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Analysis of hybrid demand pattern on a water distribution network with transition from intermittent to continuous water supply in Riberas de Sacramento, Chihuahua

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Abstract

This paper establishes a methodology to characterize the experiment design and analyze the hybrid demand pattern for a water distribution network in transition from intermittent to continuous supply and thus have a basis for the definition of a management model that defines adequate operation of a water distribution network for a sector based on the demand and the type of supply available. An analysis of the water supply situation during transition from intermittent to continuous supply in a referent sector called Riberas de Sacramento was carried out on the behavior of the network, the operating criteria of the system and the demand of the sector. For the consumption analysis, three consecutive years of data collected by government institution from micro meters were analyzed. In order to characterize the hybrid demand pattern to operate the network, prior site analysis determined the minimum amounts of pressures and consumption records to obtain series of data for analysis. After the review of the transition from intermittent to continuous water supply and the establishment of methodology to characterize the hybrid demand pattern, the need for a hybrid demand pattern is required, and this experiment design gives part to achieve it.

Key words: continuous, demand, hybrid demand pattern, intermittent, transition

INTRODUCTION

Hydraulic infrastructure in cities, according to an investigation by the Organization for Economic Cooperation and Development, is aging (OECD 2016), technology is obsolete and governance systems are often not well equipped to meet the growing demand, environmental challenges, continuous process of urbanization, climate variability and natural disasters.

The current models or design schemes usually used are based on a continuous flow and do not foresee an eviction or emptying of the pipes after starting the filling for the supply from the first time; that is, from the start of the supply and the pipe being filled for the first time, the distribution system must be pressurized (Starczewska *et al.* 2015). This current condition doesn't reflect the real situation for many communities where the design premises of a continuous flow are not those that are actually found, and these cause problems in the piping system since with intermittent flow there are transient phenomena characterized by suctions that generate weakening in the network and future failures, as in the quality of service given to the end user.

Currently, the problem of water distribution networks going from design and construction with a continuous flow, which follows the demand pattern of a daily/hourly variation curve (Arreguin *et al.* 2010), to an operation with an intermittent flow, in which the water distribution network system does not conform to the design parameters and lacks a defined management model to provide acceptable service with good pressure and availability 24 hours a day (Tzatchkov *et al.* 2014).

Deterministic models are those where it is assumed that the data is known with certainty (Tzatchkov *et al.* 2016). This pattern is related to a daily/hourly variation curve, where specific consumption is obtained by a certain point of measurement on a water distribution network on a certain day of the week depending on the time of year.

The Poisson Rectangular Pulses model has been developed in order to realistically simulate the demand for stochastic pattern (Alcocer 2007). In this way, a group of pulses will form a series of consumption that instantly reflects the real consumption data of users and these can be subsequently incorporated into the nodes that make up the distribution network.

It has been shown that the transition from IWS (intermittent water supply) to CWS (continuous water supply) is achievable and, if property managed and monitored, can lead to a decrease in the quantity of water needed (Rouse & El Achi 2019).

In this case, the study sector called Riberas de Sacramento presented a transition from IWS to CWS from 2017 to 2019, in which the government institution in charge of its operation decided to implement an operating system that could be beneficial for the population, increasing water service hours and keeping the WDN (water distribution network) pressurized at all time.

During this transition, the records of user consumption have been recompiled and this paper presents a proper analysis to detect consumption patterns and other kinds of relevant information that reflect the change of water use from IWS to CWS.

After that change of supply and analysis, there comes another type of issue, which is the hybrid demand pattern of the sector. Here, an adequate means of operation is detected by analysis of certain quantity of pressure and consumption data, recompiled from the sector by analysis of the best amount of records and its distribution. So that, here the procedure is described.

Therefore, the need for a hybrid demand pattern is required with the establishment of an experiment design to characterize it and thus have the basis for the definition of a management model that defines adequate operation of a water distribution network for a sector based on the demand and the type of supply available to provide a better drinking water service.

METHODS

Sample size quantities for the hybrid demand pattern study were obtained. These samples were selected by determining the main specific area of interest to analyze, through a study of the Water Distribution Network in the Riberas de Sacramento Sector; including the demand, the type of supply available, the behavior during a transition from IWS to CWS and operational actions on the part of the technicians.

