpose of saving water. Each gardener did as they thought best, in terms of frequency and duration of watering, to keep gardens green.
- Bottled water use at UNAM was high, with 80% of those surveyed at UNAM drinking bottled water instead of tap water.

The results of this questionnaire display the low engagement of the UNAM population with the importance of water conservation.

Bottled water versus tap water consumption in CU, UNAM, in 2012

According to Espinosa et al. (2014), in 2012, only 14% of the university community consumed tap water exclusively, while 75% consumed bottled water, and 11% consumed both. Bottled water was preferred mainly for organoleptic reasons (taste, colour, turbidity, odour), as 54% of respondents pointed out this reason, while health was the second reason (26% of respondents).

3. Smart water management solutions

The smart solutions integrated into PUMAGUA are organised in three main areas (as shown in Table 1):

- Water quality solutions
- Water quantity solutions
- Participatory community solutions

Table 1. Smart Water Management solutions

	Water Problem Addressed		
SWM TOOL	Water Quality	Water Quantity	Participatory Community
Water Observatory	X	X	X
Real-time monitoring sensors	X	X	
Telemetry system		X	
Outreach activities			X

3.1 Water Quality Solutions

3.1.1 Operation of real-time water quality monitoring system

In order to have reliable and constant information about water quality, a real time monitoring system was installed in the Institute of Engineering, where one of the researchers responsible for the Water Quality area of PUMAGUA, Doctora. Teresa Orta, is based. Real time monitoring was implemented by means of a data collection sensor system, located in one of the buildings of the Institute of Engineering of UNAM. Due to economic reasons, only one of these systems could be installed. The sensors measure six physicochemical parameters: free residual chlorine, conductivity, nitrates, pH, turbidity and temperature, through a constant water flow from the distribution network. The system collects measurements of the aforementioned parameters every five minutes and sends them through a local area network to a web site provided by the manufacturer (Figure 12).

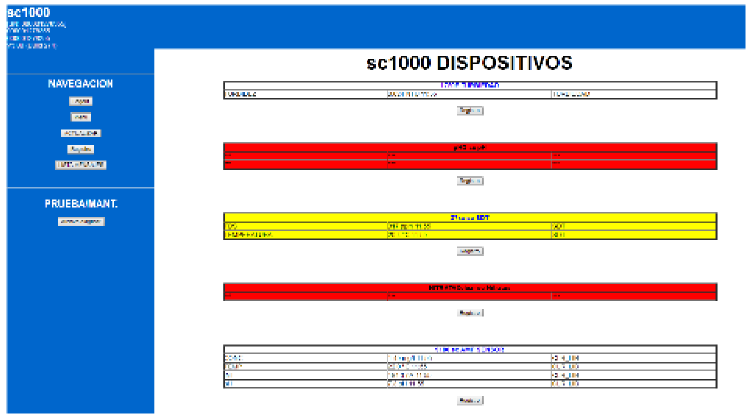

Figure 12. Download platform of the real time water quality monitoring system.
Source: http://132.248.156.11

The sensor system consists of a controller and four sensors (Figure 13), one for each physico-chemical parameter, with the exception of pH (measured by the chlorine sensor) and temperature (measured by the conductivity sensor). Water from the distribution network is fed to each sensor from a tap connected to PVC pipes (Figure 14).

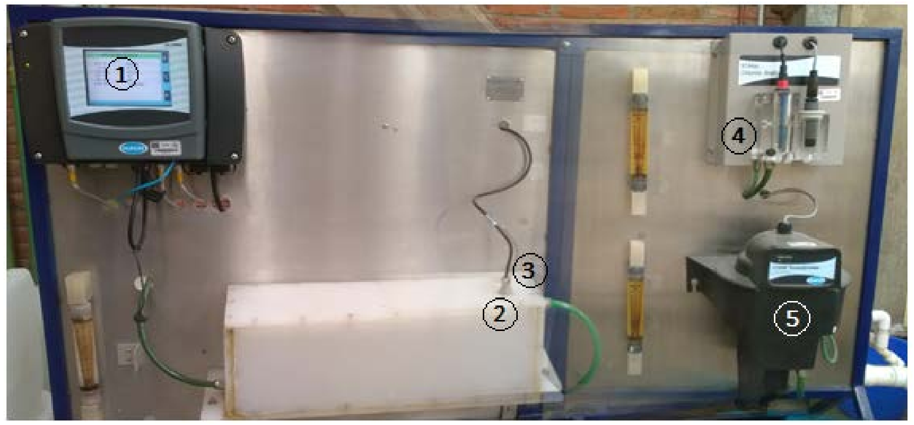

Figure 13. Real time water quality monitoring system, located at the Institute of Engineering, UNAM: (1) Controller, (2) Conductivity sensor, (3) nitrate sensor, (4) chlorine and pH sensor, and (5) turbidity sensor.
Source: HACH Company, 2006

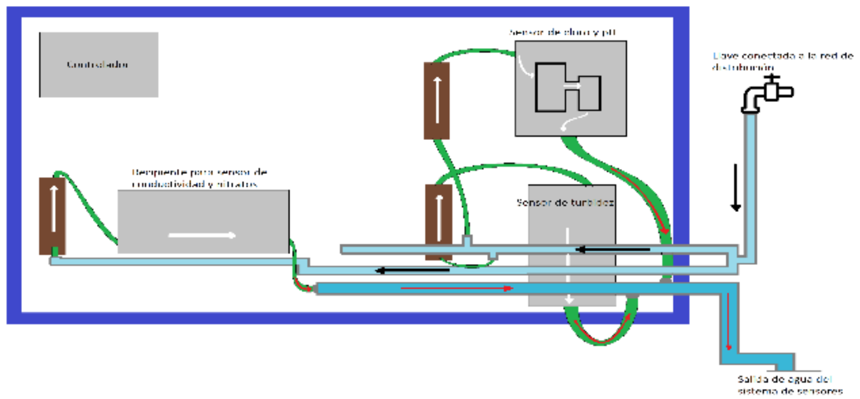

Figure 14. Water inflows and outflows in the real time water quality monitoring system. Water from the distribution network feeds this system. Black arrows represent water flowing into a sensor, while red arrows represent water flowing out of the system.

Conductivity and temperature sensor

This sensor generates a low current whose intensity is then measured by a detector. The intensity of the current corresponds to the conductivity of the volume of water in which the sensor is submerged (Figure 15). This sensor also has a resistance temperature detector.

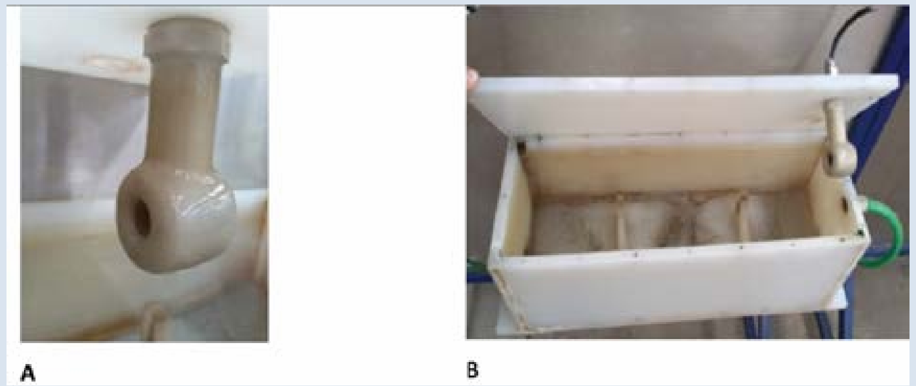

FIGURE 15. (A) Conductivity sensor of the real time water quality monitoring system; (B) a container was built to allow constant water flow. Source: Stephanie Espinosa, 2016.

Nitrates sensor

The Nitrate sensor measures photometrically the concentration of nitrates diluted in water. Similarly to the conductivity sensor, the nitrate sensor must always be submerged in water (Figure 15-B) so that it can emit ultraviolet light. Two receptors then measure absorbance (Figure 16): one of them works as a control element, while the other functions as a measurement element. The measured absorbance corresponds to the difference between the emitted light and the receiving light after its interaction with diluted nitrates.

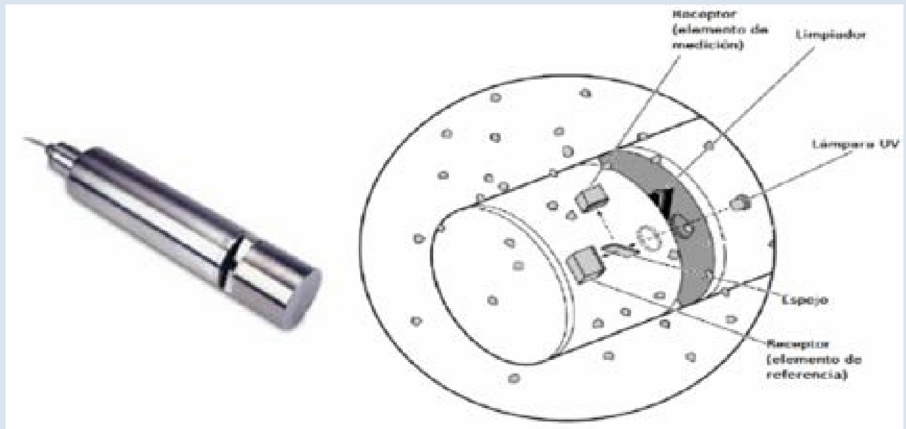

FIGURE 16. Components of the nitrate sensor. From top to bottom: Receptor (measurement element), cleaner, UV lamp, mirror and receptor (reference element). Source: HACH Company, 2006

Free residual chlorine and pH sensor

The free residual chlorine and pH sensor measure the concentration of free residual chlorine in water. This compound is made of diluted chlorine (in low pH conditions), hypochloric acid gas and hypochlorite ions. The concentration of each of these elements depends on pH and temperature. As the concentration of hypochlorite ions depends on pH, this sensor has a potentiometer (Figure 17).

