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Dynamic Model for Drinking Water Consumption in Times of SARS-CoV-2 in Corazón City, Pangua, Cotopaxi, Ecuador, South America

David Carrera-Villacrés [a,b,*], Cristian Rosero [a], Kevin Gustavo Almeida Cuasapaz [a], Bayardo Gabriel Cacuango Ruiz [a], Mabel Alejandra Carvajal Chiza [a], Wilson Steven López Vargas [a], Alexander Joel Sopa Tipanquiza [a], Valentina Aurora Villamizar González [a]

[a] *Universidad de las Fuerzas Armadas ESPE. Departamento de Ciencias de la Tierra y la Construcción, Ecuador*
[b] *Universidad Central del Ecuador. Facultad de Ingeniería en Geología, Minas, Petróleos y Ambiental (FIGEMPA), Ecuador*
*Corresponding author: *dvcarrera@espe.edu.ec*

***Abstract*—The urban parish, Corazón city, is located in the Pangua canton, Cotopaxi province, located in the foothills of the Andes Mountain range, where the water supply of drinking water is currently carried out by gravity with a storage tank to the population. This research analyzed the water supply during the period of confinement due to the Covid-19 pandemic. This was based on the change in use, behavior, and losses to the system. In order to population conditions, data from registered volumes were employed, distributed and consumed volumes registers were the variables used to develop the dynamic model, which has helped to estimate the charge in drinking water consumption due to the pandemic lockdown. Hence, the current consumption during the confinement period was determined, and the forecast considering the actual conditions. Finally, the dynamic model of water consumption was proposed; the results obtained showed that water consumption had not experienced any significant change during the social distancing period, and the maximum growth rate of 0.2755 will be reached in December 2020. A sharp change in water consumption tendency was probably not observed because the majority of Corazón city population have been working from home before and after the pandemic. To conclude, it is necessary to remark that thanks to the data provided, it was possible to model this behavior within mathematical formulas and the Vensim software, having results close to reality; Indeed, two critical scenarios have been considered on the supply system under analysis.**

***Keywords*—Modeling water; endowment; SARS-CoV-2; Vensim.**

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I. INTRODUCTION

The study work on drinking water and its vital importance in this research corresponds to the Rosero-Armijo study [1]. The water supply system was analyzed, and a numeric model for its control was developed, proposing various solutions for their reduction. The World Bank [2] estimated that 45% of the water produced in Latin America is unbilled water, which also occurs throughout Ecuador. This is done by controlling water losses. This is caused either due to apparent losses (unauthorized consumption, measurement errors, unbilled legal consumption) or actual losses (leaks in various system elements such as transmission lines, and storage tanks, connection losses) and business losses. Ramírez [3] indicates that efficient work can be generated by the service provider, contributing to the company's economic balance and representing a significant impact on the development of a population.

Being a relevant contribution to the present work since it has a base of study of the technical and commercial information of the drinking water system of the sector [4]. In addition, it counts with measurements of water flow produced, invoiced, and does a hydric balance of the unaccounted volume.

According to data from the Municipal GAD of Pangua in Corazón city drinking water supply, "the institution in coordination with the drinking water and sewerage provides to 3500 inhabitants with an endowment of 31,104 m^3 of water". The current regulations "Regulations for the study and design of potable water systems and wastewater disposal for populations over 1000 habitants" [5]. We get a supply to the sector with 180 L/hab/day, and to satisfy its demand, it needs 18900m^3/month of drinking water. Now we understand that the difference in these quantities of water is the product of the losses, having repercussions on financial and environmental terms [6]. However, now the situation changed, how it was described in Mojica-Crespo and Morales-Crespo [7] that explains how we get a different case on December finals of 2019 of atypical pneumonia in Wuhan-China. The causative agent was identified how the new coronavirus; it was named how SARS-CoV-2 [8]. According to Shereen *et al.* [9], COVID-19 caused an indeterminate number of infections and deaths, at the beginning in China, then on the world, becoming an international health emergency and then a pandemic. Until now that we do this investigation, the world does not have a treatment and vaccine to contra rest or prevent this infection for SARS-COV-2. This is why the world takes massive public health measures like isolation, social distancing, and confinement [10]. The main characteristic of social distancing is that people today must submit for their health, get away from crowded places and restrict the interaction between people [11]. We have to respect the physical distance or avoid direct contact with other people [12]. That is staying at home [13], producing variables not considered when we were designing the works, in day-to-day activities we found the supply (hydraulic work) [14], because we may have a new consumption of water by the population [15]. According to the modeling for data predictions [16] that is a drinking water, it analyzes parameters such: demand, flow, friction, speed, supply, height, speed, pressure, knots.