Study site description

The Riberas de Sacramento Sector (RDS) was chosen as a case study. RDS is a low-class housing area located in the north of the city of Chihuahua, Mexico. This area covers approximately 110 hectares with an average height of 1,500 meters, an average annual temperature of 18.5 °C, its climate is dry-temperate and the population includes 1,500 families.

WDN analysis behavior during transition

The RDS sector was operated with intermittent supply by the year 2017 and it was composed of three main subsectors (Figure 1). After the implementation of the conversion into a CWS, the RDS was transformed into four subsectors (Figure 2), perfectly defined because of elevations, topology of the network and demands of users.

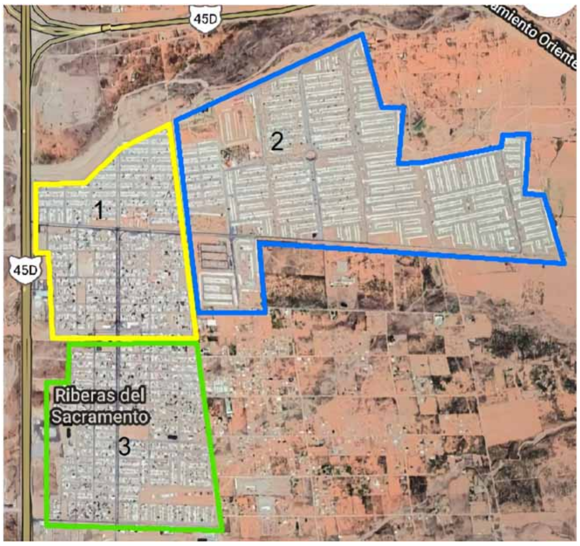

Figure 1 | Subsectors 1, 2 and 3 of Riberas de Sacramento IWS 2017.

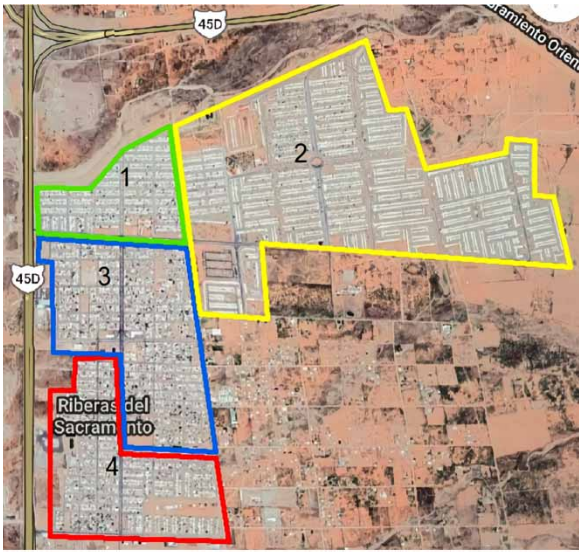

Figure 2 | Subsectors 1, 2, 3 and 4 of Riberas de Sacramento CWS 2019.

Comparing records from the government organization (Junta Municipal de Agua y Saneamiento (JMAS)) about pipe leaks and lack of water service, a general graph was generated (Figures 3 and 4) with values of years 2017, 2018 and 2019 for the months of January to September. This facilitates a visual analysis of how these factors changed during the transition from IWS to CWS.

Figures 3 and 4 show monthly and yearly averages of leaks and water shortages, represented by a straight line with the respective year of each data. It is possible to detect the months exceeding the average value (February, March and August by 2017 for water shortages, or January, February, March, May and August by 2018 for pipe leaks, etc.).

Besides the leaks and water shortages analysis, there is special attention to the occasional and necessary PRV (pressure regulating valve) checking, in which JMAS technicians report decreases in the frequency of revision of PRV because of network behaviour. Since the CWS was implemented, the transient effects have been alleviated.

