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A System Dynamics Approach for Modelling Water Consumption at USFQ.

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RESUMEN

El crecimiento actual de la población y la actividad antropogénica ejerce una gran presión sobre los recursos naturales. Uno de los recursos con alta demanda en las áreas de crecimiento urbano corresponde al agua, cuya disponibilidad es crítica y requiere una mejor gestión. En este contexto, el presente estudio tiene como objetivo identificar las principales variables que influyen en el consumo de agua en la Universidad de San Francisco de Quito, con el fin de promover estrategias y políticas de reducción. Para ello, se ha creado un modelo basado en la teoría de sistemas dinámicos y utilizando el software Vensim. La metodología utilizada para este estudio se dividió en tres fases: articulación del problema y recolección de datos, formulación del modelo, y prueba y validación. Las conclusiones del modelo muestran que la infraestructura y la tecnología eficientes son un sector prometedor para reducir el consumo de agua, lo que da como resultado una oportunidad para desarrollar políticas de agua que pueden permitir la reducción de agua del 15,46% después de la implementación. Además, el modelo mostró que la ocupación es el factor principal que influye en el consumo total de agua. Sin embargo, también mostró que la ocupación, no tiene ningún efecto en el consumo de agua per cápita. Además, el enfoque de sistemas dinámicos resultó en una metodología útil que permitió comprender la estructura y el comportamiento del consumo de agua en la universidad. Finalmente, la dinámica del sistema ayudó a construir una simulación informática formal que se utilizó como una primera etapa para diseñar políticas eficientes en el uso del agua.

Palabras clave: agua, consumo, sistemas dinámicos, modelo, políticas.

ABSTRACT

The present population growth and anthropogenic activity exerts great pressure on natural resources. One of the resources with high demand in the areas of urban growth corresponds to water, whose availability is critical and requires better management. In this context, the present study aims to identify the main variables that influence water consumption at the Universidad San Francisco de Quito, in order to promote reduction strategies and policies. For this, a model has been created based on the theory of dynamical systems and using the Software Vensim. The methodology used for this study was divided into three phases: problem articulation and data collection, model formulation, and testing and validation. Findings from the model show that efficient infrastructure and technology are a promising sector for reducing water consumption, resulting in an opportunity to develop water policies that can afford water reduction of 15,46% after implementation. Also, the model exhibited that occupancy is the major factor influencing total water consumption. However, it also showed that occupancy, has no effect on water consumption per capita. Furthermore, system dynamics approach resulted a useful methodology that enabled to understand the structure and behavior of water consumption at the university. Also, system dynamics helped to build a formal computer simulation which was used as a first stage to design water efficient policies.

Key words: water, consumption, system dynamics, model, policies

TABLA DE CONTENIDO

A System Dynamics Approach for Modelling Water Consumption at USFQ

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Abstract

The present population growth and anthropogenic activity exerts great pressure on natural resources. One of the resources with high demand in the areas of urban growth corresponds to water, whose availability is critical and requires better management. In this context, the present study aims to identify the main variables that influence water consumption at the Universidad San Francisco de Quito, in order to promote reduction strategies and policies. For this, a model has been created based on the theory of dynamical systems and using the Software Vensim. The methodology used for this study was divided into three phases: problem articulation and data collection, model formulation, and testing and validation. During the data collection, a water audit was performed which provided relevant data regarding to efficiency of facilities, occupancy, and water leakage. It showed that leakage in university is 29.8% and that efficiency is less than 60%. Findings from the model showed that efficient infrastructure and technology are a promising sector for reducing water consumption, resulting in a water reduction of 15,46% after implementation. Also, the model exhibited that occupancy is the major factor influencing total water consumption. However, it also showed that occupancy, has no effect on water consumption per capita. Furthermore, system dynamics approach resulted a useful methodology that enabled to understand the structure and behavior of water consumption at the university. Finally, system dynamics helped to build a formal computer simulation which was used as a first stage to design water efficient policies.

SECTION 1: INTRODUCTION

Global Water Distribution

Global water demand has been largely influenced by population growth, urbanization, food demand, energy security policies, and macro-economic processes such as trade, globalization, and consumption patterns (WWAP, 2015). The unsustainable development pathways and the continued weak performances on water management by the governments, have generated immense pressures on water resources (WWAP, 2015). Over the past century, the rising living standards of the growing middle class have increased their income which have led to sharp increases in water use (WWAP, 2015). In this context, water consumption can be unsustainable specially where supply, distribution and price are poorly managed or regulated (WWAP, 2015).

The increase in urbanization "is creating specific and often highly localized pressures on freshwater resource availability, especially in drought areas" (WWAP,2015). Currently, more than the fifty percent (50%) of the world population is living in cities with around thirty percent (30%) of them living in slums. (UN-Habitat, 2010). By 2050, urban population is projected to be approximately 6.3 billion due to the expansion of the forty percent (40%) of the slums located in the developing countries, which account for a ninety three percent (93%) of the global urbanization (WWAP,2015). Past research has shown that as the population of cities increases, the total water demand for municipal supply also increases (Brown et al. 2002). The increase in total municipal water demand has broken down the natural flow of the hydrological network and deteriorate the quality of water (Brown et al. 2002). According to Joshi (2015), this is mainly because urbanization has changed land use in urban spaces, which produce a reduction on the recharge area of ground water and affects the superficial water bodies.

According to the ONU (2012), although water is the most widely occurring substance on earth, only 2.53 percent is freshwater while the remainder is salt water. This available water is unevenly distributed through the world as shown in **Figure 1**. For example, Asia has for approximately 36% of global freshwater resources but comprises the sixty percent (60%) of global population. In contrast, Latin America has approximately 25% of the freshwater resources but it only comprises the six percent (6%) of global population (ONU,2012). Urbanization also causes disparities in access to drinking water as it increases the areas and number of people who is not served by public water supply facilities. According to ONU (2012), although seventy three percent (73%) of rural residents have access to a source of drinking water, only the thirty percent (30%) of them have access to piped water. Thus, the interest of this study to present relevant information on the consumption of water in an urban area, is that there is a needing of tools that promote a responsible use of water resources in these high-pressure areas such as cities.

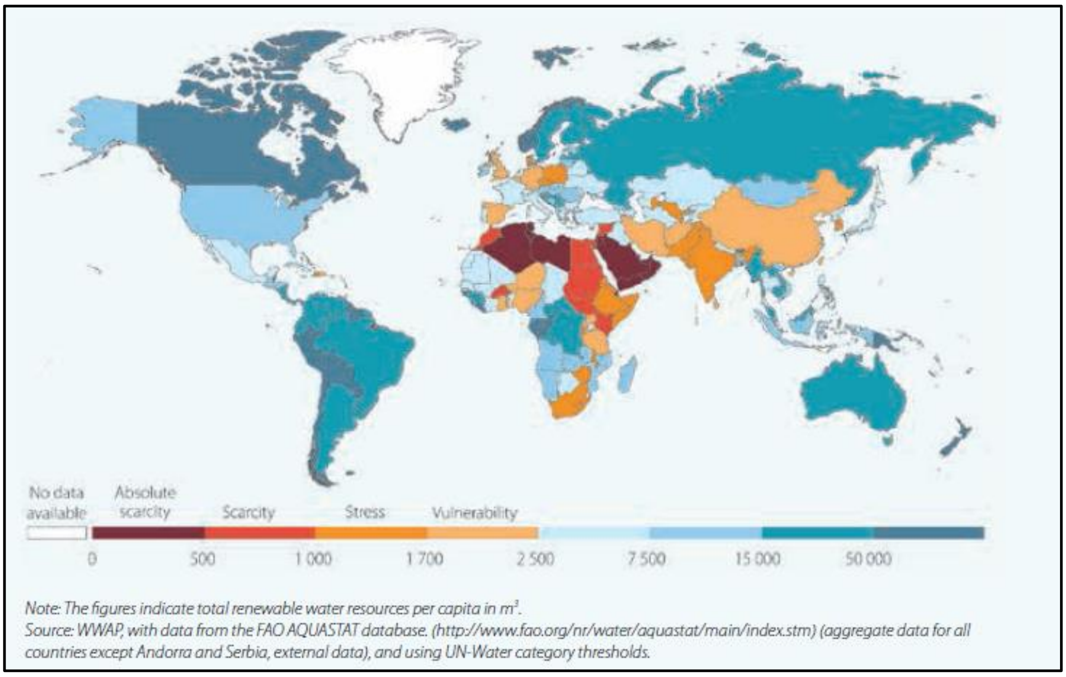

Figure 1.- Total Renewable water resources per capita Source: (FAO, 2013)

Water Consumption in Ecuador

The INEC Report (2012) shows that monthly consumption of drinking water per person decreased from 12.4 m^3 in 2011 to 9.2 m^3 in 2012. In urban areas, water consumption in 2012 was approximately 9 m^3 per capita. Meanwhile the rural water consumption per capita was of approximately 12m^3. In 2015, the average monthly consumption of Ecuadorian households was $ 11.37 U.S. dollars which corresponds to 15.79 m^3.