The sensor comprises a gold electrode, a counter electrode made of silver, an electrolyte (potassium chloride solution), and a micropore membrane, which is selective to hypochloric acid (HOCl) (Figure 17).

When the water sample is in contact with the membrane, HOCl molecules disseminate into a narrow area between the membrane and the cathode, which contains chloride potassium. At this point, a constant potential is applied to the cathode and the HOCl consequently decomposes in chlorine ions and water. The system calculates free residual chlorine by using the dissociation curves of HOCl.

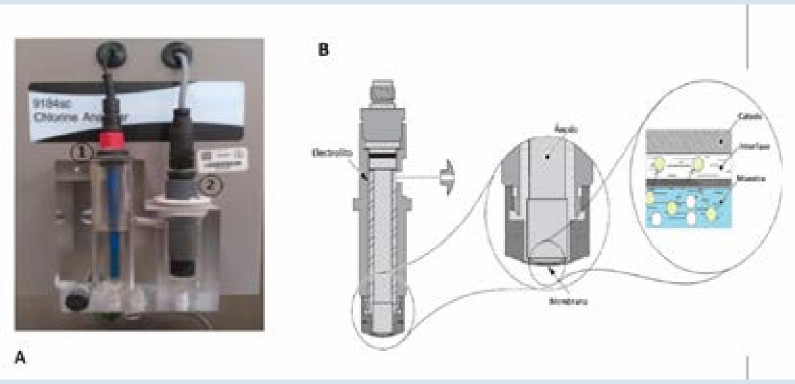

FIGURE 17. (A) pH sensor (1) and free residual chlorine sensor (2); (B) The free residual chlorine sensor consists of an anode, a cathode, and electrolyte solution and a membrane, which is selective to HOCl. From left to right, and top to bottom: Electrolyte, anode, membrane, cathode, interphase, sample. Source: HACH Company, 2006

Turbidity sensor

The turbidity sensor measures water turbidity as follows: 1) it emits a beam of light that passes through the water sample, 2) a submerged photocell then detects the light disseminated by the particles at an angle of 90° with respect to the central line of emitted light. Consequently, the greater the amount of suspended particles, the greater the amount of light disseminated towards the photocell and the higher the turbidity of the sample (Figure 18).

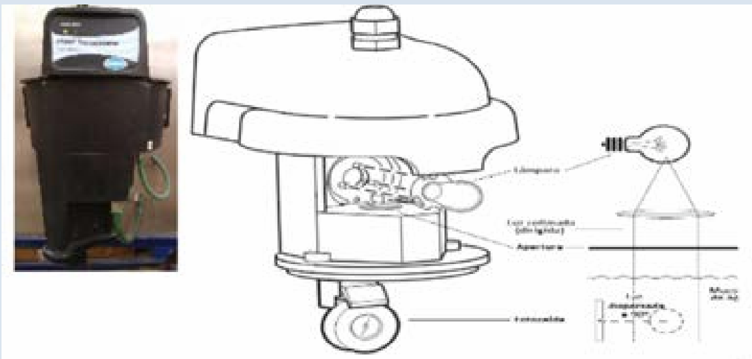

FIGURE 18. The turbidity sensor and its components. Source: HACH Company, 2006

3.1.2 Water Quality in the online Water Observatory of UNAM

The Water Observatory platform (shown in Figure 19) is an online platform that hosts the real-time data for the water users at UNAM. It has two modes, 1) administrator (which is accessible only by the staff at PUMAGUA) and 2) user (which is accessible to anyone with access to the internet). The two modes were designed to enable PUMAGUA to store all of the data in one location, while providing relevant information to the community. The decision to provide different access levels to information for the administrator and the user mode was made as a result of the abundant volume of data provided to the platform, and the need to allow the regular user to quickly access information. In addition to this, much of the technical information may be difficult for the general public to understand and might cause unnecessary alarm, while it is of the utmost importance for PUMAGUA to be aware of this data, in order to take action in case of eventualities.

CASE STUDIES
SWM TECHNOLOGY FOR EFFICIENT WATER MANAGEMENT IN UNIVERSITIES:
THE CASE OF PUMAGUA, UNAM, MEXICO CITY

The Water Observatory summarises the results obtained from the water quality analysis. Drinking water results are displayed based on three types of monitoring approaches: real-time information from sensors, on-site sampling carried out by PUMAGUA, and on-site sampling carried out by an external certified laboratory. It also hosts treated wastewater results from the on-site sampling in the Wastewater Treatment Plant of "Cerro del Agua" and six wastewater storage tanks.

On the left side of the main screen, a map of the main campus of UNAM is displayed, in which the items of interest are depicted. Information about the date of monitoring, type of water, and the water source is linked to each element displayed in the map.

The right side of the map provides an option menu. In the administrator mode, the option menu consists of eleven search criteria in order to be able to select specific consultations for each site (Figure 19).

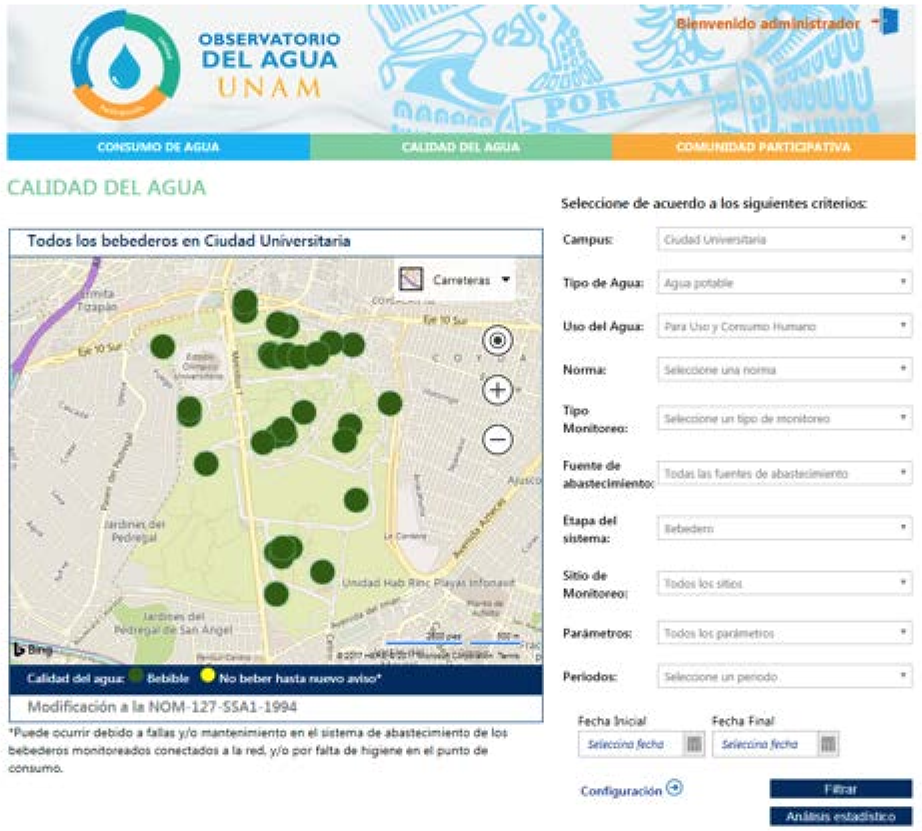

Figure 19. Screenshot of the online Water Observatory, shown in the administrator mode in Spanish.
Source: www.observatoriodelagua.unam.mx

The list below details the functions available in the option menu of the Water Observatory platform:

(1) Campus: Currently the information comes from the main campus only but in the future other campuses can be included.
(2) Type of water: drinking water or treated wastewater.
(3) Use of water: human use and consumption (for drinking water only), reuse in gardens (for treated wastewater only). In the future, reuse in toilets may be added.
(4) Applicable regulation: there are three reference standards: (1) drinking water quality, (2) treated wastewater quality (3) conditions of storage tanks.
(5) Type of monitoring: real-time or in-situ sampling.
(6) Water source: specific well, in the case of drinking water; and specific treatment plant, in the case of treated wastewater.
(7) Monitored element: drinking fountain, distribution network, intake, storage tank, regulation tank.
(8) Location of monitored element: school, institute, or administrative office.
(9) Parameter: This option includes the five parameters measured in real time, the three parameters monitored in-situ by PUMAGUA, and the 41 parameters analyzed by the external laboratory.
(10) Period: Regarding the real time sensors, the platform can show daily information, as well as data from several days, months or years.