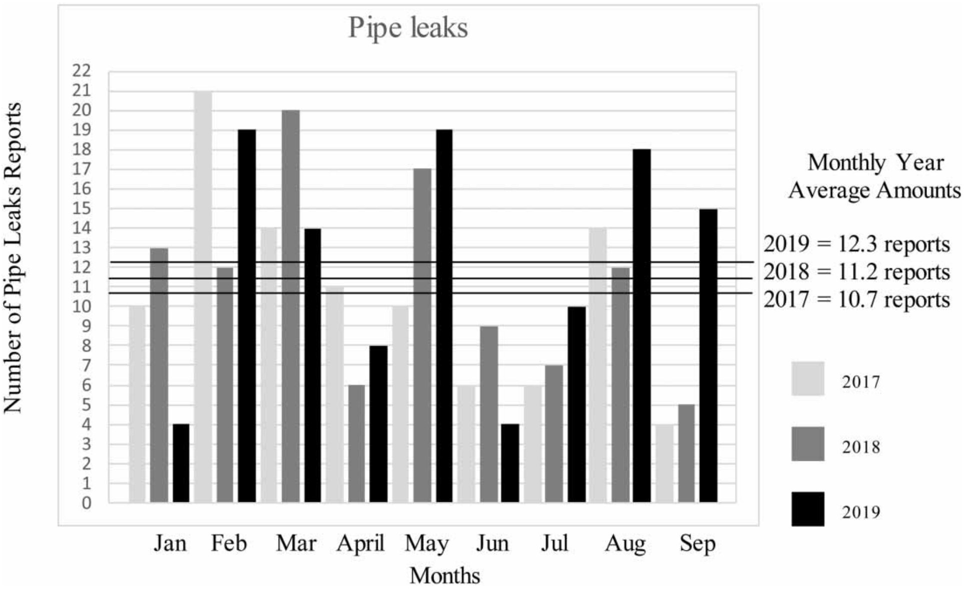

Figure 3 | RDS pipe leaks graph.

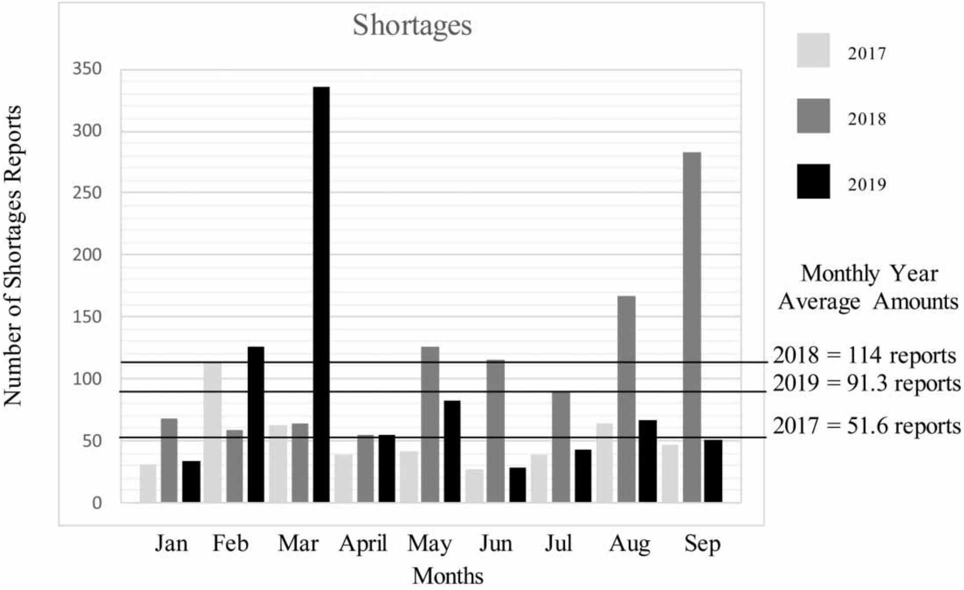

Figure 4 | RDS water shortage compilation.

Water user demand behavior

Demand of the RDS sector was analyzed with information on flow meters installed in the three principal subsectors. Flow data measured in L/s (liters per second) for each subsector was compared with the average of the month. To illustrate such results, the June graphs for 2018 and 2019 (Figures 5 and 6) are presented, where it is possible to see how the flow meter begins to measure in the middle of June 2018 and after that, despite the transition from IWS to CWS, the flow in both years is similar.