According to the Food and Agriculture Organization of the United Nations (2014), the total water withdrawal is 9.918 (10^9 $m^3/year$), with 8.076 (10^9 $m^3/year$) used for agriculture (FAO, 2015). In addition, the annual water consumption by sector in Ecuador exhibits the following: 1.396 (10^{10} m^3) are consumed by the agricultural sector, 9 (10^8 m^3) by the domestic sector and 38 (10^7 m^3) corresponds to industry (Villa,2011).

Quito Water Distribution System

Sources of water in the Metropolitan District of Quito are mainly surface waters, around 85% of the water consumed in Quito come from the paramos[1] that surround the city (FONAG, 2012). In Quito, the average daily consumption is 0.2 m^3 per inhabitant and 0.22 m^3per inhabitant during the summer (EPMAPS,2015). This value is one of the highest in the Latin American region where the average daily consumption is 0.135 m^3 per inhabitant and it is much greater than the 0.080 m^3 per inhabitant that the World Health Organization recommends for the vital necessities and personal hygiene (Duncan, 2003). It is important to mention that only ten percent (10%) of the wastewater in Quito, is treated (FONAG,2012). The main sub-basins where the untreated water is disposed are the following rivers: San Pedro, Machangara, Guayllabamba and Monjas (FONAG,2012).

[1] A high plateau in South America

Quito also shows disparities in access to drinking water. The water quality management plan of Quito (2005), mentions that the public drinking water supply network has a 98% coverage in urban areas, while about thirty percent (30%) of rural areas lack access to safe drinking water.

Water consumption in Office-Educational Buildings

Literature on urban water efficiency shows several definitions of the "nonresidential" sector (EPA, 2012). The sector containing the industrial, commercial, and institutional users of urban water is designated as the CII sector. The EPA (2012) defines the CII sector as follows:

- Commercial: Private facilities providing or distributing a product or service.
- Institutional: Public facilities dedicated to public service including schools, courthouses, government buildings, and hospitals.

The literature exhibits that many institutional buildings have the following end uses of water:

End uses of water in Office buildings	Percentage of consumption
Domestic /Restroom	37%
Kitchen	28%
Landscaping	13%
Laboratory	22%

Table 1. End uses of water in Office Buildings: Adapted from EPA (2012).

Moreover, the literature shows the average consumption per capita in office buildings for the Latin American Region. In Peru, for example, the average water consumption in educational institutions is about 100 m^3/month and 0.05 m^3/user -day (Cardona & Ocampo, 2012). Likewise, in Colombia, the water per capita consumption in universities of the main cities of the country, present values between the 0.0214 m^3 / user-day and 0.041 m^3 / user-day (Cardona & Ocampo, 2012). According to the Water Supply

Regulation of the Federal District of Mexico (2005), consumption in schools should not be less than 0.025 m^3/user-day to meet the necessities of the students (Cardona & Ocampo, 2012).

In Universidad San Francisco de Quito (USFQ), Salazar et al. (2015) indicates that the total amount of water consumed from the municipal distribution system in a year was 28 268.4 m^3, with a monthly average consumption of consumption of 2355.7 m^3. It is important to mention that water management policies have not yet been stablished in this university (Ochoa et al. 2012). However, in the year 2014 the USFQ created the Sustainability Office, which future vision is to create policies for the use of energy, water, and waste generation and also, to install water and energy meters in the university buildings.

Water and Energy Nexus

Flows of energy and water are intrinsically interconnected due to the characteristics and properties of water. Water is used in energy production and energy is used during the treatment and distribution of water for human use (U.S. Department of Energy, 2014). However, water availability will affect the future of the water-energy nexus. This, mainly because the changing precipitation patterns, increasing population, and more extreme weathers, are altering water availability (U.S. Department of Energy, 2014). According to the U.S. Energy Department, “the shifts in precipitation and temperature patterns will likely lead to a regional variation in water availability for hydropower production, thermoelectric generation, and other energy needs” (U.S. Department of Energy, 2014). These changes then represent a challenge for meeting the future people needs.

System Dynamics

System dynamics approach has been widely used to analyze complex systems and to design policies by including social, physical and technical systems during the modelling process (Flor, 2016). This theory considers three different aspects feedback loops, computer simulation and participatory involvement (Flor, 2016). In addition, the basis of the method is the recognition of the structure of the system to determine the behavior of the different variables and the feedback relationships. According with Sterman (2000) a System Dynamic Model Extrapolation present trends by examining independent factors. Each independent factor interacts constantly with the others. Furthermore, over long time periods each of these factors also feedback and influence itself (Sterman, 2000).

Justification

As mentioned earlier, many of the water systems have become stressed as rivers, lakes and aquifers are drying up to feed a growing human population or are becoming polluted due to human activities (WWF,2011). Therefore, developing knowledge and tools that allow to reduce water consumption, are relevant to counteract the effects of the expanding industry and population.

USFQ is located in a region that is in emerging development, and has around 9000 students; therefore, it is considered a space that has an impact in the use of natural resources. According to Mc Donald & Weber (2012), universities with high demand of students, represent the opportunity to become sustainability laboratories, that can help to promote sustainable behavior among young people. In this context, a study based on a system dynamics approach represents an opportunity to a) understand water consumption, and b) to develop a model that will help as a first stage tool, for developing a water policy program in the university. It is important to mention that simulation modelling as a theory development instrument, situated between pure deductive and inductive methods, can overcome the limitations of traditional approaches as far as their ability to analyze multiple interdependent processes operating simultaneously is concerned (Harrison et al. 2007). Therefore, this study will be able to provide relevant information about the water usage in the different areas of the university and identify the promising sectors to reduce water consumption.

SECTION 2: OBJECTIVES

General

Analyze the water consumption behavior in Universidad San Francisco de Quito (USFQ) with a system dynamics approach, to determine the variables with greater influence and impact in the consumption of water in order to propose reduction strategies and policies.

Specific

- Identify variables that influence water consumption in USFQ.
- Build a computational model based on the system dynamics approach to provide a better understanding of water consumption behavior at USFQ.
- Perform a model analysis to identify the variables that have a major influence on water consumption at USFQ and the areas that are promising sectors to reduce water consumption

SECTION 3: METHODOLOGY

The methodology used in this study is based on a system dynamics approach and it has been divided into three main phases: problem articulation and data collection, model formulation, and testing and validation. The methodology proposed in this study follows the main steps proposed by Sterman (2000) for modelling (Fig 3).

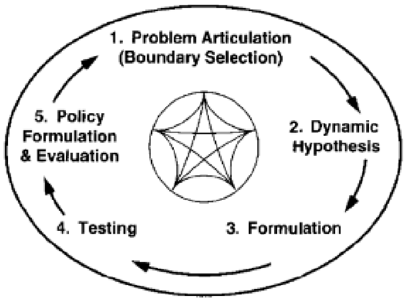

Figure 3.- Modelling Process Sterman (2000): (Flor, 2016)

3.1 Phase 1:

A literature review was performed to determine key variables that affect water consumption and to identify the relationship between them. The literature review, also helped to analyze and collect information about best practices in water consumption in university institutions.

In addition, quantitative data was collected in order to identify behavior patterns of water consumption at the USFQ. This data also provided information that helped to create reference modes[2] to allow the construction of the model. The data collected was: number

[2] Reference modes are set of graphs and other descriptive data that shows the development of the problem over time (Sterman,2000). The reference modes can be compared with the results of the model to see if both are concordant (Flor, 2016).

of students, teachers and staff from 2012 to 2016, water and energy consumption bills from 2012-2016.

Finally, in order to collect qualitative data, an expert's session and a student's session was prepared. These two sessions helped to identify the perspectives of the users regarding water consumption in the university and the main problems they face or see in the university regarding water usage.

Experts Session: Conceptualization of the problem

Focus groups have been largely recognized as a source for data collection (Luna-Reyes & Andersen, 2003). According to Gill (2008), the focus groups generate a rich understanding of the views and perspectives of the participants and the meaning behind those views. In this study, an expert session was performed to determine the key variables that influence water and energy consumption at the University San Francisco (USFQ). professors of USFQ Environmental Department participated in this session. The activities used for this session followed the proposed steps of "Scriptapedia" to facilitate a group discussion about the problem, model boundaries, and key model variables **(See Appendix A)** (Luna -Reyes et al. 2006). On the first activity, the participants were asked to write as many water and energy consumption-related variables as they can on a sheet of paper. As a second activity, the participants were asked to prioritize the variables and give a brief description of the variables selected. Then a discussion about the variables and their relationships was conducted.