A graph of the information presented within the platform can also be obtained.
In the user mode, only five options are shown, all related to drinking water:

(1) Campus
(2) Type of water: drinking water
(3) Type of monitoring: real-time or in-situ sampling
(4) Monitored element: drinking fountain, distribution network
(5) Location of monitored element

The site map is useful for users as it shows the real-time water quality of each element (e.g. drinking fountain, intake, or distribution network) on the campus. When the water quality of an element complies with the national Mexican water regulations, it is depicted in green on the map. When it does not, it is depicted in yellow. A pie graph showing the percentage of total data complying with Mexican water quality regulations is shown in Figure 20.

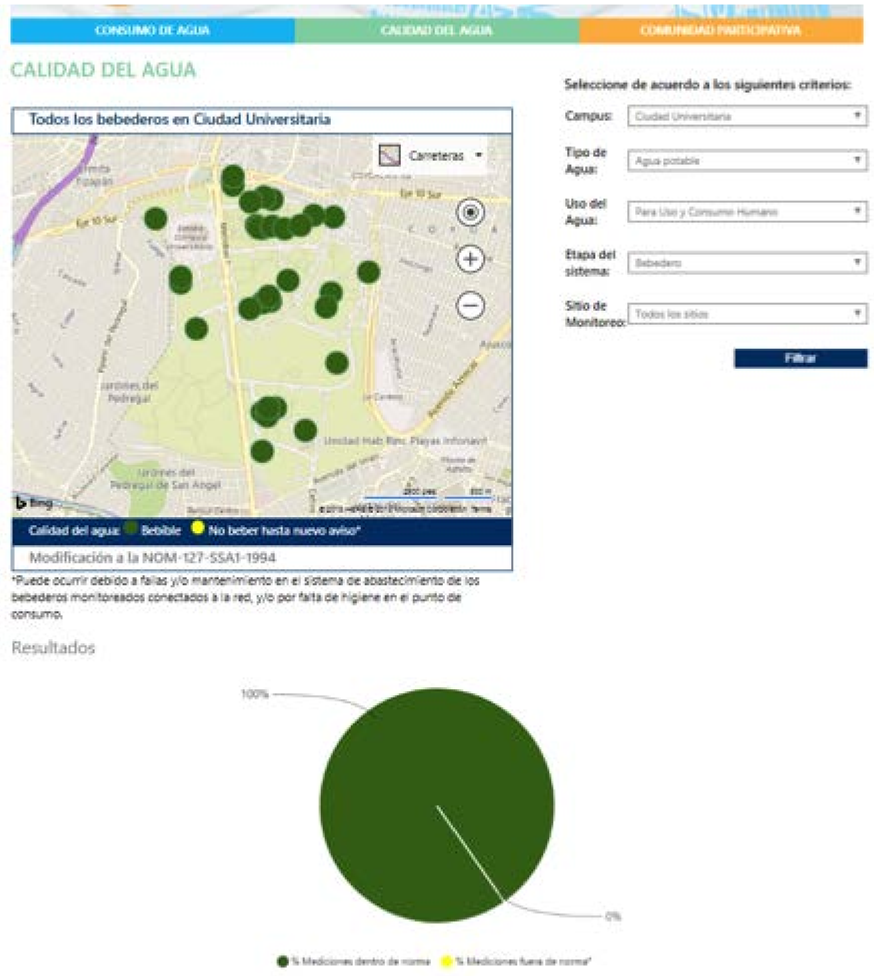

Figure 20. Information provided to a regular user by the Water Observatory of UNAM. This example shows the drinking devices whose water complies with regulation, i.e. potable water (green dots), and the water that is not to be consumed until advised due to bacteria contamination (yellow dots). The pie chart shows the percentage of compliance (100% green).
Source: http://www.observatoriodelagua.unam.mx/CalidadAgua/CalidadIndex

Statistical analysis can be performed with all the information stored in the database, since 2013. Correlations and variance analysis can also be carried out using the real-time data (Figure 21).

Figure 21. Example of statistical analysis performed by the Water Observatory of UNAM, regarding the concentration of free residual chlorine in January 2014.
Source: http://www.observatoriodelagua.unam.mx/CalidadAgua/AnalisisCalidad

3.2 Water Quantity Solution

3.2.1 Water consumption measurement points

Measurement points to assess water consumption were selected according to criteria established in various handbooks, such as the (Mexican) Handbook of Drinking Water and Sanitation (MAPAS for its acronym in Spanish) and the handbook of the National Water Commission. Electromagnetic water meters were used for macro measurement (wells, tanks, hydraulic sectors), while for water intakes of buildings (micro measurement) volumetric meters were installed (see Figure 22).

Figure 22. Electromagnetic water meters (left) and volumetric meters (right).
Source: PUMAGUA, 2012

CASE STUDIES
SWM TECHNOLOGY FOR EFFICIENT WATER MANAGEMENT IN UNIVERSITIES:
THE CASE OF PUMAGUA, UNAM, MEXICO CITY

PUMAGUA has installed 9 macro meters across the UNAM CU distribution system, one in each well, in the supply points of each hydraulic sector, and one for repumping from one tank to another. There are also 210 micro water meters in the water intakes of buildings.

3.2.2 Remote measurement

For the remote measurement system, a protocol of communication through radio frequency was selected, using a range of 900 and 920 MHz. For this kind of transmission, it is necessary to install Gateway antennas that receive data from radios of water meters every five minutes. At this point, analogous information is converted to digital information. Antennas have a radius coverage of one kilometre with line of sight. Seven antennas were installed in different parts of the campus to provide decent coverage (see Figure 23). To enable communication between antennas and water meters, it was also necessary to install 30 repeaters or boosters (used to receive the signal and send it to another receptor) throughout the campus.

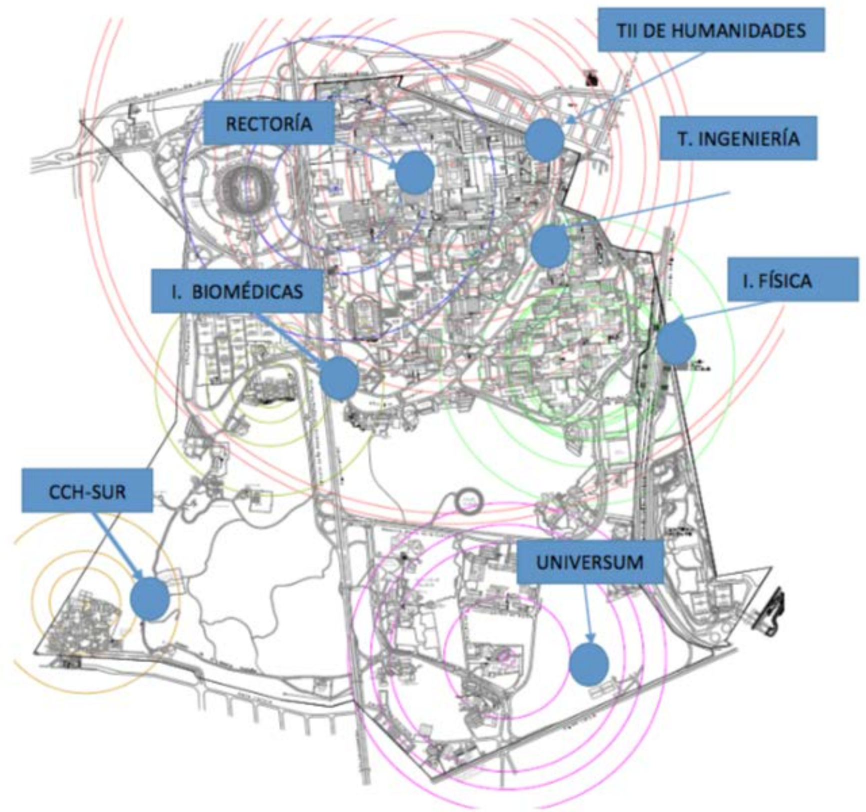

Figure 23. Location of antennas, as part of the real-time monitoring system in the main campus of UNAM. Labels represent the building names where the monitoring systems are implemented.
Source: PUMAGUA, 2012

3.2.3 Architecture of the Telemetry System

Measurement points, data transmission, data collection, as well as the presentation interface are all part of the telemetry system installed in the main campus of UNAM (Figure 24). For the whole system to be reliable, it is of the utmost importance that each one of these elements works properly.

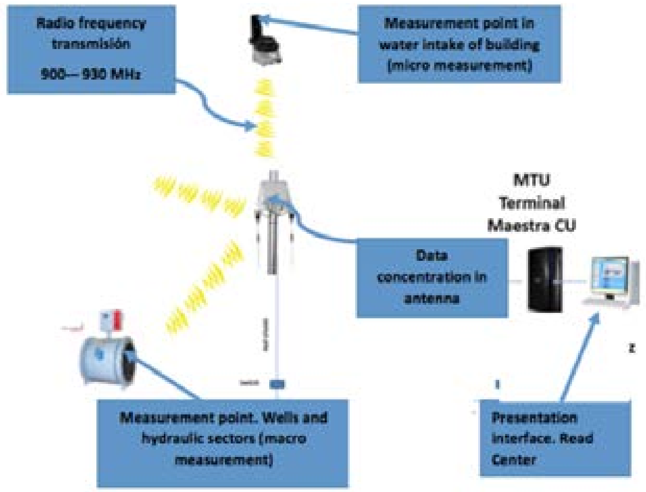

Figure 24. Telemetry system installed in the main campus of UNAM, including macro and micro meters, an antenna and the server where information is displayed and analyzed.
Source: PUMAGUA 2012

Information from water meters linked to the remote lecture system is processed, analysed and displayed using the software Read Center (from Badgermeter). Read Centre is a reading data management software application that provides a central location for performing various meter-reading tasks. It allows data sharing across meter reading solutions offered by this company.

