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Practical pressure management for a gradual transition from intermittent to continuous water supply

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ABSTRACT

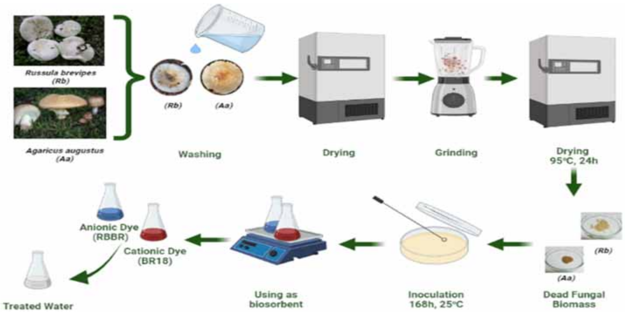
Cities in developing countries that do not consider water resources as the basis for sustainable growth usually accept intermittent water supply (IWS) as the alternative to satisfy the demand of the population. Networks designed as constant water supply (CWS) operated as IWS hinder a safe and reliable water supply; thus, feasible alternatives to return the operation to CWS are required. This paper presents a methodology based flow/pressure control to accomplish an efficient transformation from an IWS sector to a CWS in the City of Chihuahua, Mexico. The management of pressure at sector entrance and critical supply points leads to successful improvement of service, ensuring water availability with adequate pressure at the peak of demand, as well as reducing the supply of water volume by 58% compared to the sector operated in IWS. The methodology allowed the improvement of decision-making and operating policy for the water operating agency (WOA), fixing service deficiency, avoiding the loss of water volumes, and maintaining competent management control. Nonetheless, resistance to the transition of using automation and setting the volume/pressure consumption based on reliable data persists. The change process will be successful to the extent that the WOA efficiently channels the participation of the personnel.

Key words: CWS, DMA, hydraulic efficiency, IWS, pressure management

HIGHLIGHTS

- Flow/pressure control using reliable data allowed an efficient transformation from IWS to CWS.
- Measurement/control equipment and real-time network monitoring were used to assess DMA behavior.
- Management at sector entrance and critical points lead to successful improvement of service.
- Water volume was reduced by 58% compared to the DMA operated in IWS.
- In 21 months the water savings estimation exceeds one full year of supply.

GRAPHICAL ABSTRACT



INTRODUCTION

Piped water supply for a few hours a day, or intermittent water supply (IWS), is a common form of access to water in developing cities with 500,000 or more inhabitants (Ilaya-Ayza *et al.* 2018). IWS has been growing as an alternative to public policy in communities where continuous water supply (CWS) is complex to achieve (Tsegaye *et al.* 2011). Totsuka *et al.* (2004) stated that IWS exists due to poor technical management, economic scarcity, or insufficient water supply. The absence of consideration of the infrastructure or water resources as a baseline for the sustainable growth of a city causes the lack of the ability to provide water service in sufficient quantity and quality. It is the case of the city of Chihuahua where the operation of several districts is 'forged' day by day through the experience and criteria of the Municipal Water and Sanitation Board (known in Spanish as JMAS). The JMAS decides to maintain a 'more or less' service to existing zones, alternatively in new zones, a need for extraction of higher volumes has arisen to satisfy the new demand. It should be noted that the increase in supply is not equated with effective demand coverage, because of the lack of effective conduction and distribution (Klingel 2012; Galaitsi *et al.* 2016). Several studies have shown that network deficiencies caused by IWS, may not guarantee the safe and reliable provision of water (Hunter *et al.* 2009; Herrera *et al.* 2012; Kumpel & Nelson 2013; Ilaya-Ayza *et al.* 2017). One of the best ways to assure water quality in the network and to reduce deficiencies for users is maintaining a positive and continuous pressure level throughout the network (Kumpel & Nelson 2014; Ilaya-Ayza *et al.* 2018). Thus, transforming a network operating in IWS to a CWS is the main challenge in developing countries (Vairavamoorthy *et al.* 2008). The first step in the transition process is the division of the network into district metered areas (DMAs) (Paola *et al.* 2014). DMAs split an interconnected and intricate network into smaller, virtually independent sub-networks (districts) that can be better managed; each district proposes a maximum demand value, seeking to maintain homogeneity in the pressure distribution. A substantial benefit of DMA implementation is the ease of detecting any abnormality within the district (Morrison *et al.* 2007; Herrera *et al.* 2012). For a Water Operating Agency (WOA) such as JMAS, detecting abnormalities allows the recovery of water volume losses in network leaks and makes it possible to identify clandestine connections or malfunctions of the flowmeter.