Students Session: Users View

Similarly, a group session was performed with 35 engineering students. The activities used during this session were based on a similar methodology as in the expert session.

On the first activity, the participants were asked to form groups and to write as many water and energy consumption-related variables as they can on a sheet of paper. As a second activity, the participants were asked to prioritize the variables and give a brief description of the variables selected. Then a discussion about the main problems they perceived about water consumption in the university, was conducted. Finally, a causal loop diagram [3]was constructed at the end of this first phase.

Water Audit: Data Collection

In addition to the sessions, a water audit was prepared to estimate water consumption and evaluate water efficiency performance at the university buildings. This audit used a standardized water audit methodology **(See Appendix B)** proposed by Yong et al (2016) and which consist into two key sections: Pre-Audit and Audit. Figure 4. shows a flow chart depicting the steps followed during the audit process.

Regarding the audit scope, it was decided that the buildings to be audited were: the main campus building, and Hayek building. During the pre-audit phase, the inventory of kitchens, bathrooms, and laboratory areas to be audited, was prepared by using the information provided by the university staff[4]. The audit was scheduled for one week (Monday-Friday), and the audit time was from 9 am to 5 pm. During the audit, the data collected was: efficiency of facilities, occupancy, and water leakage. In order to determine the efficiency of appliances, the water flow[5] of one sink for each bathroom area in the university was measured. Also, the water requirement per flush of the toilets was

[3] Causal Loop Diagram (CLD) is defined as a causal diagram that help to explain the behavior of a system. The diagram present nodes (variables) and edges that represent the link or connection between variables. A collection of connected nodes can create feedback loops (Think.org,2015).
[4] The university staff provided a list with the number and location of the restaurants, bathrooms and laboratories that exist in the university.
[5] The water flow was measured with a volumetric test piece and a chronometer.

identified by determining the technical characteristics of each appliance **(See Appendix B4)**. In the same way, in the lab areas the water flow of the sinks was measured. In the lab areas, it was also identified the amount of water that appliances use, and the water requirement that each laboratory has for the different activities[6]. On the other hand, in the kitchen areas, the water flow of the sinks was also measured and the requirements of water of the different appliances was identified **(See Appendix B6)**.

Regarding occupancy, the number of people that use the restroom areas were determined by counting the number of people entering the areas within a period of thirty minutes during three different times of the day: morning, evening, and night. Moreover, to identify the water leakage, two readings of the water meter of the university were taken, the first one was taken when the university was empty at 11 pm and the second one was taken in the morning, at 5 am. The water consumed during this period was assumed be the leakage, since there is no other major activity occurring in this period. Additionally, qualitative data was collected, through interviews to the manager of the cleaning department and two people from the cleaning staff **(See Appendix B, Section B1)**.

[6] The information regarding the water consumption of the different appliances in the laboratories was obtained through interviews to the professors in charge of each laboratory (See Appendix B, Section B7).

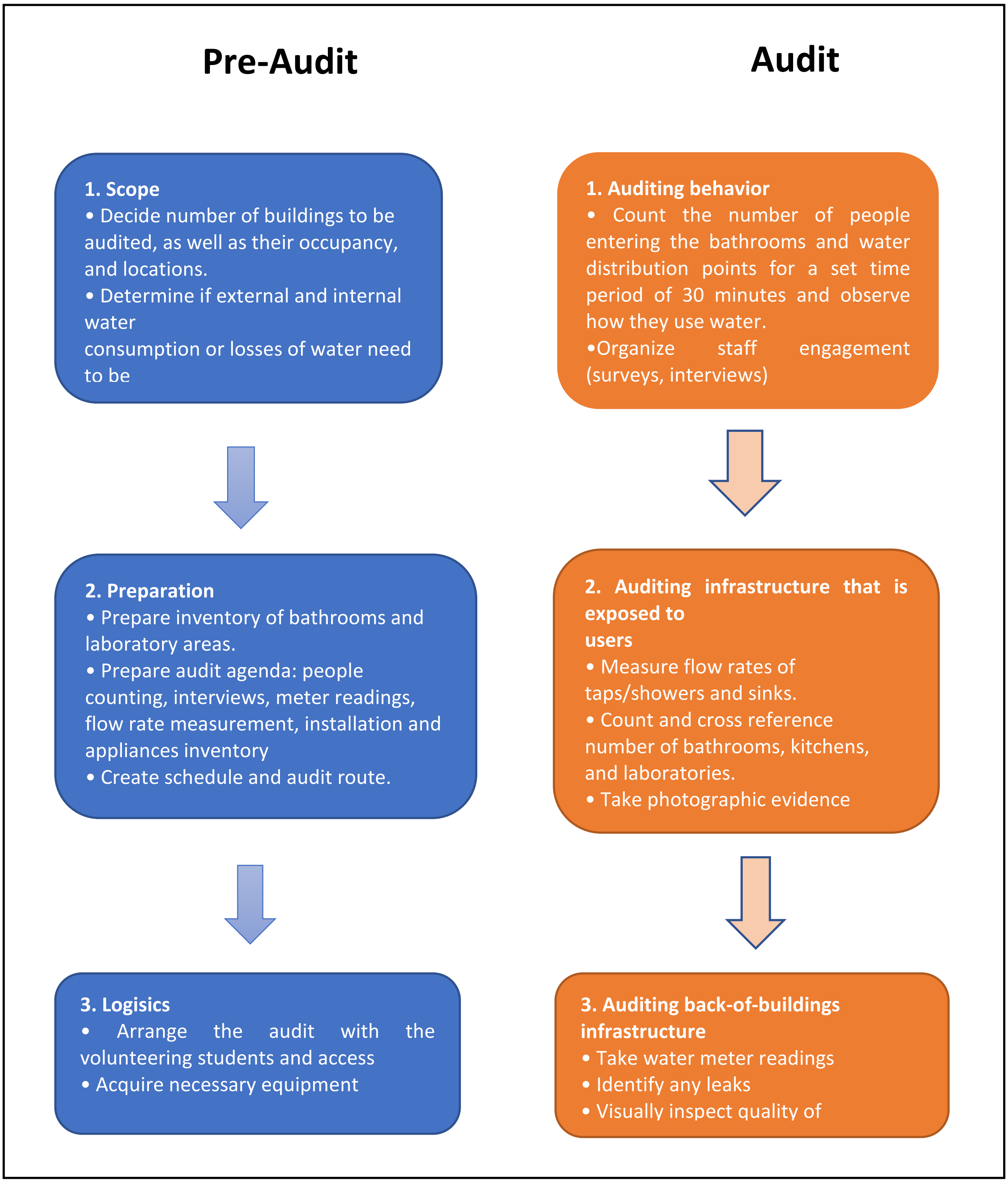

Figure 4. Water audit methodology strategy: Adapted from Yong et al (2016).

3.2 Phase 2: Model construction

This second phase focused on the selection of boundaries and key variables of the model as well as constructing the model with the information gathered during the first phase. First the model scope was determined; being the main campus and the Hayek building the selected areas for this study. In the same way, the model boundaries were selected (time horizon [7], and the endogenous and exogenous variables[8]). After the conceptualization of the problem and the identification of the boundaries, the system was mapped using the Software Vensim (student version) which is a simulation software used for developing, analyzing and packaging dynamic feedback models (Ventana Systems, 2015). First, the main variables of the model and the relations between them were identified, using a causal loop diagram, Causal loop diagrams are effective for representing the feedback structure of the systems and capturing the causes of the dynamics (Sterman, 2000). Then, the feedback loops of the model were identified. Sterman (2000) mentions that all dynamics arise from the interaction of two types of loops: the positive (reinforcing) loops which tend to reinforce or amplify 'whatever is happening in the system'. On the other hand, the negative (balancing) loops counteract and oppose change (Sterman, 2000). In this way, the causal loops diagram consists of variables connected by arrows representing causal links (Sterman, 2000). A polarity was assigned to each causal relationship. The polarity was positive (+) or negative (-), depending on the effect among variables. According to Sterman (2000), a positive link means that if a variable increases the variable affected will also increase; in other words, both variables go in the same direction (Flor,

[7] The time horizon selected for this study was 2012-2020
[8] See Table 2

2016). Contrary, two variables with negative polarity will go in the opposite direction (Sterman, 2000).

Finally, a diagram with stocks and flows, was created. Stocks and flows, along with feedback, are the two central concepts of dynamic systems theory (Sterman, 2000). Stock was used to represent accumulation and flows were used to determine the rate of increase or decrease of a stock (Flor, 20016). The model was created by using as inputs quantitative data, qualitative data, and equations. It is important to mention that model behavior was compared with reference modes[9]. The reference modes were constructed from historical data of the USFQ.