Exist a recent model of systems theory [17] gives diagnoses of real cases into the context in engineering themes, all through conventional processes; today, any company, population, or environment can be related to dynamics systems and the different software in the case of VENSIM [18]. Furthermore, all the works mentioned have an essential part for the development of the investigation, and they have accurate modeling of the current conditions of the population [19].

Water is an elemental substance for life. Its correct administration allows societies to eradicate poverty, build a peaceful and prosperous society. This, in turn, reduces inequalities, so improving the management of this resource and access to drinking water contribute to the progress of the communities [20]. Ecuador is highly rich in rainfall, with good water quality, but it has supply problems from its hydraulic works; however, many homes are still supplied with water from rain, tanks, or wells [21].

Due to the coronavirus health crisis, water consumption patterns have changed due to the restriction of public life and social activities. Causing alterations in the use of vital liquid and supply by hydraulic works, needing to recognize these changes in the population's behavior [22]. The estimated flows captured, distributed, measured, consumed measured, and the increase-decrease rate provided by the Department of drinking water from Corazon city were used to study the problem. Due to the change in conditions by SARS-Cov-2 in the elapsed time [23], variables obtained from previous years of the population of Corazón city were proposed, which allowed a precise approach to real consumption values [24].

Therefore, this research was to estimate drinking water consumption through a dynamic mathematical model carried out with the Vensim software [25]. Starting from the collection of data presented up to the revision date, which the Department of drinking water obtained from Corazon city, to assess whether the change in behavior due to SARS-CoV 2 of the inhabitants significantly affected the water distribution network [26]. It is first, estimating future population consumption (if confinement is maintained), second considering an increase of 50% of the consumption rate, and third the benefit produced by reducing losses in the system. This was all these using qualitative and quantitative variables for its calculation.

II. Materials and Methods

A. Study Zone

The study area corresponds to the urban parish of Corazón city. It belongs to the canton Pangua in the province of Cotopaxi. The canton Pangua is spatially located at 1°08'00" latitude South 79°04'00" longitude West and it has a total area of 721 km^2 (Figure 1).

B. Experimental Design

The population is distributed from the urban parish called El Corazón city and three rural parishes: Moraspungo, Ramón Campaña, and Pinllopata. It has a population of 22,856 inhabitants.