The traditional design of DMAs has been based on empirical suggestions (limits on the number of properties, length of pipes, etc.) (Nardo *et al.* 2013); in the case of Chihuahua, the number of user accounts was the criterion to elaborate the physical delimitation of the sectors, giving priority to zones with greatest service deficiency. JMAS put into operation the delimitated sectors with constant water supply (CWS), causing leaks in the surrounding areas because of the uncertainty in the cadaster, therefore, there was no impact on the perception of improvement of the service by the population. JMAS concluded that the unacceptable results were due to the quality and quantity of data generated from the delimitated sectors. The data generated through the supply and distribution of drinking water by the WOA can be 'dark data', presenting uncertainty in the flow or pressure values making them unreliable, causing the WOA to view the 'dark data' skeptically. Digitization, intelligent learning systems, information and communication technologies (ICT), and automated machine learning, are methods that led to the rebirth of water data. Nevertheless, no specific reference for the use of reliable data to improve the transition of IWS sectors to CWS may be found in the literature. WOA seeks alternatives to solve the transition from IWS to CWS, where water companies are not able to make large investments to achieve transition processes in a single and large project (World Bank 2013; Patil *et al.* 2017). As Ilaya-Ayza *et al.* (2018) stated, the gradual transition based on improvement stages is deemed to be a good option, as the first transitioned sectors to CWS serve as guidance for the next sectors. This paper presents a methodology based on reliable data (obtained by ICT) to accomplish an efficient transformation from the IWS sector to CWS. The process will allow improvement of service deficiency, avoid the loss of water volumes, and maintain competent management control. New methodologies exist to gradually increase the capacity for guaranteeing water supply equity in an intermittent and continuous coexistence network, such as that of Ilaya-Ayza *et al.* (2018), which led to improving the hydraulic behavior of the network, driving to new scenarios with increased capacity that allow higher pressure level in all sectors. However, this study addresses the use of ICT data to analyze the pressure in a sectorized network to optimize the transformation from IWS to a CWS sector. It is expected that the results will contribute to the efficient management of water resources, providing WOA with a greater understanding of the water supply and distribution making it able to ensure water equity and stable pressure for the consumers.

METHODS

Description of the case study system

The city of Chihuahua is located in the northern part of Mexico between 28°500 to 28°300 North latitude and 106°120 to 105°500 West longitude. Chihuahua is the capital of Chihuahua state (Sánchez-Navarro *et al.*

2019), and the second most populated city of the region with a population of 929 739 in 2018. The city has a land area of 224.85 km^2 and uses 3 300 km of water distribution network to serve 327,000 customers. The distribution network is a complex system, because of the extension and the topography of the supplied area (with elevations ranging between 1348 and 1500 a.s.l.). The length of the mains in the network is 829.6 km, which is only for the mains of the network that are bigger than 100 mm, the remainder of the network have a length of 2,527.1 km used for service connections. The volume of non-revenue water in Chihuahua changes every year, but the average non-revenue water volume is 49 Mm^3 per year (38% of supplied water).

There are several methods for portioning the network into DMAs (Morrison *et al.* 2007; Herrera *et al.* 2012; Nardo *et al.* 2013); recently, the JMAS in collaboration with the Mexican Institute of water technology (IMTA) designed a methodology to restructure the DMAs in the city of Chihuahua. This research, however, does not design the DMA in the Chihuahua network but focuses on integrating pressure management to evolve the DMA from IWS to CWS.