3.3 Phase 3: Model validation and analysis

The model was tested to evaluate its consistency. First, the model was compared to the reference modes to determine if the behavior of the model is consistent with the reality. Second, the model was tested under extreme conditions to determine if the behavior of the model still remains logical under these conditions.

Finally, two validation session were covered with the participation, on the first one, of Msc. Daniela Flor (Thesis Supervisor-USFQ), Msc. Melanie Valencia (Sustainability Office-USFQ) and Dr. Valeria Ochoa (Chair of the Environmental Department-USFQ), and the participation of Dr. Rene Parra (Professor expert on Modelling Systems approach-USFQ), on the second validation session. During these sessions, each section of the model was explained and discussed with the audience. Also, the behavior of the model over time was discussed and analyzed. It is important to mention that the comments and suggestions of

[9] Reference modes are set of graphs and other descriptive data that shows the development of the problem over time (Sterman,2000). The reference modes can be compared with the results of the model to see if both are concordant (Flor, 2016).

these sessions were incorporated in the model. After the validation of the model, the dominant mechanisms that influence water consumption in the university were identified, to evaluate which water policies and strategies could be implemented.

SECTION 4: RESULTS

4.1 ANALYSIS OF LITERATURE REVIEW, GROUP SESSIONS AND DATA COLLECTION

4.1.1 Analysis of the literature review

From the literature review conducted it was founded that water uses varies from region to region, due to climate and economic factors (EPA, 2009). It is also mentioned that in Office buildings, the quantity of water used can vary among the areas of the building[10], depending on the activities each area has, and the technology used for those activities (EPA, 2009). According to the University of California Berkeley, the key variables to understand the behavior of water consumption in an Office building are: infrastructure and technology, leakage, consumer general environmental education (environmental literacy) and awareness, water cost, and occupancy (UC Berkeley, 2010).

4.1.2 Group Session Analysis: Professors Session 1

This session was conducted during the first phase of the modelling process with the purpose of facilitate a group discussion about the model problem and boundaries, and to discuss the key model variables. The key variables proposed during this session were:

- Efficiency (of technology[11] and infrastructure[12])
- Consumer behavior
- Occupancy
- Awareness

Another important result from this section was the definition of the scope of this study. Because the campus of the USFQ has been subject to changes and extensions, it was

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[10] The areas of the building refer to kitchens, laboratories, restrooms, etc.
[11] During the session, the professors referred to technology as the kind of toilets, sinks and appliances used in the university areas.
[12] During the session, the professors referred to infrastructure as the water piping system within the university.

recommended during this session to include in this study, the new area attached to the main campus. This area is called Hayek building. The professors who attended to the session mentioned that ‘it is necessary to include the new annexed area to understand the real and current consumption of water throughout the university’ (Parra & Ochoa, 2017).

4.1.2 Group Session Analysis: Students Session 2

A second group session was conducted with the participation of 35 engineering students. The ideas discussed during the meeting are exhibited in **Appendix C.** The key variables determined during this session where:

- Technology
- Consumer behavior
- End uses of water
- Infrastructure

As a result of these sessions and the information gathered in the literature review, a causal loop diagram was constructed **(Fig 5)**. The aim of this diagram was to identify the main variables that affect water consumption at USFQ. Every link in the diagram represent causal relationships between the variables (Sterman, 2000). Two key feedback loops were identified from this diagram. Feedback loop **R1**, shows how awareness can impact water consumption. In this way, if awareness increases, the ratio of user that are aware also increases. This increased amount of people aware causes a more positive behavior [13]in the users, creating a reinforcing feedback loop. At the end, what happens is that the accumulated awareness produces a reduction in the consumption of water. Feedback loop **B1,** shows how technology can impact water consumption. In this way, if there is more

[13] Positive behavior refers to positive attitudes towards saving water or taking care of water

efficient technology, water consumption decreases and when consumption decreases the water bill is reduced too, creating a balancing loop. If the water bill is considerable reduced with the time, the user may not feel the necessity to continue replace to install more efficient appliances in the future.

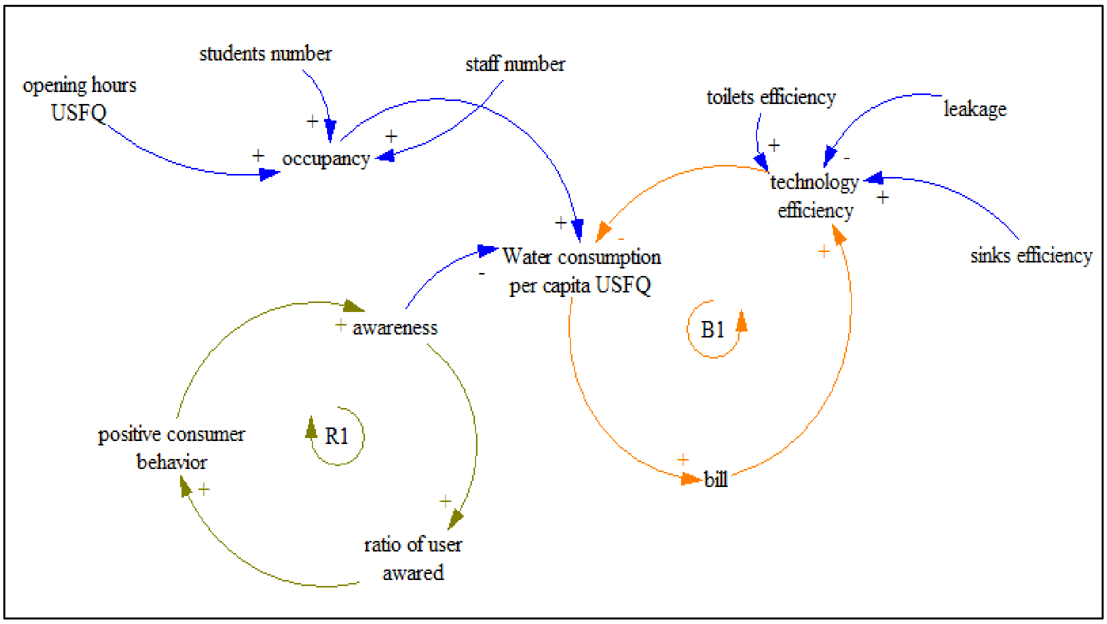

Figure 5. Causal Loop Diagram constructed from literature review and group sessions

4.1.3 Water Audit

As mentioned earlier, the data collected in the audit was: efficiency of facilities, occupancy, and water leakage. During the water audit, it was identified that the university does not have hydrosanitary plans of its facilities, nor individual water meters in buildings.

Regarding occupancy one important finding was that the bathrooms with the highest level of occupancy are the ones located in the Einstein Building, with around one hundred people entering the restrooms in rush hours **(results can be seen in Appendix B3, Table 10)**. Additionally, during the water audit a restrooms inventory was elaborated **(See Appendix B3, Table 9)**. It was identified that, despite the Hayek Building is a new area, it has around the 28% of the bathrooms. This could be mainly because at the beginning the Hayek Building was part of a Shopping Center; therefore, the number of bathrooms is higher than the ones in the main campus building which was designed with educational purposes.

Moreover, it was identified that the bathrooms in Hayek building are more efficient than the ones in the main campus **(Results can be seen in Appendix B2, Table 8)**. According to Hunt & Rogers (2014), for a toilet to achieve the efficiency level it should consume 0.0026 m^3per flush [2.6 liters of water per flush]. The restrooms in Hayek building use 0.0048 m^3 [4.8 lpf], meanwhile the restrooms in the main campus use 0.006 m^3 [6 lpf]. In the same way, Hunt & Rogers (2014) mention that for a sink to achieve the efficiency level it should consume 0.0017 m^3 [1.7 liters of water per day per person (lpd)]. The Hayek sinks use 0.00273 m^3 [2.73 lpd per person], meanwhile the sinks in the main campus use 0.0024 m^3 [2.4 lpd per person].

Another important finding was the level of leakage. The water losses due to the water distribution system of the university are about 29,8%[14]. This value is within the range mentioned in the literature which indicates water losses between 25-45%, in the municipal water distribution systems in Latin America and the Caribbean (UNESCO-IHE, 2008). It is important to mention that this value is higher [15]than the one reported by the municipal water company in Quito which has a 27,75% of water losses (EMMAPS,2014).

[14] The first lecture of water meter at midnight was 48 831 m^3 and the second lecture at 5 am was 48 831.05m^3.
[15] During the audit the manager of the cleaning staff was interviewed and mentioned that the piping system has never received maintenance.