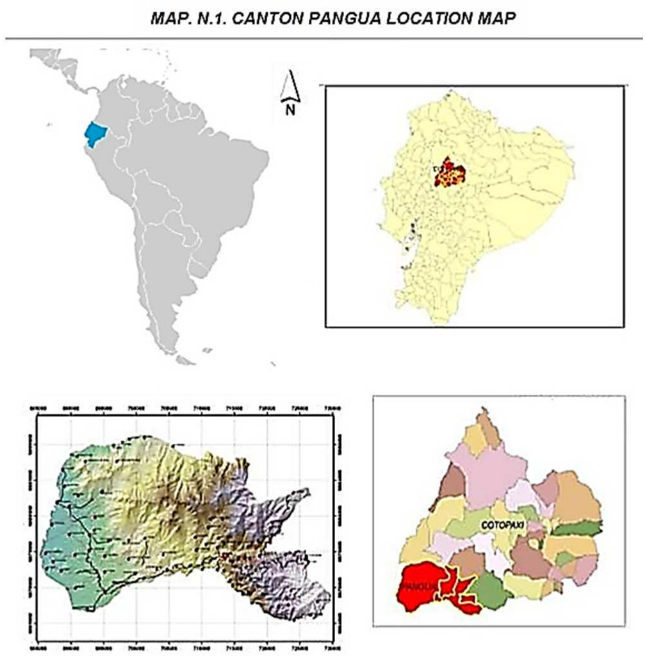

Fig. 1 Study area canton Pangua. Pangua GAD, 2018

There are approximately 700 homes connected and distributed from the Muligua neighbourhood in the upper part to the gas station MASGAS in the lower part, which is the entrance of the canton. The supply is done by gravity from a storage tank of 400m³ [1]. Stratified sampling is of interest when the characteristics in question may be related to the variable to be studied. Pangua GAD data were used to estimate water consumption during the confinement time by the Covid-19 pandemic [11]. Once the location of the area to be studied was obtained, the water consumption was verified and its daily supply per inhabitant (Figure 1).

C. Process

Exploratory research was used to characterize water consumption in a pandemic in the Corazón city with a quantitative methodology, using the Vensim dynamic model. The following variables and their respective units were taken into account to estimate the increase, decrease, or continuity of water consumption [27].

1) Captured Flow: 27994 units (m^3/month) this variable is a constant type of variable obtained by the official data of the drinking water system the heart given in (l/s) by 10.8 l/s.

2) Captured: Auxiliary type variable (m^3/month)= Collected flow rate.

3) Initial flow: 11231 units (m^3) this variable is a constant type of variable that was obtained by the Department of drinking water of Corazón city as "consumed flow rate measured" in (m^3/month) for January, the model begins the analysis of projection starting from January 2020 to continue with the projection of the following months.

4) Loss Rate: 0.679 units (1/month0), a constant rate variable obtained from the study [1]. This value corresponds to the percentage of unaccounted for water index in the Corazón city

5) Table Consumption Rates: Table obtained by determining variation in the percentage of the values of the consumed flow rate of the averages per month for (2017 to 2019) increased 1.

6) Time: Shadow type variable used for the variation of the rates table as a function of time (month).

7) Consumption Rate: Variable type auxiliary unit (1/month) is equal to table consumption rate depending on (time).

8) Consumed Flow Rate: Auxiliary type variable (m^3/month) = Initial Flow*Consumption rate

9) Loss: Auxiliary type variable unit (m^3/month) = Stored flow rate*Lost rate

10) Stored flow: Level type variable units (m^3) = Collected-Consumed-Loss.

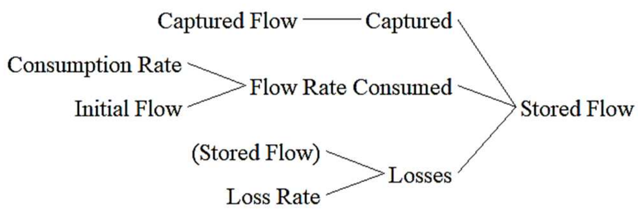

Fig. 2 Example of an unacceptable low-resolution image

Figure 2 shows the Cause-Effect Diagram of the dynamic system that behaves as unstable. In the second and third analysis case, changes in consumption rates and loss rates are inserted, respectively. The results of the flows consumed and stored suffer noticeable alterations. The Cause-Effect Diagram contains the critical elements of the system and the relationships. Arrows between the variables affected represent the different relationships. Positive loops respond to a directly proportional relationship, while negative loops respond to an inversely proportional relationship [28]. It is an unstable system that any disturbance affects the entire system in an unforeseen way.