The DMA is part of a zone composed of 8 sectors that supply water to an estimated population of 35,994, the study sector has a population of 3850 and an average volume consumption prior to pressure management of 450,900 m^3/yr. The studied DMA has 1100 customers connected to the network, of which 99.5% are households and the rest commercial services. The mains length in the DMA is 1.63 km (0.20 and 0.45 m diameter), and the length of sub mains and service connection is 7.4 km (diameters less than 0.20 m). The DMA has an area of 0.356 km^2, with elevations ranging between 1486 and 1474 a.s.l. in a length of 606 m (Figure 1). The DMA before the application of the methodology had an IWS with two schedules, from 4:00–9:00 and 16:00–20:00. The IMTA and JMAS carried out a pressure survey to record the pressure within the sector. With the network pressurized, pressure gauges were installed in 55 households' outlets. The results were a minimum pressure of 0.7 kg/cm^2, maximum pressure of 2.50 kg/cm^2, and an average pressure of 1.56 kg/cm^2. The pressure distribution within the sector allowed validation of the behavior predicted in the hydraulic model made by the JMAS using INFOWORKS PRO program.

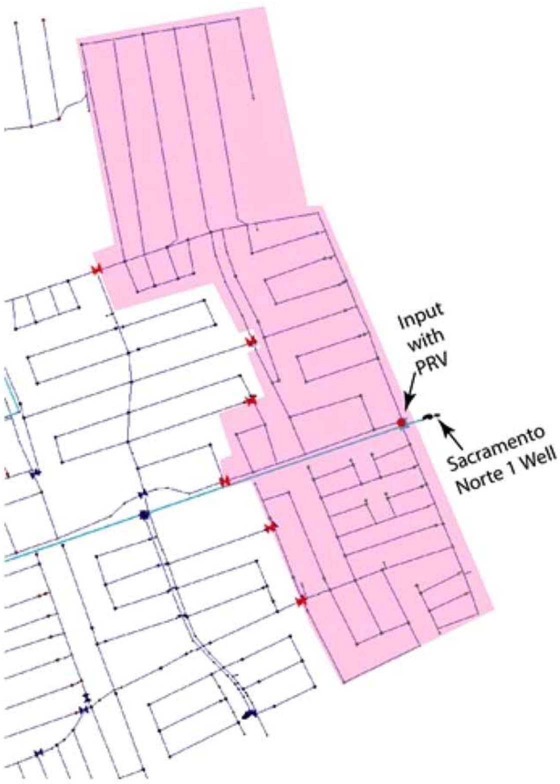


Figure 1 | The Sacramento 1, Study DMA.

Measuring instruments, real-time network monitoring, and control equipment were included to enable real-time knowledge (Maiolo *et al.* 2019). The entrance to the sector was instrumented with: Arkon electromagnetic flowmeter with pulse output, starting flow of 0.5 m^3/h maximum flow of 200 m^3/h and $\pm$2% accuracy; a Bermad pressure regulating valve (PRV) and Pegasus+ pressure control system developed by HWM-Water Ltd (Cwmbran, UK), which were installed to control upstream and downstream pressure/flow; two Multilog LX data loggers with two pressure and one flow channel developed by HWM-Water Ltd (Cwmbran, UK) were set in the most unfavorable points (high and low) within the sector to record the pressure/flow (Figure 2).

Figure 2 | Real-time instrumentation for pressure management in the city of Chihuahua, México. 1. Electromagnetic flowmeter. 2. Pressure regulating valve (PRV). 3. PRV controller with GPRS communication. 4. Multilog, advanced data logger with integral GPRS telemetry. 5. Multilog, advanced data logger with integral GPRS telemetry at a critical point.

Figure 3 shows the behavior at the DMA entrance and at the critical points, this data was taken while operating as IWS.