The software is made up of three components (see Figure 25):

- A server (Monitor) that handles communication with the Gateways.
- A client (Control) that defines reading schedules, performs system management, and runs reports.
- A database server that stores information.

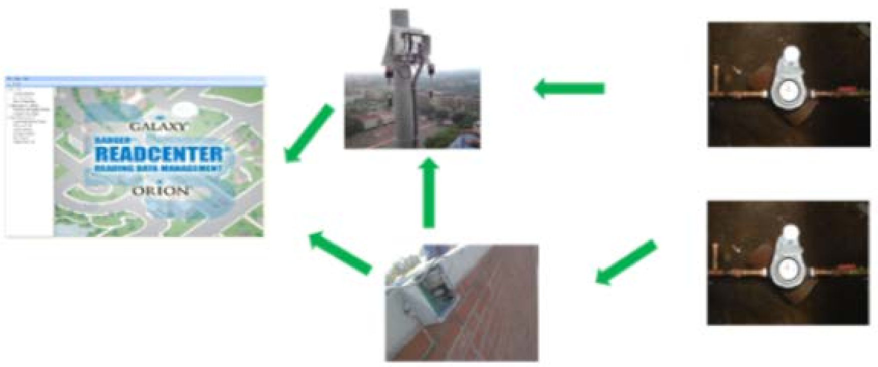

Figure 25. Direct and indirect transmission of water consumption information in the main campus of UNAM.
Source: PUMAGUA, 2016

For the water meters that have not yet been linked to the system, PUMAGUA's staff make regular trips to collect the data with a portable computer called Ranger Trimble. This is possible as the water meters have a data logger that stores information every hour. The collected data is later processed manually in Microsoft Excel.

3.2.4 Water Quantity in the Water Observatory of UNAM

In order to link the database of Read Center with the database of PUMAGUA, additional software was developed for PUMAGUA. This software collects information from the Read Centre database, replicates the information and modifies its structure in order to make it compatible with the Water Observatory database. The latter database is administered and operated with the SQL Server software. The water consumption measurements collected with the portable computer are also stored in this database (Figure 26).

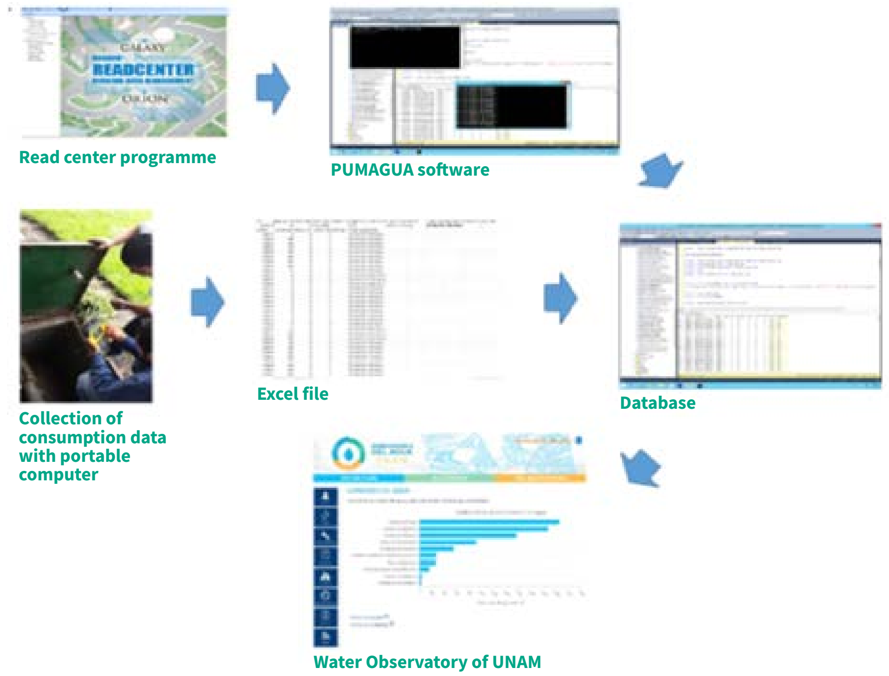

Figure 26. Integration of information to PUMAGUA database and to Water Observatory of UNAM from water meters linked to the remote system and from water meters that have not been linked yet.

The ReadCenter program stores water quantity data, which the Water Observatory then processes and displays. In Figure 27 you can see the main screen, which shows a graph of the monthly water consumption of ten randomly selected institutions (schools, institutes or administrative offices).

Figure 27. Main screen of the water quantity section, showing monthly water consumption of ten schools/institutes/offices randomly chosen every month.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/ConsumoIndex

In the administrator mode of the Water Observatory for water quantity monitoring, the left-hand menu has eight functions:

1. Allows you to include or to eliminate any displayed element, such as water meters, antennas, or repeaters.
2. Shows the magnitude of leaks related to each water meter, through micrometers, which send continuous information in real-time. When the consumption appears to be constant, particularly during the low-use periods, such as at nighttime, the system determines that there may be a leak. This is then verified in-situ to determine the extent of the leak and to resolve the issue as quickly as possible. (Figure 28).

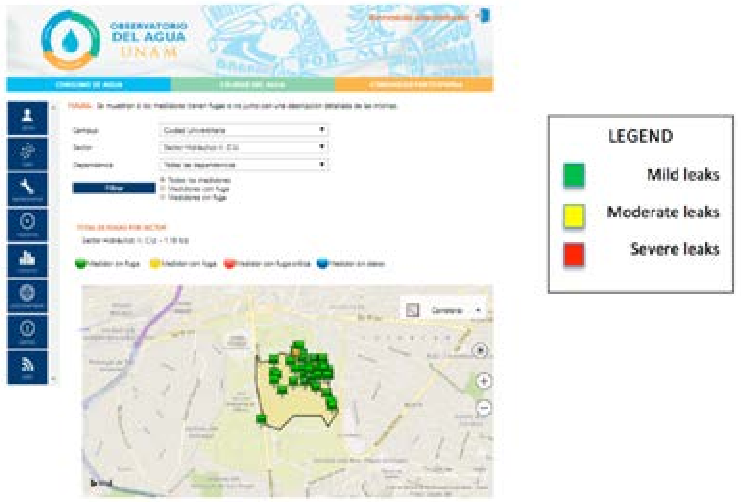

Figure 28. Screenshot of the Water Observatory of UNAM showing leak magnitude. One of the hydraulic sectors of the main campus is represented in the map.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/Fugas

3. Shows the maintenance due date of water meters. It is presented as a “traffic light” system, in which if the maintenance due date is far off, a green colour is shown; if the due date is approaching, a yellow colour will be shown, and if the due date has already passed, a red colour will appear.
4. Displays every water meter installed in UNAM’s campuses. A short data sheet is linked to each device, which shows the number of the water meter, its location and its average water consumption (see Figure 29).

Figure 29. Identification of water meters and their fact sheets within the water quantity section of the Water Observatory of UNAM.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/Medidores

5. Shows the measurement of water supplied to each intake that has a water meter installed. Graphs showing daily, monthly, and yearly consumptions are displayed (see Figure 30). It is possible to make comparisons between consumptions of the University units, as well as comparisons between different periods for a given unit. This is considered one of the most important functions of the Water Observatory platform.

Figure 30. Graph showing annual water consumption of one of the buildings of the Institute of Engineering, UNAM.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/Consumo

6. Displays the location of the entire hydraulic infrastructure, including wells, tanks, pipelines, antennas, signal repeaters, water meters, etc.
7. Provides access to an alarm system. In this function, it is possible to include a list of the emails of people to be notified in case of an occurrence, such as leaks that require immediate attention.
8. Enables you to check the signal quality of each water meter. If a signal is too week, PUMAGUA’s staff will physically inspect the water meter or the repeater to solve the problem.

With regards to the user mode, there are only two functions available: consumption and leaks, as it was considered that this would be the information of most interest for a regular user. For the same reason, consumption and leaks refer to a whole institution (school, institute, administrative offices) and not to each water meter.

3.3 Participatory Community Solution

In order to enhance community participation in responsible use and management of water at UNAM campuses, several activities have taken place:

- Regular meetings with authorities of institutes, schools, and administrative offices to invite them to implement the following actions: installation of water meters, installation of water saving toilet appliances, landscape management, installation of water fountains, attendance at PUMAGUA’s workshops, and dissemination of PUMAGUA’s communication campaigns.
- Activities addressed to students and academics, such as contests of proposals to improve water management and use, water festivals, artistic contests, water audits at schools.

- Capacity building activities, such as workshops for maintenance staff and for gardeners.
- Undergraduate and postgraduate theses conducted under the supervision of PUMAGUA.
- Popular science and indexed articles (e.g. Modern Environmental Science and Engineering; Rivista Digital Universitaria; Revista Ciencia y Desarrollo; and Revista ¿Cómo ves?)
- Appearance in the media: newspapers, television, radio, and digital media.