After the review of the flow comparison, a table with the average flow of each subsector for 2018 and 2019 (Table 1) was obtained, that represents the flow before and after the transition from IWS to CWS. It's important to point out that Subsector 4 doesn't have a flow meter yet because of the lack of government funding and thus no measurements were available for comparison.

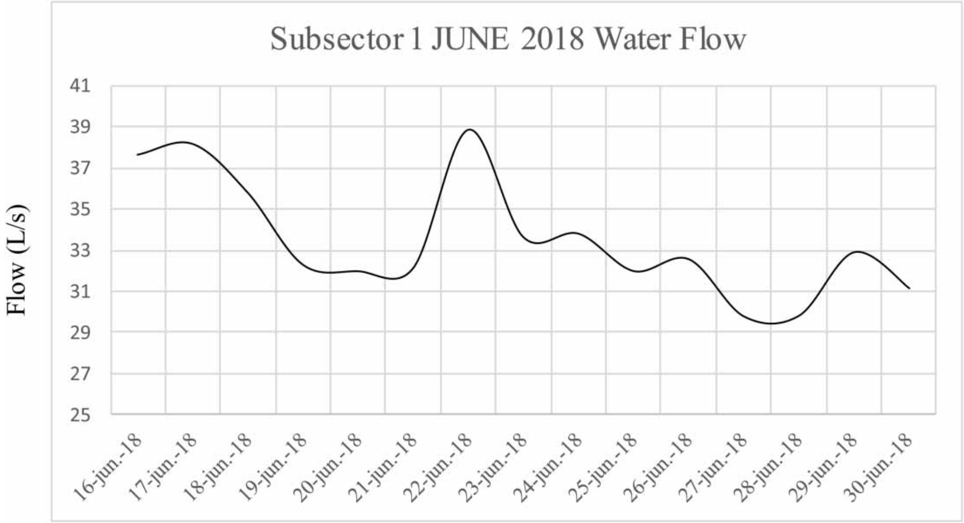

Figure 5 | Subsector 1 flow behavior 2018.

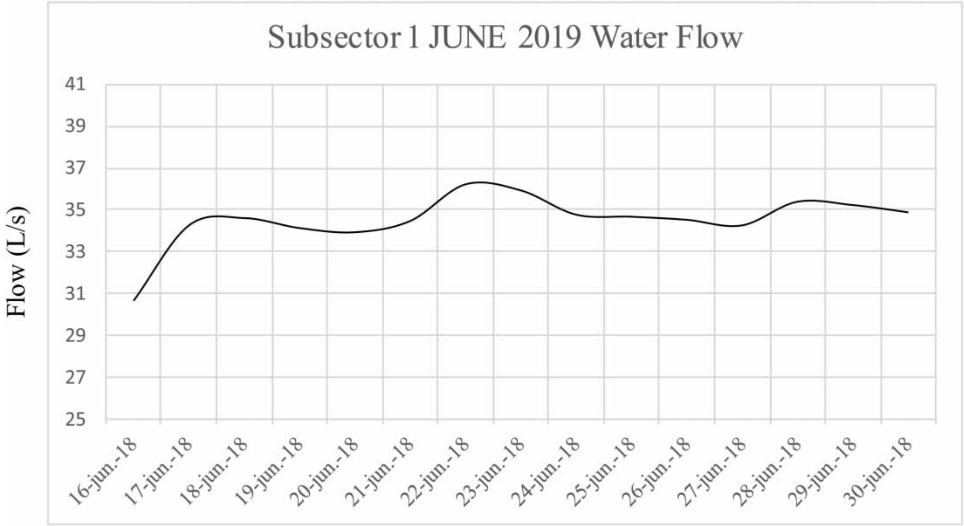

Figure 6 | Subsector 1 flow behavior 2019.

Table 1 | Subsectors average flow

Subsector	Flow 2018	Flow 2019
1	33.53 L/s	33.96 L/s
2	26.09 L/s	35.93 L/s
3	53.02 L/s	63.56 L/s

Analyzing the data from flow meters, randomly selected by careful clustering of areas with homogeneous characteristics (provided by JMAS for the month of August in the years 2017, 2018 and 2019), the variation in consumption was obtained, as seen in Figure 7 and Table 2. These variations show how the consumption of users has changed the volume supplied.