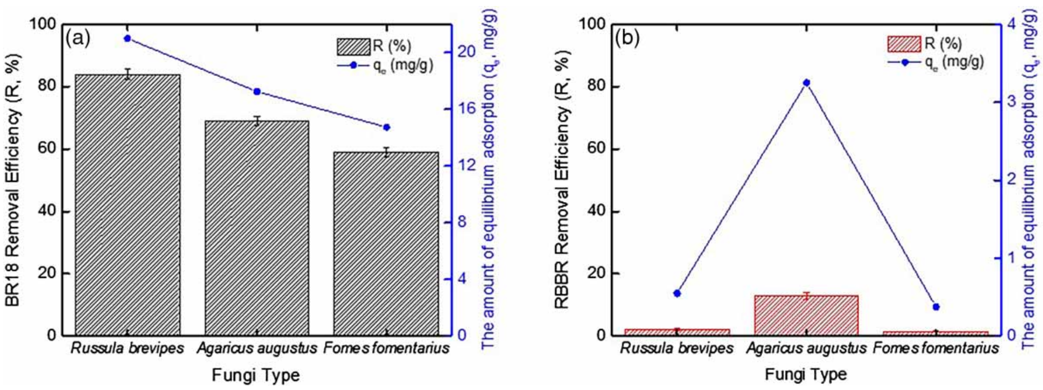


Figure 3 | Flow/pressure data at PRV and critical points within sector 01. This data register was taken in an intermittent water supply (IWS).

A peak can be observed at the beginning of the flow service hours (black line) which serves only to displace air in the pipe network (saturate the sector); this volume of water does not turn into consumption by the user. It took an hour between the opening of the PRV and the gauging of the operating pressure at the critical points, as it is appreciated in the displacement between the pressure downstream of the PRV and the pressure in the critical points (highest and lowest point respectively). This displacement can only be observed through *in situ* measurement, since all simulation models are based on the assumption that, once in operation, the network remains loaded.

Flow values of 132 to 0 l/s are presented in the DMA, upstream of the PRV values of 50 m are reached, decreasing to a pressure range of 35 to 0 m downstream. Critical points showed a 31 to 6 m pressure range at the lowest, and 13 to −7 at the topographically highest point, exhibiting suction in the network.

Knowing the flow/pressure behavior in the DMA allowed establishment of a multi-step methodology to achieve an efficient transformation from IWS to CWS.

Methodology of transition from IWS to CWS

In the first step, the command was to establish the schedule to have sufficient pressure and flow at the time of greatest demand in the sector (Nyende-Byakika 2018; Taylor *et al.* 2019; David *et al.* 2020). The second step included a supply modulation considering a critical point or the most unfavorable point within the sector; in this stage, there is a constant pressure supply schedule in the PRV. Equitable distribution of pressure was sought by contemplating the loss due to topography, which supports the uniformity of available service time (Ameyaw *et al.* 2013). The last step included the regulation of the flow to determine the minimum night flow (MNF). MNF analysis is the most common method for leakage assessment at the scale of the DMA (AL-Washali *et al.* 2018). The MNF is the lowest inflow in the DMA over 24 h of the day. MNF occurs depending on the consumption pattern of the DMA when most of the customers are probably inactive and the flow at this time is predominantly leakage (Farley & Trow 2003; Farley & Liemberger 2005; Puust *et al.* 2010).

RESULTS AND DISCUSSION

In the first step, the timing instruction was given to set the pressure and water flow in higher demand. The service schedule was determined by the day-night cycle on a weekday of July 2018 (hot season) operating in CWS. As can be appreciated in Figure 4 when there is high demand, the pressure in the network decreases and vice-versa. The highest demand occurs between 07:00 and 11:00, reaching max. flow values of 55 l/s and pressure of 18 m; while the lowest demand occurs between 22:00 and 06:00 reducing the consumption up to 10 l/s with a max. pressure of 60 m, these values were measured downstream of the PRV.