The PUMAGUA "Participative Community" module is comprised of two elements. The first is the implementation of the aforementioned six actions suggested by PUMAGUA to the schools, institutes and administrative offices of UNAM. The platform assigns different weights to each action according to their impact on water saving. For example, the installation of water meters and toilet appliances had a higher weight than workshop attendance. The actions are then added up and a "medal ranking" is applied. Consequently, each entity is awarded a gold, silver, or bronze medal (see Figure 31). The purpose of this system is to give recognition to the most enthusiastic institutions and therefore encourage participation in responsible water use.

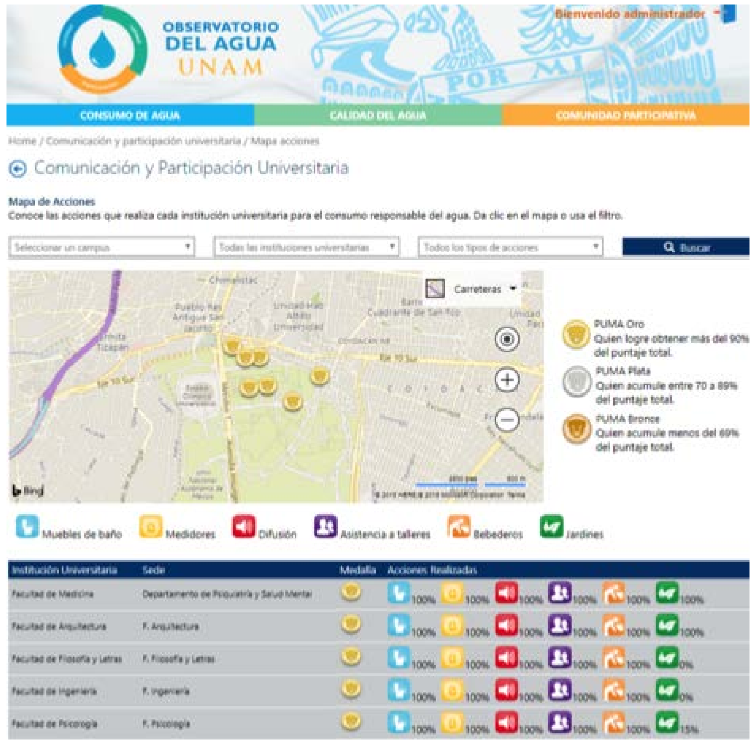

Figure 31. Screenshot of the Participatory Community module of the Water Observatory, showing water saving actions implemented by institutions of UNAM, as well as the "medal" assigned as a result.
Source: http://www.observatoriodelagua.unam.mx/Comunidad/MapaAcciones

The second element of the "Participative Community" module consists of a survey designed to enable PUMAGUA to send questionnaires to different university constituencies: students, professors, researchers, administrators, and maintenance staff (see Figure 32). The purpose of the survey is to assess the community's perception regarding water management at the campus as well as to learn their attitudes, beliefs, and behaviors regarding water use.

Figure 32. "Participative Community" screenshot of the Water Observatory of UNAM, showing the surveys implemented, as well as a graph displaying the results of one of those surveys.
http://www.observatoriodelagua.unam.mx/Comunidad/ModuloEncuestas

3.3.1 Dissemination of the Water Observatory of UNAM

In order to announce the Water Observatory of UNAM to the Mexican public, a press conference, organized by the General Direction of Social Communication of UNAM, took place in December 2016. The general structure as well as all the functions of the Observatory were explained. Likewise, the Water Observatory was included in the most important means of internal communication.

Announcements of the UNAM Water Observatory in digital media

Gaceta UNAM
http://www.gaceta.unam.mx/20161215/monitoreo-en-tiempo-real-del-agua-en-distintos-espacios-de-la-universidad/

UNAM en línea
http://www.unamenlinea.unam.mx/recurso/83546-observatorio-del-agua

Fundación UNAM
http://www.fundacionunam.org.mx/ecopuma/unam-monitoreara-uso-de-agua-en-tiempo-real/

3.4 Benefits of SWM solutions within the PUMAGUA Program

3.4.1 Water quality

The use of smart technology has been highly beneficial for PUMAGUA and for the University community. It has helped the community to gain confidence in the drinking water quality, through enabling the immediate detection of issues in the water and providing transparency through real time water quality data. In addition, having automated monitoring and control systems for the water on campus has increased trust within the community, as there is less potential for mistakes than with manual monitoring. Implementing SWM technology at UNAM has also resulted in a rapid response time when a water quality parameter does not comply with Mexico's water quality regulations, enabling water quality to remain within drinking water requirements at all times.

Furthermore, the automation of water quality monitoring has resulted in an increase in acceptance and trust in drinking tap water on campus. In 2012, a face-to-face survey conducted on the main campus of UNAM, found that only 14% of those interviewed drank the tap water on campus (Espinosa et al. 2014). In contrast, in 2017, an online survey, via the Water Observatory of UNAM, found that 49% of interviewees were now drinking the tap water (either directly from the tap or from a water fountain). While care should be taken with the comparison between these results as the first survey was conducted using randomly selected participants, while the second was advertised in PUMAGUA's social networks, the significant increase in willingness to drink tap water on campus indicates the benefit of continuous monitoring and display of information.

3.4.2 Water quantity

The use of smart technology for water quantity measurement was fundamental to gain control over the water supply and distribution system at UNAM. It permits the accurate measurement of water consumption, allowing for comparisons between institutions and between different periods for the same institution. This information is then used to encourage water saving actions across the campus. Smart technology also permits the identification of leaks and classifies them according to their volume, which in turn, allows rapid response times for major leaks.

Water consumption measurement and leak repairs have helped to obtain a consumption pattern of UNAM institutions that corresponds to institutions characteristics, such as whether or not they have laboratories or gardens, and their population number, etc. (Figure 33). Before the SWM technology and intensive leak repair, water consumption did not correspond to the type of institutions.

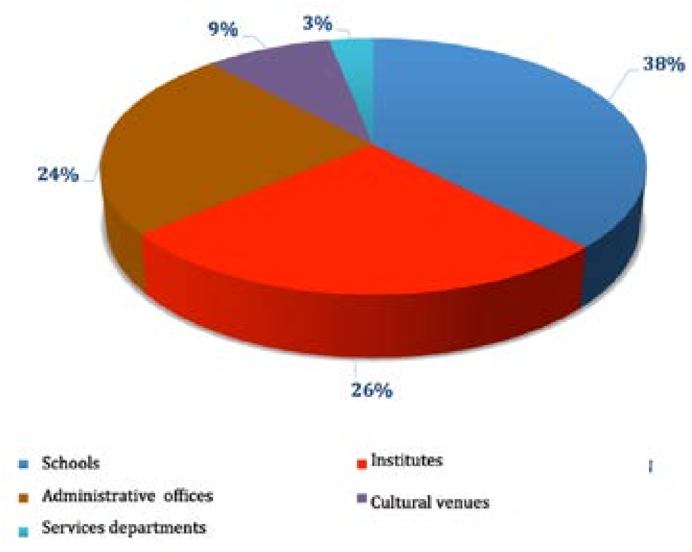

Figure 33. Water consumption pattern of different type of institutions in CU, UNAM

3.4.3 Enablers

The following is a list of project elements that contributed to PUMAGUA's success at UNAM:

- Establishment of a dedicated program and staff (i.e. PUMAGUA), with the participants deeply dedicated to PUMAGUA's goals, working even on holidays.
- Interest of specific authorities (directors, secretaries of Institutes and Schools). As PUMAGUA did not have funding to support the purchase of water saving equipment, it depended on the good will of these stakeholders, who were committed to the environment and willing to invest in water saving equipment and processes.
- Funding from the University. Without the funding from UNAM it would not have been possible to be successful in our activities.
- National targets and policies. In particular, the goal of PUMAGUA to achieve good water quality coincided with the national and local policies and laws regarding the installation of water fountains in schools.
- Visibility of the Program nationally and internationally. As a lot of work was done in order to make PUMAGUA visible outside UNAM and Mexico, this helped us to be more taken into account by UNAM's authorities.
- Multidisciplinary: Having engineers, biologists, doctors, communication professionals, architects, amongst other disciplines, working as part of the team and together in specific projects of PUMAGUA helped to have an integrated, flexible and adaptive vision.

3.5 Barriers

The main barrier across all elements of the project relate to limited resources including financial, human capital and technological resources. The following section details these limits within the project areas of water quality and quantity.

3.5.1 Water quality

One of the main challenges for the PUMAGUA project was that despite the automated water management system it introduced, supervision is still required as the sensors have occasional functionality problems, requiring constant calibration and periodic maintenance. This requires a significant investment, which must be incorporated into the budget. This has been difficult as the funds provided by UNAM have been reduced in recent years.

3.5.2 Water quantity

The Water Observatory of UNAM has become one of the main tools of the water quantity area of PUMAGUA, and it is therefore of the utmost importance that it works properly. Accordingly, the PUMAGUA team checks the information displayed through the Observatory on a daily basis, to detect and correct any possible errors. Some of the most frequent errors are found in incorrect consumption data. This can be caused by a water meter sending information to two repeaters, resulting in the duplication of information. Another detected error has been the occurrence of negative measurements (Figure 34), which are caused by signal interruptions from repeaters, water meters, or antennas. Incorrect graphs also need to be corrected immediately, as do any difficulties found when editing the information in the Water Observatory.