4.2 CONSTRUCTION OF THE MODEL

4.2.1 Time Horizon and Model Boundaries

The time horizon selected for this study was the period between 2012-2020. The year 2012 was selected based on the availability of information and real data that could be provided by the university administrative department. The year 2020 was selected based on the Water Consumption Reduction Plans that have been implemented in universities through the Latin American region (Cardona & Ocampo, 2012). These plans set their annual reduction targets for the next four years following the implementation of the reduction strategy (Cardona & Ocampo, 2012). The conceptual and causal boundaries are exhibit in **Table 2.** The endogenous variables correspond to dependent variables whose value is determined by one or more functional relationships in the model (Sterman, 2000). In contrast, the exogenous variables correspond to independent variables that affect the model without being affected by the relations on the model (Sterman, 2000). The characteristics of the exogenous variables are not specified by the model builder (Sterman, 2000).

Endogenous	Exogenous
• Water consumption at USFQ facilities • Water consumption per capita • Infrastructure and appliances efficiency • Awareness • Water bill • Change in water consumption	• Occupancy • Water cost • Frequency of campaigns • Number of restrooms: toilets and sinks • Drinking water consumption

Table 2. Conceptual and Causal boundaries of the model

4.2.2 Model Structure Analysis (See Appendix F)

The first variable modeled was the Occupancy at the University San Francisco de Quito. The references modes of: students number, professors number and staff number were plotted by using real data provided by the Sustainability Office. On the other hand, to model occupancy, information gathered from the literature review was used. Occupancy was formulated in the model as the sum of the number of Students, number of Professors, and number of Staff people. To calculate the number of students entering the USFQ, a rate of students[16] enrolled in private universities was determined **(See Appendix D, Section D1).** In the same way, to obtain the number of students leaving the university, the number of students who graduate or retire from the university was calculated by using the rate of graduated students[17], the average graduation time[18], and the rate of retired students[19]**(See Appendix D, Section D2)**. Moreover, to model the number of professors and staff, the workforce molecule was used **(See Appendix E)**. According to Jines (2005), this molecule is a smooth of the desired workforce. To model the number of professors, it was considered a professor to student ratio (0.1375) which was obtained from The World University Rankings (THE). The reference modes were built using the data provided from the Innovation and Technology Office-USFQ. *Model* run [20]and reference modes showed similar trends which suggest that the occupancy in this model can be used for future analysis (Fig 6-8).

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[16] The average rate of students enrolled in private university used was 0.2022 and it was obtained from (Senescyt, 2016).
[17] Rate of graduate students used was 0.5792 and it was obtained from (Senescyt, 2016).
[18] The average graduation time was obtained from the Registrar office
[19] Rate of retired students used was 0.19 and it was obtained from (Senescyt, 2016).
[20] *Model* run is the result obtained from the simulation of the model.

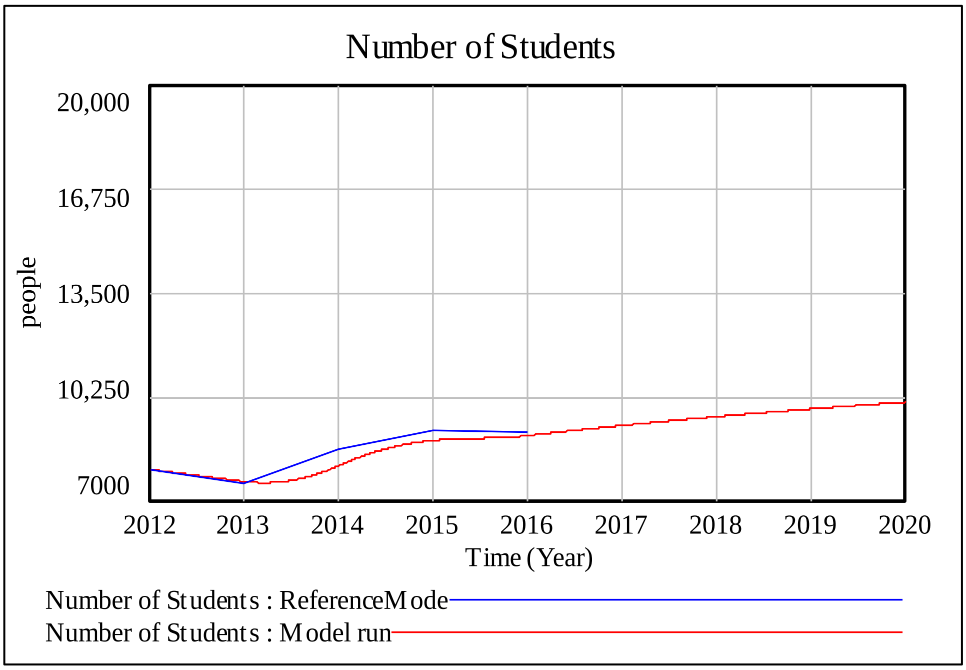

Figure 6. Comparison between Number of Students simulation and the Reference Mode

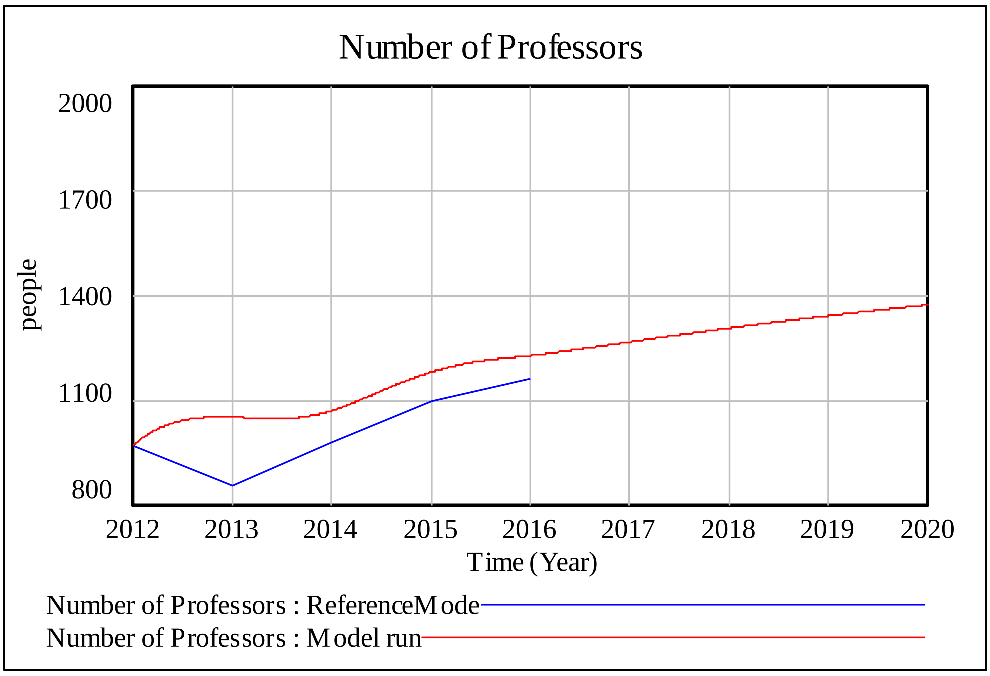

Figure 7. Comparison between Number of Professors and the Reference Mode

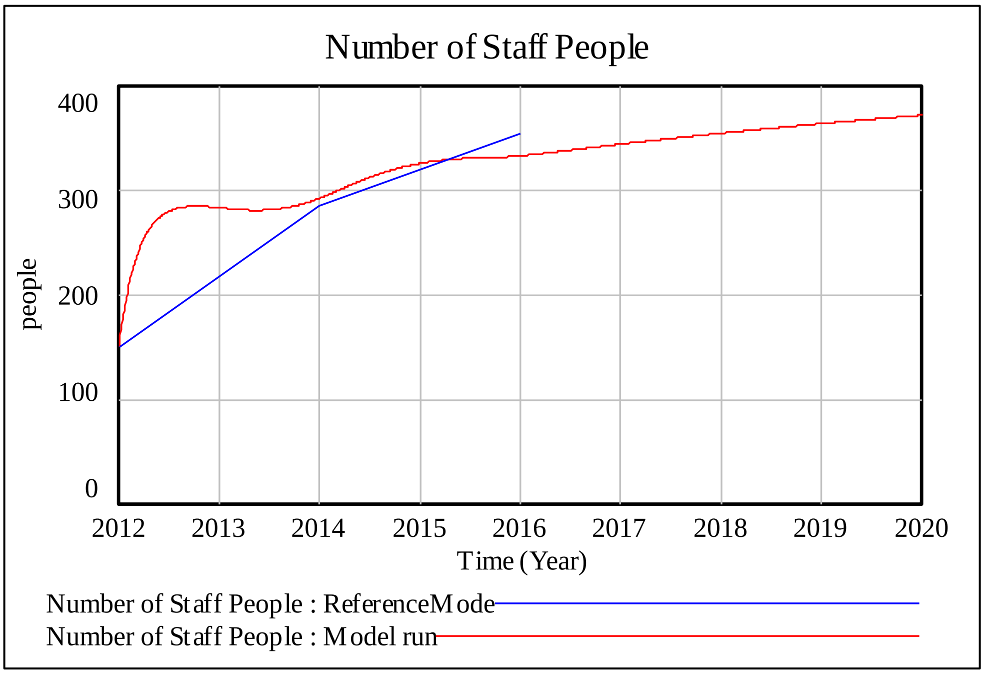

Figure 8. Comparison between the Number of Staff People and Reference Mode[21]