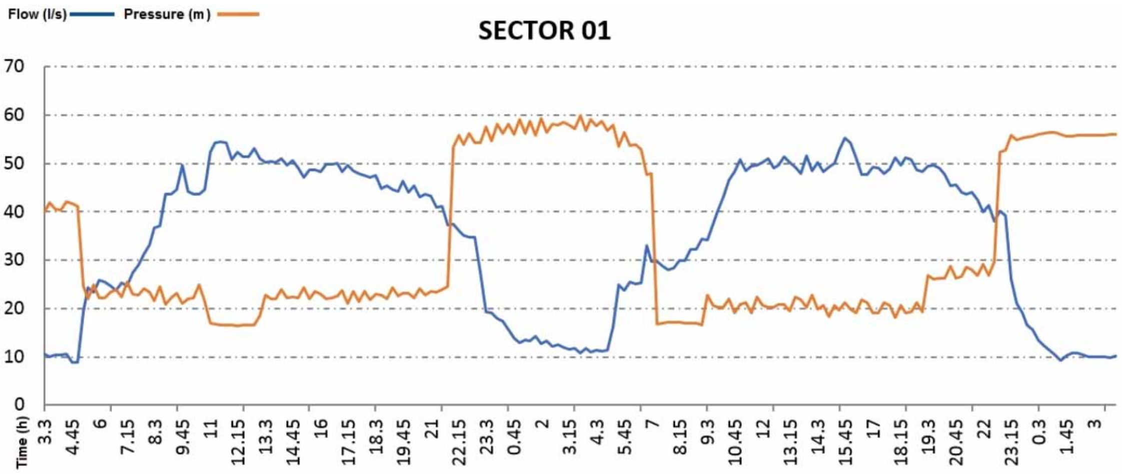


Figure 4 | Pressure and water flow pattern downstream of the PRV in sector 01.

The behavioral pattern identified in Figure 4 was used to establish the service hours in the sector. This schedule was based on the flow displacement and minimum required pressure, seeking to avoid negative pressures and peak flows at the beginning of the water supply.

Figure 5 shows the DMA as it was adapted to the water demand based on the behavior. In this stage, because there is an equalization of the water supply with the demand, the peak of filling of cisterns or water tanks is no longer so pronounced, decreasing the max. flow to 106 l/s compared to 130 l/s operating as IWS.

The water pressure and flow were aligned, offering water availability with pressure downstream of the PRV. The change in pressures within the sector can be recognized; displaying values of 17 to 13 m at the lowest topographic point, having water availability during the 24 h service. Alternately in the highest topographical point, minimal essential pressures are shown, without reaching suction ranging values from 10.5 to 2.5 m.

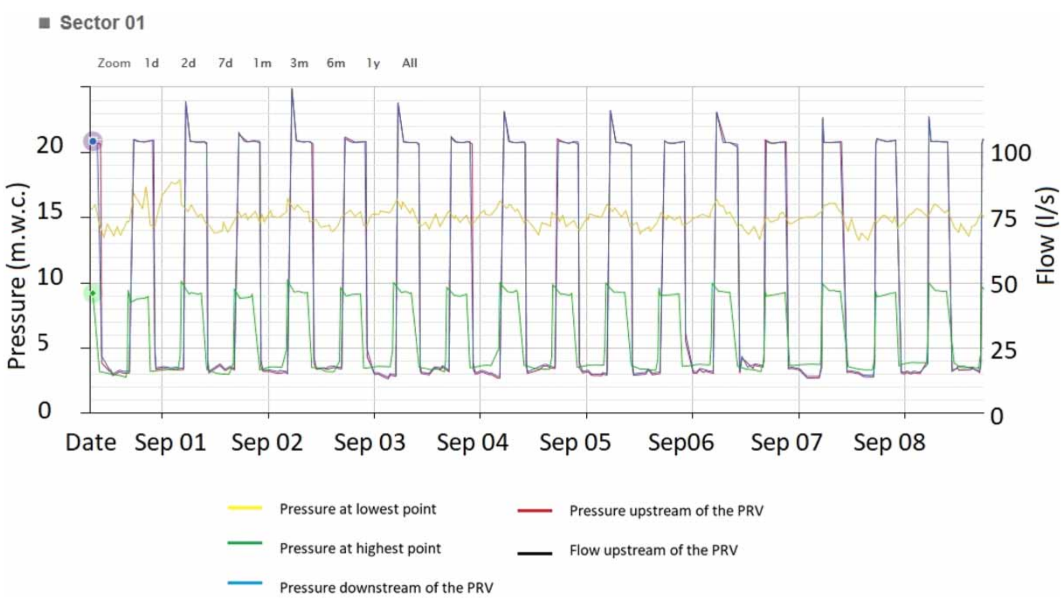


Figure 5 | Pressure/flow adapted according to the behavior of the DMA.