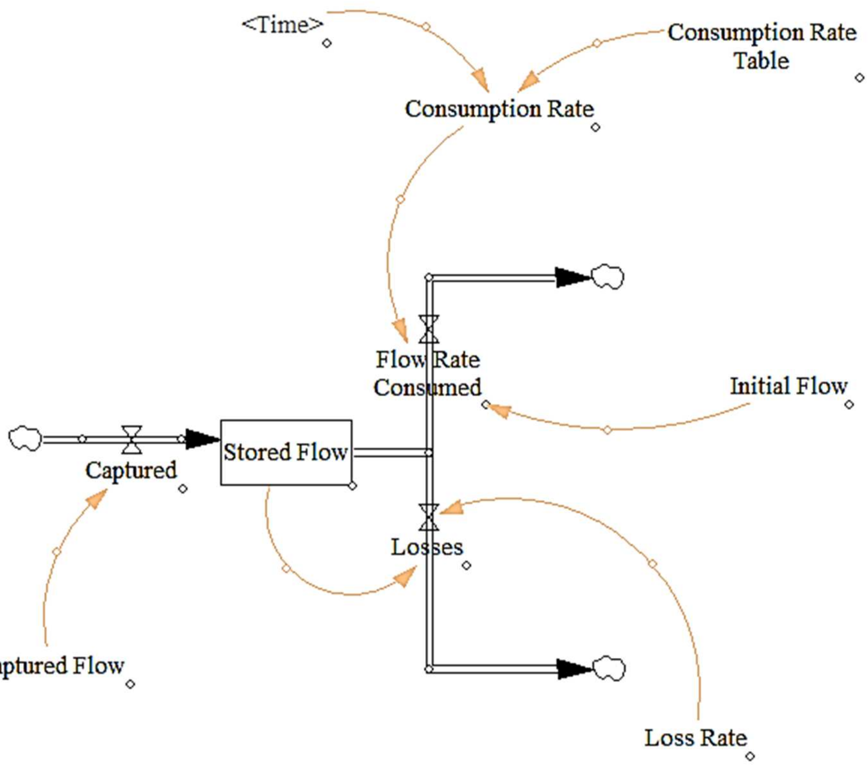

Fig. 3 Vensim dynamic model

Model: The dynamic model was made with Vensim software; this is a visual modeling tool that allows conceptualizing, document, simulate, analyze and optimize systems dynamics models, making presentations flexible and straightforward to build simulation models through diagrams of influences and Forrester diagrams [29]. Also, it uses its methodology, which allows understanding and restructuring complex situations of each system and process. The significant global changes have been an essential factor in different organizations to generate processes by systematization and simulations to improve and optimize.

III. Results and Discussion

Table I shows actual drinking water consumption in Corazón city. The Department of drinking water was given this information and was used as a guide to determine the parameters to generate the model in the Vensim software.

TABLE I
CORAZÓN CITY DRINKING WATER CONSUMPTION INFORMATION

(m^3/month)	Estimated captured flow/year				Measured distributed flow				Measured consumed flow			
	2017	2018	2019	2020	2017	2018	2019	2020	2017	2018	2019	2020
January	27994	27994	27994	27994	27994	27994	27994	27994	9582	10721	8509	11231
February	27994	27994	27994	27994	27994	27994	27994	27994	9681	10680	9804	9613
March	27994	27994	27994	27994	27994	27994	27994	27994	8181	13125	10532	10745
April	27994	27994	27994	27994	27994	27994	27994	27994	10931	11619	10811	9035
May	27994	27994	27994	27994	27994	27994	27994	27994	10931	11395	11979	8535
June	27994	27994	27994	27994	27994	27994	27994	27994	9137	13251	4998	9488
July	27994	27994	27994		27994	27994	27994		10095	6299	9806	
August	27994	27994	27994		27994	27994	27994		12480	15297	14590	
September	27994	27994	27994		27994	27994	27994		13268	11208	13621	
October	27994	27994	27994		27994	27994	27994		12138	11109	10719	
November	27994	27994	27994		27994	27994	27994		11202	12625	9332	
December	27994	27994	27994		27994	27994	27994		9772	13791	13188	

Table 2 shows the average flow consumed per month for 2017, 2018, 2019. This also indicates the variations in the rate of increase or decrease that have been generated in these three years. It is essential to mention that the results obtained from previous research of unaccounted for water index were used. With these data groups, it was possible to generate some study scenarios in the actual situation of Ecuador due to the pandemic and how it affects the population of the area and variations in water consumption.