Figure 34. Error in water quantity section: a graph showing negative values of water consumption within one of UNAM's Institutes taken from the Water Observatory.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/ConsumoIndex

As a result, there is still a need to have people constantly supervising and correcting errors in the digital platform and database, as well as in the equipment installed throughout the campus, despite the automated technology. Solving this problem requires an investment in human resources, which PUMAGUA cannot afford at this stage.

Another challenge this project faces is the constant updating of technology. It required significant investments to acquire the technology described above, and recently PUMAGUA was informed that the manufacturing company is no longer producing antennas, and that mobile cellular signal has become favoured over radio-frequency. Although investing in a technological update would result in the challenge of finding the necessary financial resources, it is also an opportunity to acquire technology that will solve the problem of occasional water consumption reading errors and high maintenance requirements.

3.6 Replication of PUMAGUA outside UNAM

To share the success of the PUMAGUA project outside of the university campuses, PUMAGUA ran trial replications of the program three times throughout Mexico with varying success. The following section provides an overview of these three replication attempts, including the barriers faced and successes achieved.

3.6.1 Cities within the states of Puebla, Oaxaca, and Tlaxcala

In order to contribute to improved drinking water supply in disadvantaged cities in Mexico, the PUMAGUA program was replicated as the Project for Hydraulic Support for the States of Puebla, Oaxaca, and Tlaxcala (PADHPOT, for its acronym in Spanish), which was launched in 2013. As an initial step in the project, ultrasonic water meters were used to make a first diagnosis of water volumes for each city (Figure 35).

Figure 35: Use of smart water technology to measure water flow in one of the cities addressed by PADHPOT, UNAM.
Source: Rocha Guzmán 2013

Table 2. Existing, effective, and needed water flow in the Mexican cities involved in PADHPOT

State	City	Population	Average needed water flow (l/s)	Average existing water flow (l/s)	Average effective water flow (l/s)	Water provision (l/person per day)
Oaxaca	San Francisco	12, 000	17	9	5	37
	Ocotlán	21,000	36	15	5	28
	Zimatlán	19,000	44	14	9	37
	Cuetzalan	47, 000	55	66	40	72
Puebla	Izúcar	73, 000	126	134	80	95
	Tehuitzingo	11, 328	20	9	6	44
Tlaxcala	El Carmen	15, 000	27	51	15	85

The analysis showed that the hydraulic systems of these cities operated with physical efficiencies of less than 50%, due to the infrastructure being used for twice its lifespan and the water capacity of the infrastructure not being properly considered during installation. A lack of updated infrastructure plans and statistical registers of their operations also created a challenge, as did the reduced access to water for most residents of the cities, who only received water on average of twice a week for five hours at a time (González and Arriaga, 2014).

Deficiencies in drinking water services had forced the inhabitants of these localities to buy water from mobile water tanks distributed by tanker trucks and bottled water, spending up to 15 times the amount they pay for the tapped drinking water service (González and Arriaga, 2014).

With regards to water quality, the water was manually disinfected with chlorine hypochlorite. In some localities it was not done regularly, putting the inhabitants' health at risk (González and Arriaga, 2014).

In order to improve the water provision for these communities, the project developed two lines of action:

1. Drinking water and sanitation: Smart technology macro-meters were installed in wells and in distribution tanks, providing the basis for an action plan. To increase the water supply efficiency, concrete actions regarding infrastructure were also proposed, and technical staff were provided.
2. Water Observatory: To enhance the perceptions of the water supply system performance in the community, participatory workshops were delivered alongside technical courses to engage with the operators of the water services (González and Arriaga, 2014).

Unfortunately, after three years of work, the project was abandoned due to the constant change of water system authorities, at all government levels (federal, state, and municipal) and prolonged delays in bureaucratic procedures (e.g. signing contracts and gaining funds), both from government institutions and UNAM. Despite this, the initial success of the project did result in some benefits for the local community: works were started in Ocotlán, Oaxaca to improve the drinking water supply system, several talks about the importance of water disinfection were given, as well as water culture workshops for children to increase the awareness sustainable water use in the community (Rocha Guzmán, pers. comm).

3.6.2 National Autonomous University of Baja California Sur (UABCS, for its acronym in Spanish)

In 2014, at the request of the authorities of the National Autonomous University of Baja California Sur (UABCS) and with the facilitation of the nongovernmental organisation Niparajá, an agreement was signed with PUMAGUA in order to implement some of its actions at UABCS.

As part of this agreement, PUMAGUA's staff carried out a diagnosis of the hydraulic infrastructure of the UABCS' campus and prepared digital plans for the staff (see Figure 36). Using a portable ultrasonic water meter, the water supply on the UABCS campus was also calculated (Figure 37).

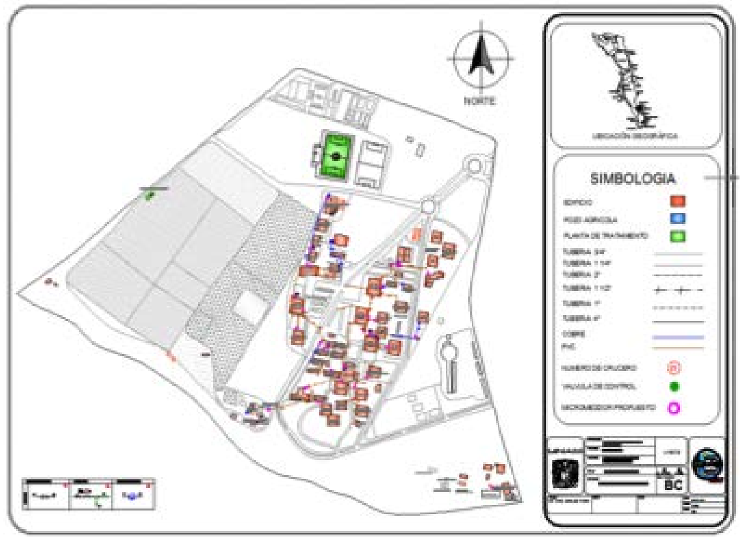

Figure 36. A digital plan of hydraulic infrastructure of the UABCS campus.
Source: PUMAGUA 2014

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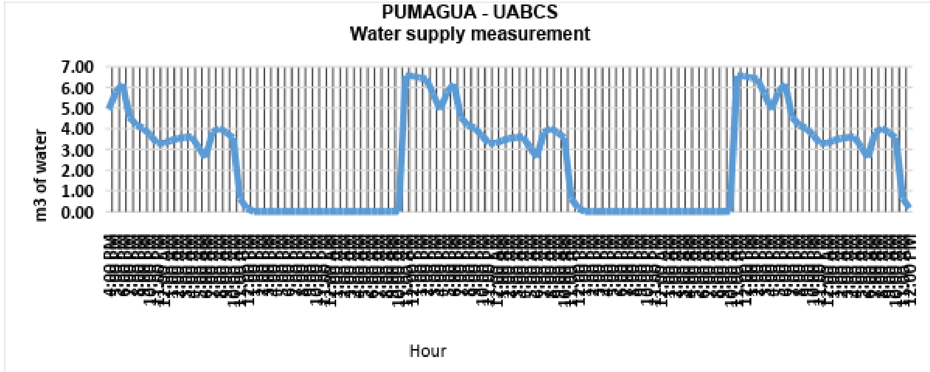

Figure 37. Hourly water supply measurement at the main campus of UABCS, using an ultrasonic water meter.
Source: PUMAGUA, 2014

As a result of these measurements, it was determined that 29 water meters using mobile signal to transmit information (instead of radio frequency) should be installed throughout the campus. As of June 2018 half of these meters have been installed. There were changes in the personnel authorities of UABCS, and these new authorities were not as interested in this project, causing delays in the projects continuation. Despite this, a new agreement with NIparaja, UABCS and PUMAGUA will be established in 2018 in order to continue actions regarding installation of remaining water meters, and also to implement actions regarding water quality and community participation.

3.6.3 Low income Housing in Mexico City

In 2017, the Ministry of Social Development of Mexico City signed an agreement with UNAM with the purpose of implementing actions of PUMAGUA in low-income housing. As part of this project, a diagnosis of the hydraulic infrastructure of the housing development called "Los Rojos", in the eastern part of the city, was carried out.

With the use of an ultrasonic water meter, it was possible to measure the water supply as well as the average water consumption in the buildings of Los Rojos. It was determined that the average water consumption corresponded with what the World Health Organization considers as sufficient to ensure that the most basic needs are met (between 50 and 100 litres per person per day), with the exception of one of the buildings, where only 43 litres per person per day was consumed. To monitor water consumption for each building, water meters were installed in each of the nine buildings (Figure 38).

Figure 38. Micro meters installed at the low income housing of "Los Rojos" in Mexico City.
Source: Josué Hidalgo, 2017

Based on the diagnosis, a list of suggestions were made to improve water supply in Los Rojos by improving infrastructure, taking management actions and promoting water savings by users with high water consumption. A second stage of this project is planned to monitor actions and to implement activities to monitor drinking water quality.

To understand the community's perceptions of the water service and their behaviour regarding water use, 30 residents were interviewed (10% of housing population) (as shown in Figure 39). The survey revealed that residents acknowledge their responsibility in water saving, and that the majority carry out important actions such as repairing leaks and closing faucets when not using water. However, less than half of the survey participants reuse water and 20% of those who have cars wash them using a hose instead of a bucket. In addition, the majority of survey participants take long showers (over 10 minutes), and very few have water saving toilet appliances. As such, these surveys showed that there is still a lot of work to do in helping this community to reduce its water consumption.