The second step addressed the modulation through critical points within the sector to set a homogeneity of the water supply. This was accomplished by controlling the differential of pressure downstream of the PRV, to pair the flow with the required demand. As illustrated in Figure 6, the pressure lines downstream of the PRV and at the critical points show similar behavior presenting water availability with adequate pressure at the peak of demand. The flow values were decreased in the DMA to 75 l/s with a min. of 30 l/s stating a reduction of 43% with respect to the use of IWS and 30% compared to the first step. The downstream pressure of the PRV was modified to a range of 16 to 6.5 m. The lowest critical point increased its pressure range to 20.5–29 m, staying within the acceptable limit to avoid generating overpressures in the network. The highest topographic point also increased its pressure range to 3.5–12.2 m, obtaining enough pressure to supply water even in households with the highest elevation during the 24 hours.

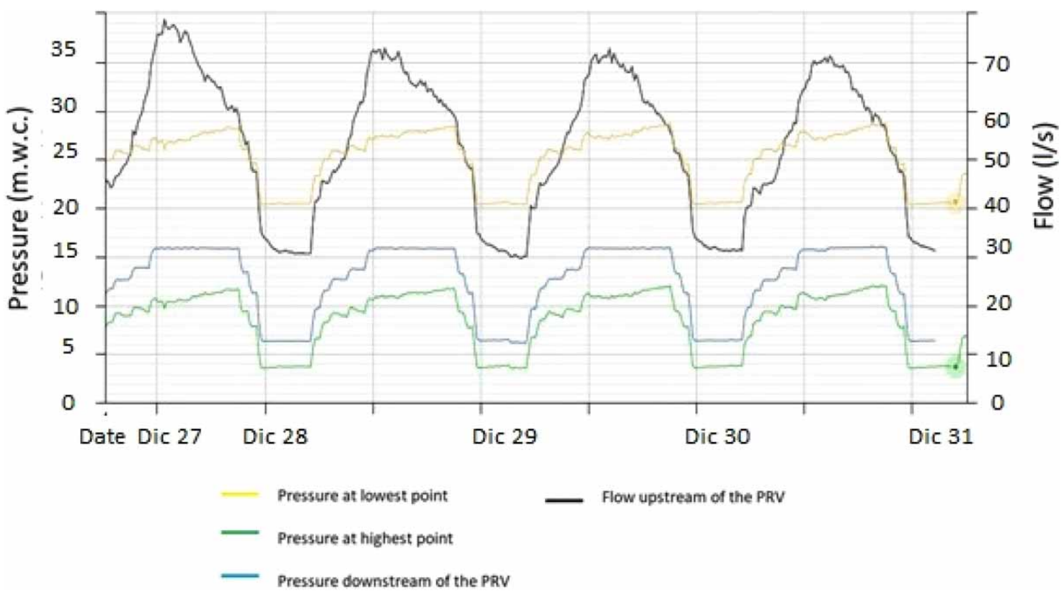


Figure 6 | Pressure/flow aligned according to the critical topographic points of the DMA.

The third step consisted of reducing the flow to a minimum using legitimate night consumption (AL-Washali *et al.* 2018), the use of MNF will allow identifying the leak volume. The downstream PRV instruction was to reduce the flow to 16 l/s between 23:00 and 05:00, maintaining a minimum pressure of 0.6 m to prevent void in the network (Figure 7).