Considering the consumption variation from IWS to CWS, the analysis of a specific kind of users had to be made. Thus, from the four subsectors of the RDS sector, subsector 1 was chosen and

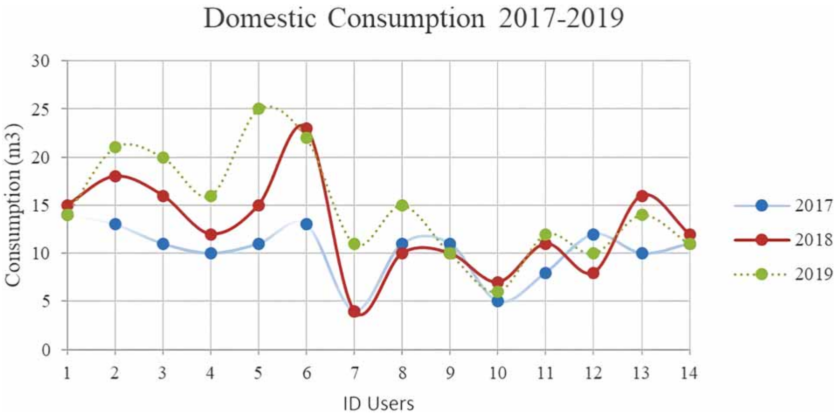

Figure 7 | Water consumption variation of various subsectors.

Table 2 | Water consumption in selected subsectors

ID	Sub Sector	ID Users	Adress	Consumption (m3)		
				2019	2018	2017
2	4	1	RIO EBRO 1402	14	15	14
1	4	2	RIO PO 1403	21	18	13
3	4	3	RIO ROJO 2427	20	16	11
5	3	4	RIO COLUMBIA 1400	16	12	10
6	3	5	RIO MURRAY 1401	25	15	11
16	1	6	RIO DIAMANTE 2441	22	23	13
4	4	7	RIO GUADIANA 2400	11	4	4
8	3	8	RIO META 1827	15	10	11
9	2	9	RIO RHIN 2408	10	10	11
10	2	10	RIO UBANGUI 249	6	7	5
11	2	11	CIRCUITO RIO BANAS 24	12	11	8
12	2	12	RIO CHARI 888	10	8	12
13	1	13	RIO HERRERA 1623	14	16	10
14	1	14	RIO FAJARDO 1812	11	12	11

characterized with a specific methodology utilizing a minimum quantity of records needed to analyze and determine the hybrid demand pattern for the best network operation.

Data collection subsector 1

The topology of the existing network in the study area was updated based on the existing cadaster plan of the network and through field trips, (valves, pipes, registers, tanks and pumps), then it was digitized in Arc Gis and Epanet computer software for further analysis (Figure 8).

Carrying out field trips supported by the existing cadaster, the characteristics of diameter and existing materials in the drinking water network of the sector were updated (Figure 9).

To obtain the experimental data, a placement of data loggers with pulse sensors in flow meters at strategically selected points was carried out, according to the homogeneity of the sector, determined by characteristic areas based on topographic, social characteristics, hydraulic characteristics and consumption features.

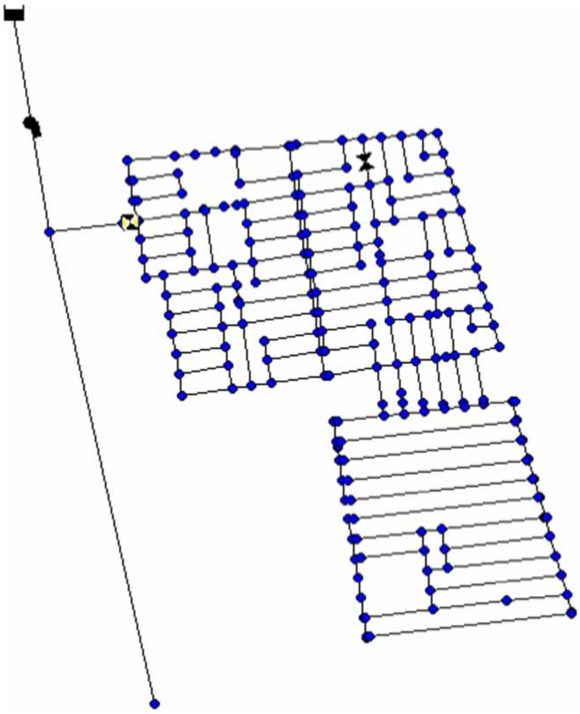

Figure 8 | EPANET model of Subsector 3.