Figure 39. Survey in the low income housing Los Rojos to assess users' perceptions of the water service and behaviours in terms of water use.
Source: (Josué Hidalgo, 2017)

4. Links to the SDGs

PUMAGUA is linked to sustainable development goals (SDGs) 1 (towards zero poverty), 6 (clean water and sanitation), 9 (building resilience), 12 (sustainable consumption), 13 (climate action), and 17 (partnerships for the goals). Table 3 lists the specific targets within these SDGs that are addressed by PUMAGUA.

Table 3. A list of the SDGs and their specific targets that relate to the PUMAGUA program.

SDG 1: Towards zero poverty **End poverty in all its forms everywhere**	
1.4	Ensure access to basic services, including natural resources and appropriate new technology
SDG 6: Clean water & sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.1	By 2030 achieve universal and equitable access to safe and affordable water for all
6.2	By 2030, achieve access to adequate and equitable sanitation and hygiene for all
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.B	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 9: Building resilience **Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation**	
9.4	Upgrade infrastructure and retrofit industries to make them sustainable with increased resource-use efficiency
SDG 12: Sustainable consumption **Ensure sustainable consumption and production patterns**	
12.2	Achieve the sustainable management and efficient use of natural resources
12.8	Ensure that people have the relevant information and awareness for sustainable development and lifestyles in harmony with nature
12.a	Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns and consumption
SDG 13: Climate Action **Take urgent action to combat climate change and its impacts**	
13.3	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
13.B	Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities
SDG 17: Partnerships for the Goals **Strengthen the means of implementation and revitalize the global partnership for sustainable development**	
17.6	Enhance access to science, technology and innovation and enhance knowledge-sharing

Specifically, PUMAGUA is linked to goal 1.4 as the main consequence of its efforts is to enhance water availability for next generations of UNAM's community, as well as for the inhabitants of Mexico City. Technology is fundamental in this sense.

The main goals of the Program are tightly linked to goals 6: access to sufficient good quality water, both in terms of drinking water and treated wastewater. There is also a strong commitment to improve efficiency in water management and to increase water savings by consumers. Participation from the community and from authorities has been one of the main goals of the Program, and a lot of work has been done on that end.

Regarding SDG target 9.4 to upgrade infrastructure for sustainability and resilience, substantial investments have made within the PUMAGUA program to upgrade infrastructure at target sites: e.g., the disinfection system for drinking water and the refurbishment of wastewater treatment plants.

A significant aspect of the PUMAGUA program was in education and information dissemination, through the Water Observatory and several communication campaigns, in order to increase awareness and participation. This aligns with several targets within the SDGs, including 12.8 of ensuring people have the relevant information for sustainable consumption, 13.3 of impact reduction and increasing education for climate action and 17.6 of enhancing knowledge-sharing through partnerships. Also, regarding target 12.a, the efforts of PUMAGUA to strengthen UNAM's scientific and technological capacities towards sustainable development can serve as a model for the rest of the country and for other developing nations. All the efforts of PUMAGUA to diminish water consumption mean also adaptation to climate change, as water sources are being protected. Furthermore, the decrease in bottled water usage may help to reduce the demand and required energy for production of bottled water, and for its transportation, contributing to a reduction in greenhouse gas emissions (SDG 13).

5. Lessons learned

Smart water systems cannot fully replace traditional approaches for water management. However, complementing real time information with in-situ water sampling and analyses enriches the end results and the validity of information. Despite the newly automated water management and monitoring system, it will still require a lot of maintenance at least in the short-term. It is therefore important to consider this in the budget when planning SWM implementation to ensure sufficient funds are saved for staff and the training required to upkeep the SWM technology. A summary of lessons learned throughout the implementation of PUMAGUA are listed below:

- Technology can change and become outdated quickly. It is important to study which technology will be the most suitable, and also to conduct research on whether there are any new technologies soon to come on the market that might be more effective than the technology currently available. For example in the PUMAGUA case, sensors that use radio frequency were chosen, requiring additional infrastructure to ensure the radio waves reach the entire campus. Now mobile frequency sensors are available that do not rely on additional infrastructure, which may be more cost effective in the long-term.
- Care should be taken in order to prevent the use of SWM technology creating a dependence on one particular commercial product or manufacturer. It would be desirable for companies to have products compatible with each other in order to have different options. Compatibility would also likely accelerate their response time to project inquiries and issues.
- Despite the initial maintenance requirements of SWM technology, this project acts as a learning experience that will allow technology and the system to advance to a point where maintenance issues are fixed and it becomes more robust. As with any other technology, as smart water management becomes mainstream it will become cheaper and easier to implement.
- Through PUMAGUA, it was found that people are much more trusting of automated data than they are of people manually monitoring and updating data. This became evident throughout this project as people started to trust the drinking water quality when they knew the monitoring was automated, and when they could see the results for themselves on the Water Observatory platform. This was also observed during talks with the UNAM community, where all community members responded positively when informed that real-time automated data was available for the water quality of UNAM water taps every 5 minutes. This shows that people appreciate having access to real-time data for water quality as it assures them of the safety of the water. Automated monitoring plays a role in increasing trust in water quality in comparison to the manual monitoring of data, which is incapable of providing updated, accurate data on water quality every 5 minutes.
- This confidence from the public on automated monitoring could be of use to water utilities in some cities of Mexico, where water quality is adequate and people do not drink tap water because of distrust.
- Real time information can be very useful to build patterns about the behavior of parameters during different periods as it is possible to obtain continuous information. This could be useful to identify possible threats of pollution. For instance, if concentration of nitrates is gradually approaching regulation permissible limits, this may indicate organic pollution, which could be prevented.
- PUMAGUA originally had plans to implement SWM in some of the poorer areas of Mexico City to assist with improving water quality and leak detection. However, it was found to be increasingly difficult, especially in areas where basic infrastructure is limited or of very low quality, because it can be a challenge to implement effective monitoring systems where there is little to monitor. Instead, by focusing on what could be assisted with (monitoring the houses that did have a water connection) we were able to make a difference in these areas that we hope to extend upon in the future. It was concluded that in order for SWM to be implemented in poor areas, at least a basic water distribution and infrastructure system must exist.

6. Next steps

6.1 Water quality

Our next step in regards to water quality is to foster more tap water drinking through the installation of new water fountains throughout the UNAM campus. Due to project budget limitations, this will be accomplished with the help of other institutions of UNAM. The water fountains will be installed in schools, but also in social meeting places, such as green areas, sport facilities, and cultural venues.

PUMAGUA will keep maintaining the real time monitoring system and, if we have the necessary funding, we would like to install this kind of system in another part of the campus, in order to increase reliability of information.

The digital platform of the Water Observatory allows for the connection with other systems of UNAM campuses. Therefore, if in the near future any of the campuses of UNAM acquires a real-time monitoring system, they can also be linked to the platform and information from in-situ water quality sampling can be uploaded.

6.2 Water quantity

In order to upgrade the remote water consumption system at UNAM, we are planning to carry out a pilot project that allows us to decide which potential new system is the best one. On one hand, we will install some water meters that use mobile signals instead of radio frequency. This system has several advantages, for example, it does not require antennas or signal repeaters, reducing the infrastructure costs. However, while signal transmitting through radio frequency is free, in the case of a mobile signal, an annual fee must be paid to the mobile phone company and therefore, we will need to evaluate the pros and cons of this technology and the costs associated with these fees.

With the help of researchers from the UNAM Institute of Engineering, we will also try to develop our own technology for a remote water consumption system, in order to stop depending on private enterprises. This process will take longer, and will include water consumption measurement, data transmission, data reception, and uploading into the Water Observatory. Although this strategy is time consuming, working with a university institute represents an opportunity for research and capacity building, especially for students.

We are also looking to test a sensor to detect soil moisture in order to determine if the gardens on campus are being overwatered. If the sensor is functional, several sensors will then be installed throughout the green areas of the University City, and will be linked to the Water Observatory. This will help to involve the whole community, including gardeners, in the responsible use of water in irrigation.

6.3 Social participation

Information about the implementation of actions recommended by PUMAGUA and implemented by schools, institutes, and administrative offices, will be continuously updated in the Water Observatory.

Also, the survey module of the Water Observatory will be continuously used in the future. We are particularly interested in monitoring the ongoing progress of communication campaigns to encourage tap water drinking at UNAM and consequently the decrease of bottled water purchases.

7. Conclusion

PUMAGUA was created to improve water management, use and reuse at the campuses of UNAM. Since the implementation of PUMAGUA, there have been several achievements in terms of water savings, water quality improvement, capacity building and enhancement of community participation. The use of SWM technology has been fundamental for these achievements. It has helped to produce and disseminate a substantial amount of information, and to convince the community about the validity of this information, as it is perceived as free from human error.

This technology however does not work independently from human beings: it needs human resources for updating and for the correction of errors. Also, SWM must be supplemented by other sources of information, such as on-site sampling. In the case of PUMAGUA, real time sensors are located only in one place and provide information about six water quality parameters. In contrast, our on-site water sampling allows us to monitor 75 drinking water fountains, 25 intakes, and 52 water storage tanks. Moreover, water sampling allows us to analyze 47 parameters included in Mexican regulation, which could not be monitored by real time sensors.