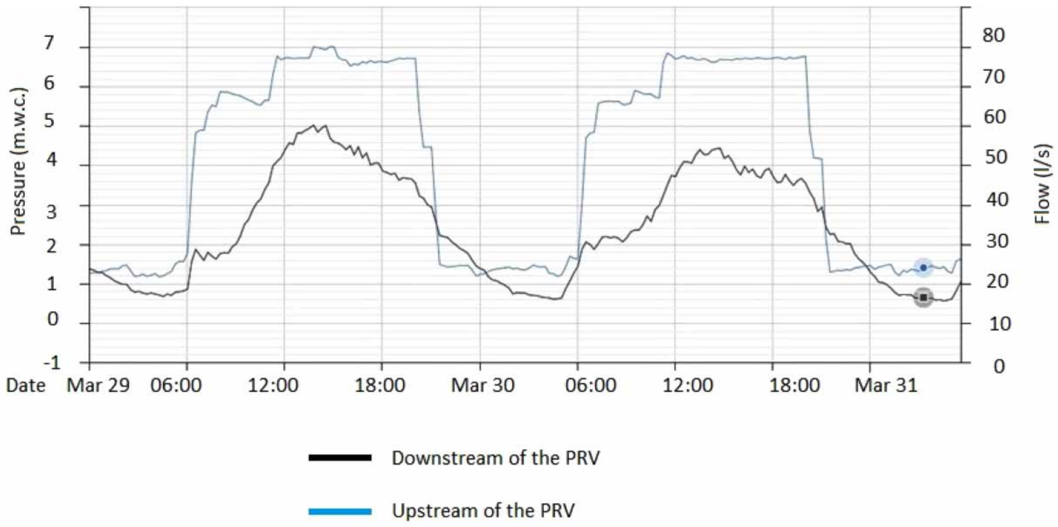


Figure 7 | Regulation of flow by setting the minimum night flow.

This methodology started after the JMAS finished the proper delimitation of the sector and operated the DMA as CWS to establish the behavior of the sector (Figure 4) during July 2018. The sector when operating in IWS required a daily supply of 1,509 m^3, 1.37 m^3 per household (hh) per day. The first step of this study began in August 2018 (Figure 5), in which 770 m^3 per day were supplied to the sector (0.7 m^3/hh/day) reducing the consumption compared to the IWS operation in 49%. The second step was set up from November 2018, in which the daily consumption increased to 1,013 m^3 (0.92 m^3/hh/day) compared to the first stage, however, this step provided water volume with sufficient pressure to the entire sector during 24 h. The last step began in January 2020, managing to reduce daily consumption to 636.8 m^3 per day (0.58 m^3/hh/day) leading to a 58% reduction in consumption compared to the operation of the sector in IWS. The estimation of the water savings by April 2020 is 477,280 m3, in 21 months from the origin of the study.

CONCLUSIONS

In this paper, the results of practical pressure management were given, to evaluate the transition from intermittent to continuous supply using reliable data (obtained by ICT). Data were collected by monitoring a district of the Chihuahua (Mexico) water distribution network. The district serves around 1,100 properties with a total population of about 3,850. Pressure and flux were measured upstream/downstream of the PRV and at the topographic critical points (highest and lowest), in order to establish the water consumption behavior of the DMA. The methodology set in the study improves the decision-making and operating policy for the JMAS. However, it should be noted that the operators and users are skeptical because they have become accustomed to a water supply routine and they consider that lowering the pressure is to lower the quality of the service. Furthermore, leaks come into sight because keeping the network charged at a minimum pressure makes them visible instead of having the leaks disappear in the discharge of the line, therefore, rehabilitation and leak detection is a priority. It should be noted that the volume supplied in the DMA operating in IWS is more than double, opposite to the water consumption using this gradual transition with restricted pressures. Nonetheless, resistance to the transition of using automation and setting the volume/pressure consumption curve based on reliable data measurement persists, because the perception of the operator is that the data is not registered or measured correctly. The change process will be successful to the extent that the WOA efficiently channels the participation of the personnel involved in the improvement of the processes. The management approach is directly related to institutional strengthening, and specifically to the direction and support actions required by the technical aspect.

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CONFLICTS OF INTEREST/COMPETING INTERESTS

The authors have no financial or proprietary interests in any material discussed in this article.

AVAILABILITY OF DATA AND MATERIAL

Available upon request.

CODE AVAILABILITY

'Not applicable'.

AUTHORS' CONTRIBUTIONS

Credit author statement

D H Sánchez: Conceptualization, Methodology, Investigation, Software.

JR Sánchez-Navarro: Software, Validation.

CJ Navarro-Gómez: Data curation, Writing-Original draft, Supervision.

M Rentería: Investigation, Supervision, Writing-review and editing.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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