Figure 9 | The characteristics of diameter and existing materials in the drinking water network.

Experiment design

To characterize the hydraulic behavior of the area, consumption data for users of the sector provided by the commercial area of the JMAS of Chihuahua over a period of one year was taken into account. These data were analyzed and classified into variants of 0–15 m^3 and 16–200 m^3 as they were the majority of one of the two ranges (Figure 10). There is not another highest level because there were so few data with values above 100 m^3 and for the analysis in question it was not relevant since the desired interval was represented; that is, consumers above the common 0–15 m^3.

The classification of homogeneous areas was carried out through a review of topographic areas of the sector, marginalization level (CONEVAL 2015), population density and social level (Figure 11).

Figure 10 | ARCGIS subsector 3 consumption data.

Figure 11 | ARCGIS subsector 3 homogeneous areas.

The experiment design was carried out using the Military Standard (MIL-STD) 105E sampling and acceptance technique (Montgomery 2004). The way to use this technique is by following a few steps, listed below, which are just a continuous sequence of selecting values depending on the population quantities, Acceptance Quality Level (this represents the acceptance or rejection of the sample if at the end of measure, the sample complies or not with the minimum acceptable level) and measure precision.

Process

1. Choose Acceptance Quality Level (recommended 1% for important defects and 2.5% for minor defects)

2. Choose the level of inspection I, II or III (recommended level I because of fewer measurements).
3. Determine the population size.
4. Find the appropriate code letter for the sample size (A–P)
5. Determine the appropriate type of sampling plan to be used (single, double, multiple).
6. Determine the inspection plan to use (normal, rigorous or reduced).
7. Consult the appropriate table to find the type of plan to use

With an acceptable quality level of 1%, inspection level I, reduced inspection and zero acceptance (Table 3) to obtain the minimum sampling quantities to represent the sector (Table 4).

Table 3 | Code letters for sample size on a reduced inspection (MIL STD 105E)

	General Inspection Levels				
Population size	**I**	**II**	**III**	**Code letter for sample size**	**Sample size**
2–8	A	A	B		
9–15	A	B	C	A	2
16–25	B	C	D	B	2
26–50	C	D	E	C	2
51–90	C	E	F	D	3
91–150	D	F	G	E	5
151–280	E	G	H	F	8
281–500	F	H	J	G	13
501–1,200	G	J	K	H	20
1,201–3,200	H	K	L	J	32
3,201–10,000	J	L	M	K	50
100,001–35,000	K	M	N	L	80
35,001–150,000	L	N	P	M	125
150,001–500,000	M	P	Q	N	200
500,001 >	N	Q	R	P	315

Table 4 | Sampling quantities obtained

Sector	Classification	Population Size	Inspection level	Sample size
1	(0–15 m^3)	456	F	8
1	(16–200 m^3)	28	C	2
2	(0–15 m^3)	502	G	13
2	(16–200 m^3)	38	C	2
3	(0–15 m^3)	1,339	G	13
3	(16–200 m^3)	178	D	3
4	(0–15 m^3)	680	G	13
4	(16–200 m^3)	98	D	3

Minimum sample sizes were obtained (Table 4), subsequently the investigation proceeded with a choice of domiciliary flow meters (remote smart meter with direct photoelectric reading) and loggers to read pressure and flow data for the analysis of the sector demand pattern and then realize the analysis of the data to obtain the hybrid demand pattern that best fits a sector with a non-permanent regime. That will be theme of a subsequent article.

RESULTS AND DISCUSSION

Transition from IWS to CWS

From the analysis, the variations shown in the transition from IWS to CWS reflects how the consumption of the users has changed, increasing the amount consumed for the majority of users because of the change in water supply. Specifically, in Table 2 the users ID 1, 9, 12 and 14 are the only ones with no increase in consumption of the 14 users randomly selected, thus illustrating an increase in the volume supplied to subsector 1.