Updating SWM technology is an opportunity to extend it to other aspects of monitoring and maintenance, for instance, the installation of sensors to measure soil moisture. Also, it is an opportunity to start to develop our own technology, in order to decrease dependence on commercial providers.

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Appendix

Population and economic conditions in Mexico

Mexico is the second largest economy in Latin America, after Brazil, and the fifteenth in the World (its Gross Development Product was worth 1026 billion US dollars in 2016, with an annual growth of 2.3% (World Bank, 2017). It is the country of the Organization for Economic Cooperation and Development (OECD) with the highest inequality level: the incomes of the richest are more than 25 times those of the poorest (OECD, 2017). Furthermore, the top 1% has an average annual income 47 times that of the poorest 10% (del Castillo Negrete Rovira 2012). In 2016, according to the National Social Development Commission (CONEVAL, for its acronym in Spanish), reported that 53.4% of Mexicans were poor and 9.4, extremely poor.

It has the highest inequality level of any OECD (Organisational for Economic Cooperation and Development) country with the incomes of the richest equaling more than 25 times those of the poorest (OECD, 2017). Strong disparities are also seen in the geographical and temporary distribution of water in the country. While the wealthier central, northern and north-western regions (constituting two thirds of Mexico), have a lower per capita water availability of 2044 m^3/year they contribute 84% to the GDP, increasing their ability to fund water related infrastructure. In contrast, water availability in the poorer southern regions, while significantly more abundant than the northern regions, (14,291 m^3/year per capita), presents a water management challenge in itself due to the reduced ability to develop and maintain infrastructure (Tortajada, 2006) (Figure 1).

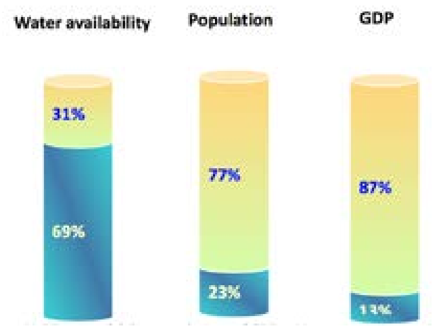

Figure 40. Map of Mexico showing water availability in regions
Figure 41. Water availability, population and GDP in Mexico

Water resources in Mexico

México receives around 1.5 millions of cubic meters of rain per year. About 72% of this water is lost through evapotranspiration, 22% flows through rivers and 6% infiltrates and recharges the aquifers. Considering the exports and imports to and from neighbor countries, Mexico has about 470 millions of renewable water (CONAGUA, 2014.).

There are strong disparities in terms of geographical and temporary distribution of water in the country. On one hand, in the central, northern and northwestern regions, which constitute two thirds of the territory, per capita water availability is of 2044 m^3 /year, while in the southern states water is an abundant resource (per capita water availability of 14 291 m^3/year) (Figure 1). However regions with low water availability contribute with 84% of the GDP, and the southern part of Mexico only produces 16% of GDP, has high rates of poverty, and low development of infrastructure (Tortajada, 2006)
Also, there are notorious differences in water availability throughout the year. Most of the rains occur in summer (from May to October), while the rest of the year is relatively dry (CONAGUA, 2014).

Climates in Mexico

As the country has many mountains with rapid changes in elevation, temperature and rainfall, in a relatively small area it is possible to find several Köppen climate categories. However, by aggregating these areas seven main climate regions are obtained (Geo-Mexico, 2017): Af (tropical wet), Aw (tropical wet-and-dry), BS (semi-arid), BW (Arid (desert), Cw(temperate with dry winters), Cf (humid subtropical), Cs(Mediterranean). Most of the territory has mean annual temperatures above 15C.

Gastrointestinal diseases and water

Temperature is widely recognized as an important factor in enhancing bacterial growth. Therefore, in climates where water temperatures are warm (above 15 °C), bacterial growth may be fast (LeChevallier, 2003). This is particularly notorious in storage tanks where water is in contact with ambient temperature and does not flow. However, water that is distributed through underground usually does not present bacterial growth (A.C. Espinosa García, November 20, 2017). Therefore in Mexico occurrence of gastrointestinal diseases is related to poverty and lack of good drinking water services, and not to temperature (see Table). The Mexican states with highest percentage of inhabitants in extreme poverty are Chiapas, Oaxaca, Guerrero, and Veracruz (CONEVAL, 2017). These four states have also the lowest drinking water coverages in the country (80% or less) (CONAGUA, 2011). It is worth pointing out that 95 of households in Mexico have water storage containers (tanks, cisterns, bottles) and more than 60% of them has more than one container (González Villarreal and Lartigue in press).

Figure 42. Valley of Mexico in pre-columbian times.
Source: Iracheta-Conecorta, 2000.

According to the last census, the ZMCM has a population of approximately 22 million, 9 of which live in Mexico City (OCDE, 2015). One in five Mexicans live in the ZMCM, considered as one of the biggest agglomerate urban areas in the world. Several studies calculate that the population will increase by 13% between 2010 and 2030 (OCDE, 2015).

The ZMCM is supplied with 72.5 m^3/s of drinking water, of which 72% come from the aquifer of the Valley of Mexico, 18% from the Cutzamala system in the State of Mexico, and Michoacán, 8% from the Lerma system in the State of Mexico, and 2% from springs and runoffs within the Valley of Mexico (Jiménez Cisneros et al. 2006).

About 10 m^3/s are used for irrigation of agricultural lands, and from the remaining 62.5 m^3/s, about 30 m^3/s are consumed by domestic users, 9 by industrial, commercial and service users, and the rest are lost through network leaks (23 m^3/s) (Jiménez Cisneros et al. 20006)

Per capita consumption volume was measured by Capella-Vizcaino et al. (2008). Although its average is 184 l/person per day, there are severe inequalities between water consumption volumes in different areas of the city (Figure 3): from less than 125 to over 475 l/person per day.

Temperature and water quality

Temperature is widely recognized as an important factor for decreased water quality, as it can play a role in enhancing bacterial growth. Therefore, in climates where water temperatures are warm (above 15 °C) such as in Mexico, bacterial growth may result quickly (LeChevallier, 2003). While this is the case, water distributed through underground infrastructure is less likely to present bacterial growth issues (A.C. Espinosa García, November 20, 2017), and therefore the issue of water quality through high bacterial growth is related to poverty and lack of good drinking water services, and not to temperature.

Climates in Mexico

As the country has many mountains with rapid changes in elevation, temperature and rainfall, in a relatively small area it is possible to find several climates including tropical, semi-arid, desert, temperate, humid subtropical and Mediterranean. Despite this range in climatic conditions, Mexico's mean average temperature is above 15°C (Geo-Mexico, 2017).

The Metropolitan Area of Mexico City

Mexico City, formerly Federal District, is part of the Metropolitan Area of Mexico City (ZMCM), which includes 59 municipalities of the State of Mexico, and one of the state of Hidalgo (OECD. 2015).

The ZMCM is located in the Valley of Mexico, one of the four valleys inside the Cuenca de México (Watershed of Mexico), which was originally an endorheic watershed (a watershed that is contained and does not flow into the ocean).

The ZMCM has six different climates (Table X), with an average annual temperature of 15oC (8oC higher in summer and lower in winter). Most of the average annual precipitation (between 600 mm in the northern areas and 1,200 mm in the southern areas) occurs between May and September, with little or no precipitation during the rest of the year (Romero-Lankao), and therefore severe floods are frequent during the rainy season.

Table 3. Climates of the ZMCM and percentage of area occupied by each one

Climate description	Symbol	Percentage of area
Temperate sub-humid, with summer rains, low humidity	C(w0)	30
Temperate sub-humid, with summer rains, medium humidity	C(wi)	17
Temperate sub-humid, with summer rains, high humidity	C(w2)	16
Semi-cold sub-humid, with abundant summer rains	C(E)(m)	2
Semi-cold sub-humid, with summer rains, high humidity	C(E)(w2)	17
Semi-dry temperate, with summer rains	BS1kw	18

Source: FUENTE: INEGI. Cuaderno Estadístico de la Zona Metropolitana de la Ciudad de México edición 2002. Aguascalientes, Ags., 2002

According to the last census, the ZMCM has a population of approximately 22 million, 9 of which live in Mexico City (OCDE, 2015). One in five Mexicans live in the ZMCM, considered one of the biggest agglomerate urban areas in the world. Several studies calculate that the population will increase by 13% between 2010 and 2030 (OCDE, 2015).

The ZMCM is supplied with 72.5 m^3/s of drinking water, of which 10 m^3/s are used for irrigation of agricultural lands, and from the remaining 62.5 m^3/s, about 30 m^3/s are consumed by domestic users, 9 by industrial, commercial and service users, and the rest are lost through network leaks (23 m^3/s) (Jiménez Cisneros et al. 2006) Per capita consumption volume was measured by Capella-Vizcaino et al. (2008).

Concerns about the environmental impacts of PET disposal have also been raised in different forums, such as the Congress, the Senate, and in several Civil Organizations, and Academic Institutions (see, for instance, Freshwater Action Network, 2017, Quadratin, 2017). In March 2017, the Federal deputy German Ralis Cumplido presented a legislative initiative to make people aware of the environmental impact of PET through labeling of bottled water (Jiménez, 2017).

K-water (the Korean Water Resources Corporation)
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