Then the effect of awareness in water consumption was included in the model (**Fig 9**). According with the literature, awareness is influenced by the attitude of the students and their knowledge about environmental issues [22](Shamuganathan, 2015). In the model, it was considered that only a fraction of the total occupancy of the university has knowledge about environmental issues (environmental literacy ratio[23]) and therefore only a fraction of the population would change their behavior because of awareness (ratio of users aware). Moreover, the values assumed to build the base run of the model were a campaign duration of six days every six months[24], with a rate to forget awareness of 0.6[25]. The model shows how the accumulated awareness mainly depends on the frequency of campaigns

[21] Reference mode in the Staff Number model does not show the accurate number of staff people working at the USFQ. This is because the information was obtained from an interview with the Jeaneth Montenegro (Head-Human Resources Department) where she mentioned de proximate number of staff people working every year and not the accurate ones.
[22] Knowledge about environmental issues is called Environmental Literacy in the literature.
[23] This value was assumed to be 0.12147 from the Study performed by the University of Malaysia (Shamuganathan,2015).
[24] Assumed from the recycling campaigns at USFQ and the E-Waste Campaign at USFQ.
[25] Linked to the number of people (students, staff people and professors) that leave the USFQ every 4.5 years.

and the rate to forget awareness. It is important to mention that this rate to forget awareness is also linked with the time to lose awareness[26] **(see Figure 9).**

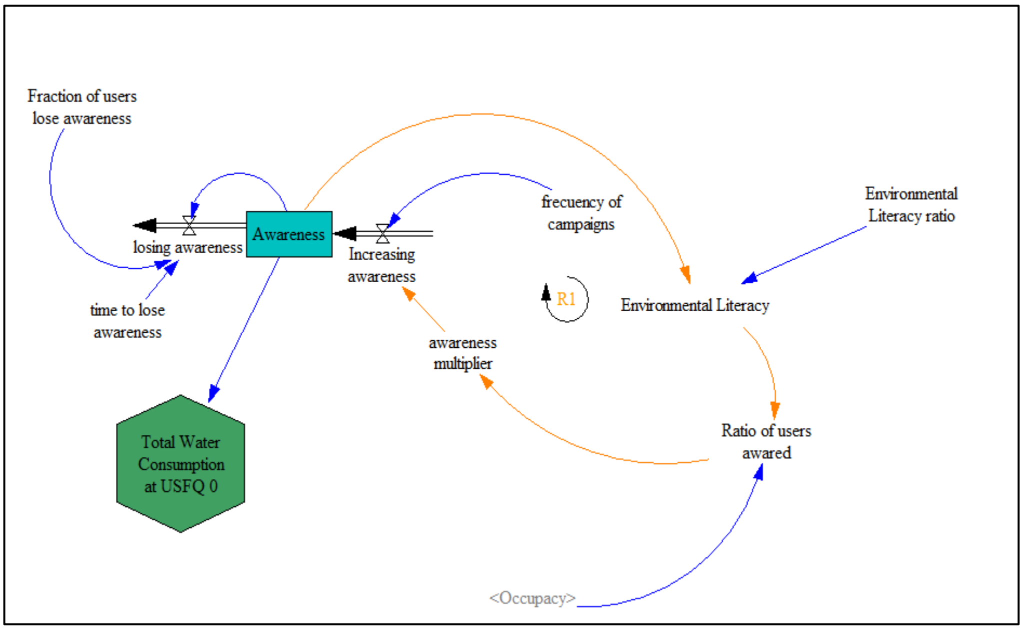

Figure 9. Awareness Loop R1.

Moreover, the literature emphasizes that efficiency in terms of appliances and infrastructure is a factor that influence water usage (EPA, 2009). According to the U.S. Environmental Protection Agency, water-efficient technologies in commercial buildings have received less attention than the residential sector, largely due to the lack of data on water usage within the commercial buildings subsectors (schools, hospitals, universities, etc.) (EPA,2009). In this way, using less efficient technologies, within the university areas, can negatively impact water usage (EPA, 2009). This behavior was incorporated in the model by using the water consumption appliances characteristics[27] **(See Appendix B, Section B.2)**, and comparing them to the water efficient appliance characteristics[28]. By

[26] 4.5 years which correspond to the average graduation time
[27] Obtained from the water audit data.
[28] Obtained from a Benchmarking System proposed by the University of Birmingham (Hunt and Rogers, 2014). Toilet=0.0026 m^3/flush. Sinks:0.0017 m^3/day

dividing this two parameters, the efficiency multiplier factor[29] was obtained for each area. It is important to mention that the areas included in this efficiency analysis were: kitchen areas located in the main campus, restroom areas located in the main campus and Hayek building and laboratory areas located in the main campus and Hayek building.

Additionally, the frequency of use of appliances was obtained from the UC Berkeley Water Usage & Conservation Study Report, which assumed for the calculations the following: Female restroom user rate is 3 times per day, Males 1 a day for Toilets/Twice a day for Urinals, average length of hand washing is 10 seconds. Additionally, an occupancy factor was calculated for each one of the two buildings of the university (Main Campus-DR and Hayek building-H). This occupancy factor was obtained as a relation of the number of people who enters the restrooms and the number of toilets [30], in each area. Then in kitchen areas, the multiplier factor was based on the water demand of the area, the dishwasher machine efficiency [31]and sinks efficiency[32].Finally, an Infrastructure Efficiency Multiplier was calculated by assuming that a value of one (1) corresponds to the highest level of efficiency and values under one represent less efficiency of the appliances analyzed. The efficiency section is exhibit in the figure below **(Fig 10).**

[29] Efficiency multiplier represents the increment or reduction in water consumption due to the appliance characteristics in restrooms, kitchen or laboratory areas.
[30]The occupancy factor was calculated by the relation (Number of people per restroom*Number of toilets) (See Appendix B, Section B3).
[31] Water requirements of the dishwasher were compared to the Energy Star dishwashers recommended by the EPA.
[32] Obtained from the comparison between the benchmark and the water audit data.

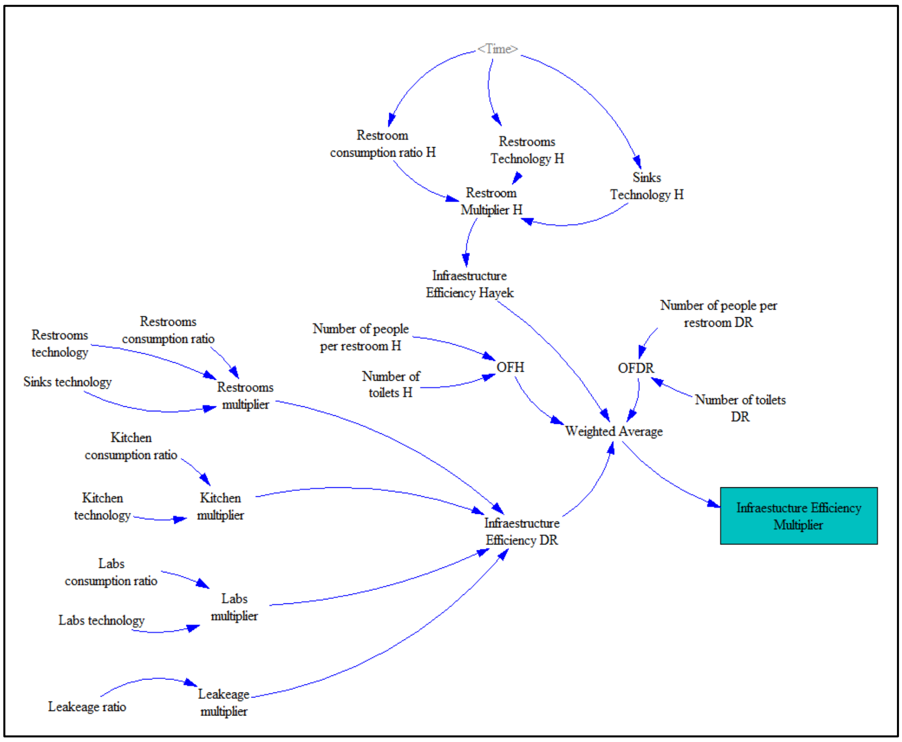

Figure 10. Infrastructure Efficiency Multiplier model

Furthermore, a variable that represents the drinking water consumption in the USFQ was added to the model. From the water audit it has been identified that there are three water distribution machines in the university areas.[33] The level of use of the water distribution appliances, was incorporated in the model through the variables "Drinking water consumption DR" and "Drinking water consumption Hayek",[34] which are influenced by the variables "ratio of consumption DR " and "ratio of consumption H", respectively. These ratios, represent the percentage of people that use the water distribution machines in each building and were calculated by dividing the number of people that use the machine[35] to the number of people that attend to each area of the university every day **(See Appendix B5)**

[33] Two water distribution machines are located in the Main Campus-DR building and one at Hayek-H building.
[34] These variables " Drinking water consumption" represent the per capita consumption of drinking water in the university.
[35] The number of people that use the water facilities was obtained during the Water Audit by using a people counting method which stablish a time period of 30 minutes (3 different times per day).