Behavior of the network during transition denotes an increasing appearance of leaks but a decrease in water shortage reports after stabilization; the operating criteria of the system transformed the need to repair PRVs to an occasional maintenance visit, and the sector demand increased a little in just two of the three subsectors during the transition.

Experiment design to obtain the hybrid demand pattern

According to the homogeneity of the sector, a minimum number of data loggers and pulse flow meters were determined and is shown in Table 4. The positions were determined through a topographic, social, hydraulic and consumption analysis.

Discussion

Analyzing Figures 3 and 4, where is easy to see graphically which month bar exceeded the monthly year average, creating a dilemma as to why both graphs don't complement one another (shortage complaints should go down and leaks should go up), assuming that theoretically an increase in service hours favors greater scope in the satisfaction of water needs and thus fewer complaints of shortage are obtained, consequently there will be a higher number of pipe leaks due to the constant pressurization of the networks. It is assumed this dilemma is due to the IWS period, where the analysis began, not being clearly documented and thus it is not easy to associate with a consequence like the high occurrence of pipe leaks or a reduction in complaints of water shortage when the water supply becomes continuous. IWS is unpredictable and both factors can increase or decrease because of transient events occurring as the water supply transforms into a continuous supply; it may take years before it can be considered a CWS because the transition is in progress and some variation will occur during that time.

The transition from IWS to CWS becomes the first step in providing better water service to RDS users and the analysis made in this investigation contributes to understanding the impact of that change, including searching for the hybrid demand pattern that reflects the best operating criteria for the sector in the future.

In Chihuahua City, the RDS zone is the pilot area for the transformation from IWS to CWS. All the information generated here and by the organization is fundamental to determining the next steps for the supply transformation in other city zones. With these precepts and the results obtained in this analysis, the behavior of the WDN in other zones of the city needs to be analyzed in the same manner as part of the future work.

A final consideration of consumption is the increase in flow from IWS to CWS. Table 1 shows the increase in water flow of the three subsectors; this may represent that in IWS there is a lower quantity of water supplied and in the transition to CWS a greater quantity of water is supplied. It is expected that with the complete establishment of the CWS the flow of water supplied will stabilize and begin to fall, but in the meantime the data show a general increase.

This work will continue with another article where the analysis of specific kinds of users and their consumption behavior will be performed, in order to search for a hybrid pattern of demand so the behavior of user consumption can be better understood.

CONCLUSIONS

This paper begins the design of a methodology to characterize the hybrid demand pattern in a network in transition from an intermittent to a continuous water supply. The case study used for testing this model was one of the principal sectors of Chihuahua City, Riberas de Sacramento, with specialization in one of the four subsectors operated by the organization in charge (JMAS).

This investigation detected the impact of water supply change. An increase could be observed in certain problems like pipe leaks, but the theory marks that with the change of flow to continuous, the occurrence of leaks should be reduced, so the data collected is expected to support this in the future. So there was also an increase in water shortages the first year of the change to CWS but then the following year they began to fall, which may mean that the CWS is beginning to be established. It reflects how the transition is taking place and the effects it causes to reach the establishment of a complete continuous flow.

This work found an increase in consumption by users of the WDN when beginning CWS, shown in Table 2. This consumption increase could be associated to a cultural reason of excess consumption because the people in RDS were not used to having water service throughout the course of the whole day and leave the sink tap open, for example, until the water bill comes. The increase in the water bill makes them react and then a water conservation culture appears. That probably will take a year of assimilation, but in the meantime they have the benefit of water service all day.

A transition is beneficial but every organization has to know what kind of issues need to be overcome to provide a better drinking water service. The issues are the increase in pipe leaks and water shortage reports for some time until the stabilization to a continuous flow, where both factors should go down.

After a hydraulic, social, demographic, topographic and consumption analysis of subsector 3, this work identified a number of users for whom water consumption and pressure will be measured and conglomerated to carry out a general group review, as well as a drinking water supply service review depending on their principal supply entrance. With this data, future works will begin the analysis of the hybrid demand pattern sought.

This research will serve as the basis for a management model based on a hybrid demand pattern and considering the type of existing flow, which defines the adequate operation of a water distribution network so that a sector is provided with a better potable water service.

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