TABLE II
AVERAGE FLOW CONSUMED YEARS 2017, 2018, 2019

(m^3/month)	Average flow consumed: 2017, 2018, 2019	Rate of increase or decrease	Coefficient of increase or decrease for average consumption vensim
January	9604	-	-
February	10055	0,0470	1,0470
March	10613	0,1050	1,1050
April	11120	0,1579	1,1579
May	11588	0,2066	1,2066
June	9129	-0,0495	0,9505
July	8733	-0,0907	0,9093
August	14122	0,4705	1,4705
September	12699	0,3223	1,3223
October	11322	0,1789	1,1789
November	11053	0,1509	1,1509
December	12250	0,2755	1,2755

Note: Table elaborated from Department drinking water Corazón city Values for modeling in Vensim software.

Table II shows the average consumption that the population of El Corazón has had in the last three years before the pandemic affects the world. This data is obtained according to the amount of water that has been consumed each month. In the same way, the calculated increases or decreases were multiplied by the initial flow corresponding to January of the year under analysis.

Through the structural modeling of a system of interaction between variables and key actors in the system, situations were found where the same action had different short and long-term effects and the consequences it generated locally and consequences in other parts of the system under analysis. Complicated, non-linear problems can be modeled using feedback loops; as one of the auxiliary variables, we considered the value of the coefficient of increase or decrease, depending on how it is affected by time. Concerning the captured flow, the data provided by the Department of drinking water of Corazón city was taken as a reference. The estimated captured flow is 10.8 l/s, doing the proper operations are calculated 27994 m^3/month. These changes are given to generate an adequate use of units in the software, in the same way. The initial flow of 11231 m^3/month consumed by the population at the end of January was obtained; this data was taken as a basis for the consumption estimate of the following months of the year 2020.

The rate of losses was taken as an important parameter, as it is well known that the distribution systems for drinking water, no matter how efficient they are, will always present different types of losses, whether because they are not counted, apparent or real. These factors will always influence the flow that the population of around 3,500 inhabitants of Corazón city receives [1]. After a series of studies and measurements, the difference between the volume of water produced and the consumption estimated by the community, reducing daily waste, results in a percentage of 67.90% (0.67901/Month) of unaccounted for water index. The exact value provided a realistic approach to future estimates of water consumption.

A key variable within the model is the stored flow, which is an indicator of the amount of water that will be available to the population, where the calculation of this indicator is dependent on and directly influenced by other indexes such as: captured (amount of flow captured m^3 / month) for this study is applied to the data provided by the GAD in Table 1, it has remained constant within the past three years, unaccounted for water (m^3 / month) that depended on the fixed rate of 0.679 and the amount of water produced to the population, and the flow consumed in a given time (m^3 / month).

As can be analyzed in Figure 1, the levels flow and auxiliary variables are part of a practical and summarized model that is a function of the consumption that the population will have over a certain period; in this work, the months were considered from January to December of 2020, thus modeling consumption during the health emergency season.

As a result of the base model, it can be seen that the values of the flow rate consumed remain within the normal range for the area. It was estimated that the drinking water available for the population did not have significant modifications, as shown in Figure 4, which shows the estimated flow consumed, and in Figure 5, the estimated stored flow from July to December 2020.

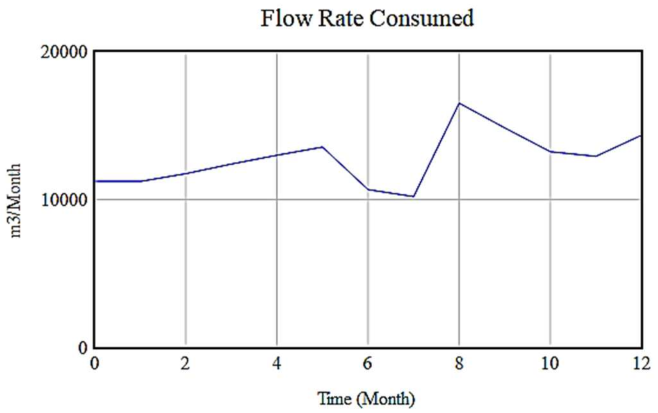

Fig. 4 Vensim model flow rate consumed – the first case

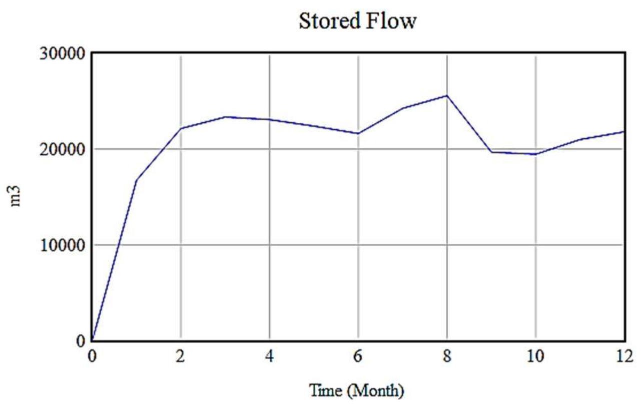

Fig. 5 Vensim model stored flow rate – the first case

In the second case, a model was proposed with an increase of 50% in the previously calculated consumption rates; this increase is necessary for the analysis since it could be produced by the current health emergency, where more water is used following the instructions of personal hygiene and the disinfection of the homes. The modeling estimated consumed and stored flow with the factor mentioned earlier, as shown in Figures 6 and 7, respectively.

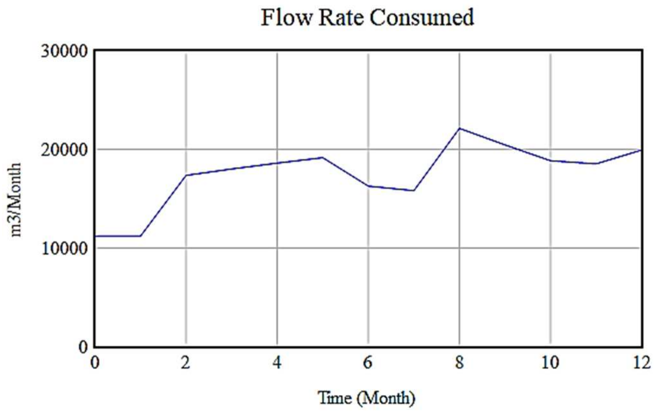

Fig. 6 Vensim model flow rate consumed – the second case

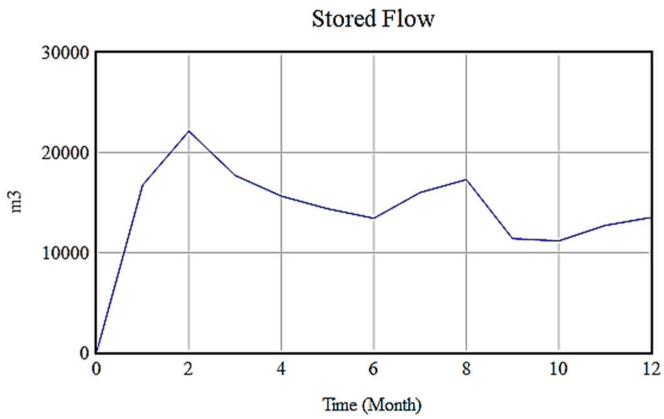

Fig. 7 Vensim model stored flow rate – the second case

As the last research analysis, the third scenario was proposed to decrease the rate of flow losses, in this case. It was considered that it would reduce the index of unaccounted for water and bring the losses of drinking water to the average values worldwide, that is 34% [30], the results are seen in Figure 8.

Fig. 8 Vensim model flow losses – third case

When this scenario was considered, the large increase in the available flow was significant. In Figure 9, the variations that these results reflect are appreciated. With this, the great need for and importance of implementing programs for the reduction and control of physical losses in the drinking water network in the projects can be corroborated once again, which seek to control the volume of water that is lost, gradually reducing the amount of unaccounted-for water as well as giving adequate maintenance, achieving optimal performance of the water balance within the system.

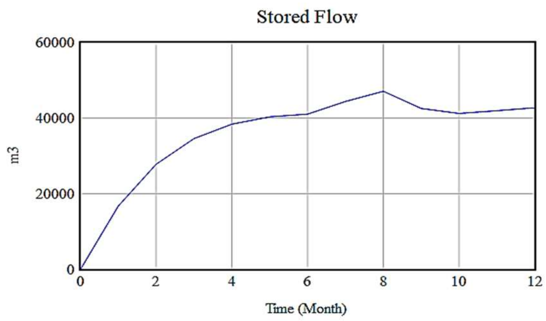

Fig. 9 Vensim model stored flow – third case

Figure 10 and Figure 11 show comparative graphs of the three cases addressed for the flow consumed and stored, respectively. In Figure 10, the curves of the analysis case 1 and 3 overlap because the consumption rates and, therefore, the consumed flow considered are the same and can be compared with the average flow of the years analyzed.

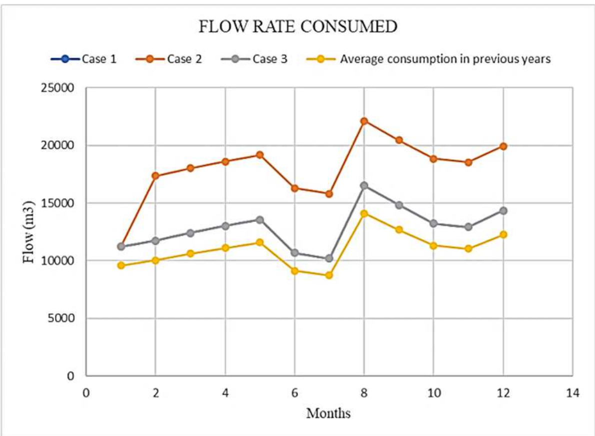

Fig. 10 Three cases of analysis of the flow consumed and the average flow consumed in the years analyzed

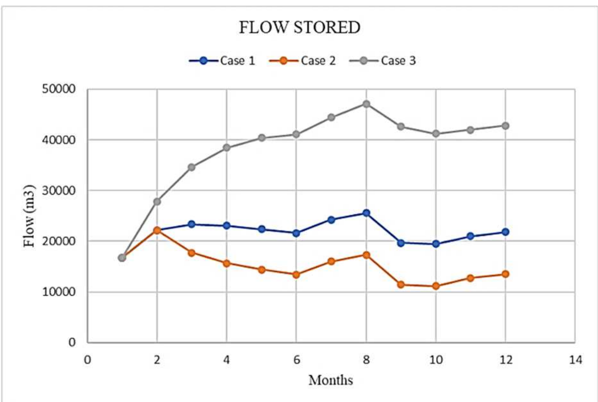

Fig. 11 Three cases of stored flow analysis

IV. Conclusion

Dynamic modeling was developed, obtaining the averages of increase or decrease in January to December of 1 calendar year from the average values of 2017, 2018, and 2019. In this way, it was estimated what the trend would be in the months after the events (from July to December 2020) since Covid19 declared the quarantine. As a result, the model showed that consumption had not undergone a major change due to the distancing, reaching the maximum growth rate of 0.2755 in December. It is probably because most of the population of Corazón city had been working from their homes since before the confinement.

On the other hand, a second dynamic model was carried out in Vensim, increasing the consumption rates by 50%, in which a significant increase was obtained to consider. Finally, the last modeling was carried out considering a decrease in the loss rate from 67.9% to 34%, a world reference value, which produced an increase in the stored flow available for the use of the population.

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