The number of people who attend to the main campus and Hayek building was obtained by adding the average number of students and professors that occupy each university building daily[36]. This information was provided by the Technology and Innovation Office-USFQ, and it exhibits the following:

Number of Students that attend to Hayek building daily					
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
HAYEK	3887	3630	3991	3709	297
SALAS PSF	555	1201	584	1391	0
TOTAL	4442	4831	4575	5100	297

Table 4. Hayek Building Daily Occupancy (Cruz,2017).

At the end of this analysis, it was found that the percentage of people using the water machines is similar between both buildings of the University. At the main campus, approximately eight percent (8%) of the daily occupancy at the main campus use the water machine; meanwhile around 7,84% of the daily occupancy use the machine in Hayek building.[37].

Moreover, the effect of water bill on water consumption behavior was included on the model **(Figure 11).** First, the cost of water was used to define the water bill value. It is considered as a typical expenditure if the cost of water in an office building is of 0.72 cents per cubic meter of water consumed (EMMAPS,2015). To determine if people will be willing to reduce their water consumption, the variable "acceptable water bill" [38]was

[36] The ratio of professors whose offices are at Hayek building was observed to be around 15 %. (Data obtained from the water audit-Offices counted)

[37] The data obtained from the water audit day was: 656 bottles filled per day in Hayek building and 1143 bottles filled per day in Main Campus building. The average volume of water consumption each time a person uses the water machine is of 0.005 m^3 (500ml). This data was obtained from the water audit and compared with a Report proposed by (Santana & Moya, 2014).

[38] The acceptable water bill corresponds to the average value paid by the university for water consumption during the last four years 2012-2016.

introduced. Then, the gap existing between the water bill and the acceptable water bill was calculated (water bill divided to acceptable water bill). According to Flor (2016), the expected behavior will be that if this gap is above one, then people will be willing to reduce their water consumption, but if this gap is less than one then people will not reduce their consumption, in contrast, water consumption could increase. For this run it was considered that the maximum reduction in water usage due to infrastructure changes can be 15-17% [39] (Selvam & Nazar, 2011). The fractional change in water consumption was determined to be a stock as it is a feature that accumulates over time.

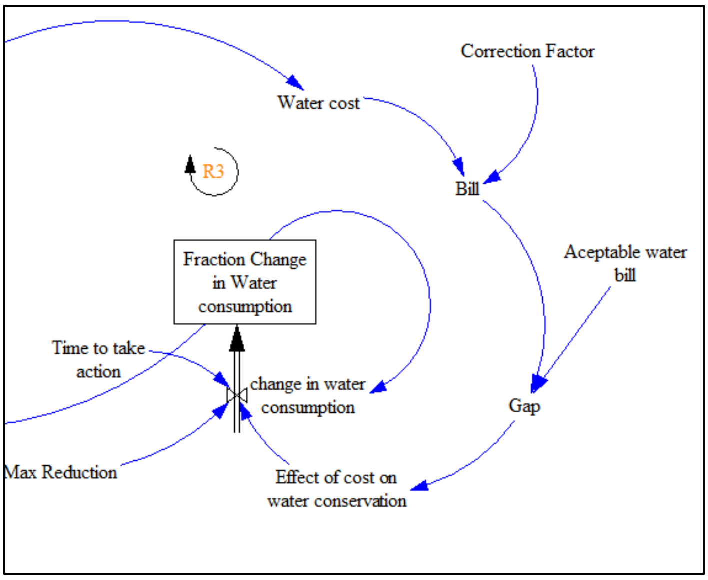

Figure 11. Effect of water bill in water consumption

Finally, the total water consumption of water at USFQ was modeled. The total consumption was considered to be a result of the multiplication of 'water demand per capita' and the 'Occupancy'. The water multiplier is the average amount of water consumed per day and per person in an educational or office building[40]. The total drinking water consumed was also added to the total consumption variable. Additionally, the total

[39] Obtained from the Water Conservation Reports of UC-Berkeley and University of California.
[40] This value was considered to be 0.0095 m^3 (Ciria, UK)

water consumption was multiplied by the 'Infrastructure Efficiency Multiplier', to show how water consumption increase or decrease due to the efficiency of the technology used in the university buildings. Moreover, the impact of water was related to the total water consumption to show the percentage of reduction in water consumption due to awareness. Through the incorporation of the variables selected and formulations, the following behavior was obtained for Total Water Consumption at USFQ and for Water consumption per capita respectively:

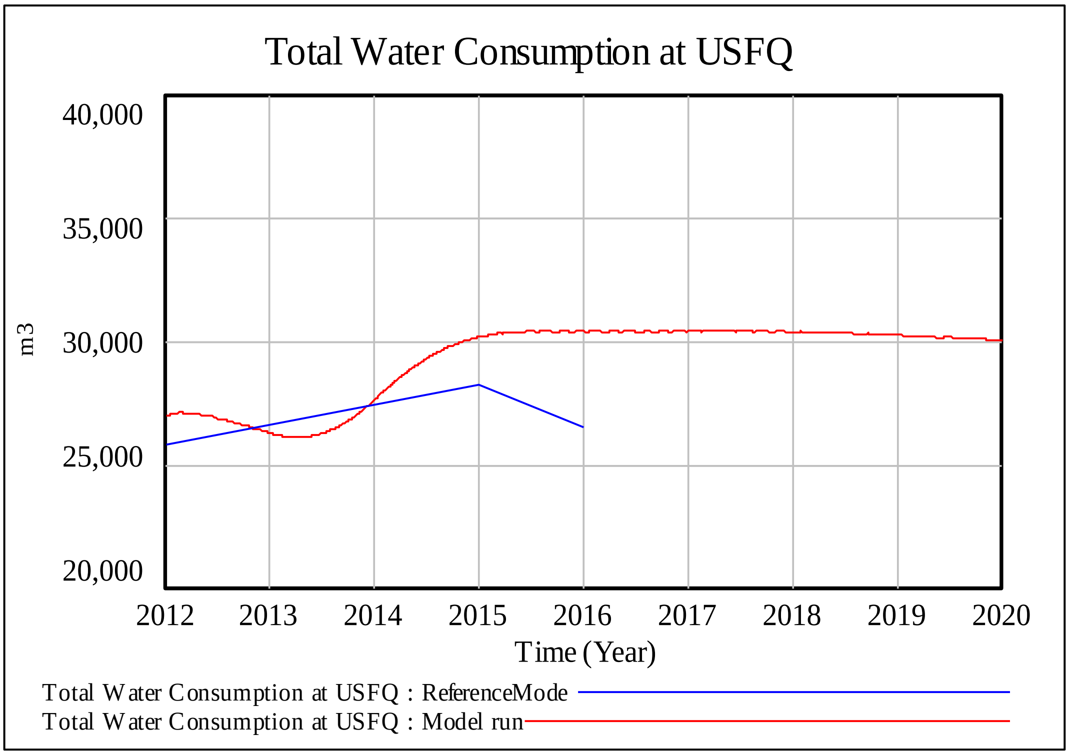

Figure 12. Total Water Consumption at USFQ

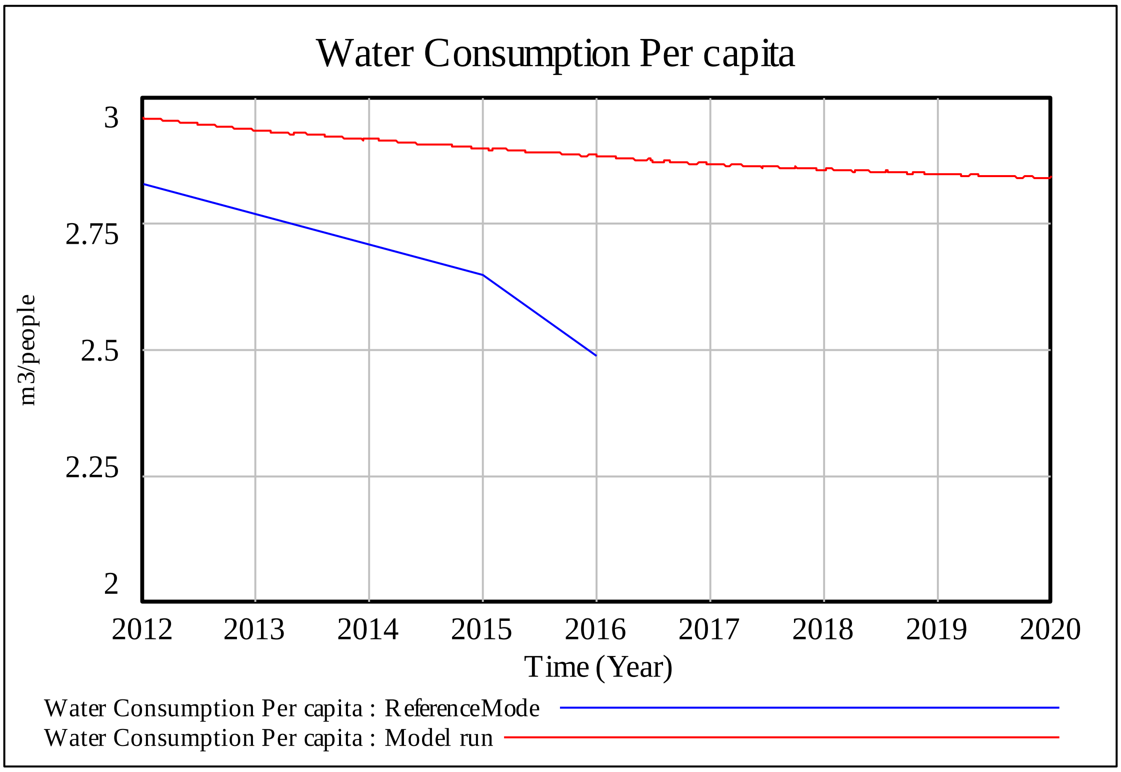

Figure 13. Water Consumption per capita at USFQ

Figure 12 exhibits in the *Mode*l run, how water consumption at USFQ decreases between 2013 and 2014. This reduction in water consumption could be attributed to the reduction in the number of students[41], due to a decrease on the number of students registered that year to enter the university (Senescyt, 2016). Also, the *Model* run shows an increase in the total water consumption with time. This increase reflects how occupancy affects the total water consumption of the university. However, **Figure 13** exhibits that water consumption per capita remains almost constant. The reference modes in **Figure 12 & 13** show a decrease on water consumption between 2015-2016, this is because the water

[41] In 2014, the number of students entering the university was reduced to the incorporation of the governmental test. The number of students from 2015 starts to increase due to the increment on the number of students that choose private education due to the difficulties that test present for access public education (Senecyt, 2016).

consumption of the Hayek building is not reflected in the water bill paid by the university, compared to the model run which includes water consumption of both campus

4.2.3 Model Behavior Analysis

The *Model* run for total water consumption and consumption per capita (Fig 12 & 13), show similar behaviors to that on the reference modes. This suggests that the structure of the model is similar to reality and can be used for the purposes of this study. The main findings from the model were:

Finding 1: Occupancy is one of the most important factors affecting total water consumption in the university. **Figure 14** exhibits how the number of students affect the number of professors and the number of staff, creating a reinforcing mechanism as follows: as the number of students increases, the number of professors increases and consecutively the number staff increases. This effect, impacts the total water consumption at USFQ making it higher **(See Figure 15).** However, occupancy appears to have no effect on water consumption per capita **(Figure 16)**. The literature explains that in academic buildings, water demand profiles does not seem to be strongly connected to occupancy patterns because the users have less access to water and minimal control on deciding if use an efficient appliance or not because the appliances at the university are already installed. Also, Flor (2017), explains that the activities in the university are individual activities and not collective like the ones at home. In this way, occupancy does not directly affect water consumption per capita.

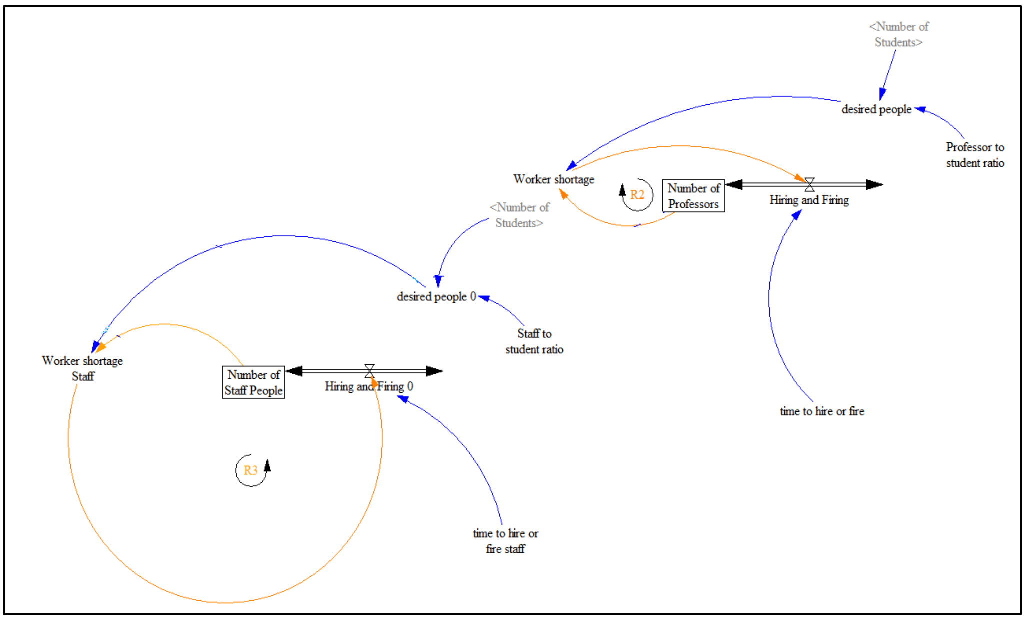

Figure. 14. Occupancy effect on Water Consumption: Reinforcing feedback loops R1 y R2.

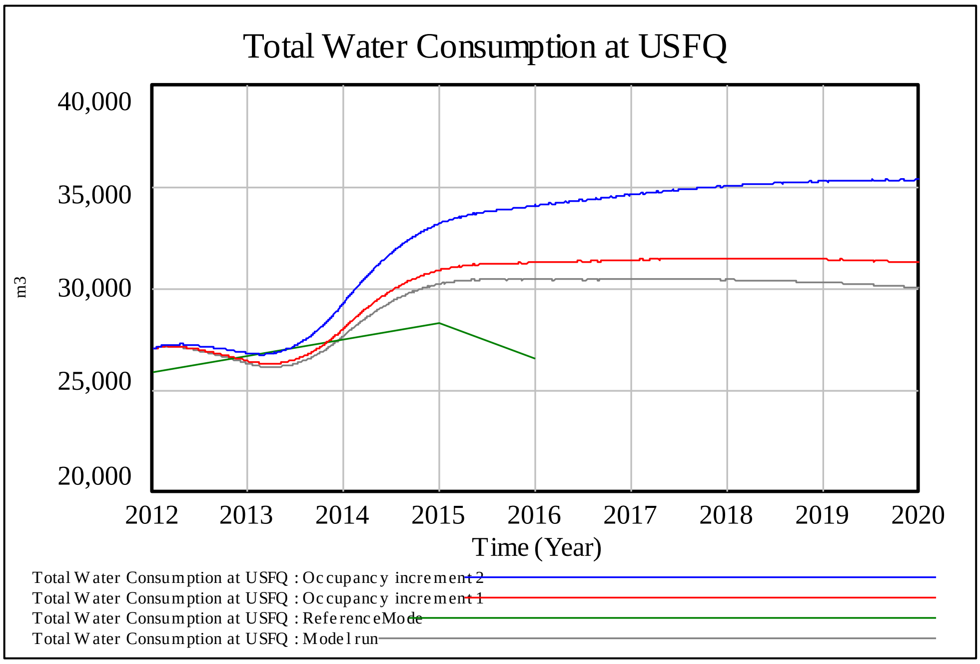

Figure 15. Total Water Consumption with a variation in occupation

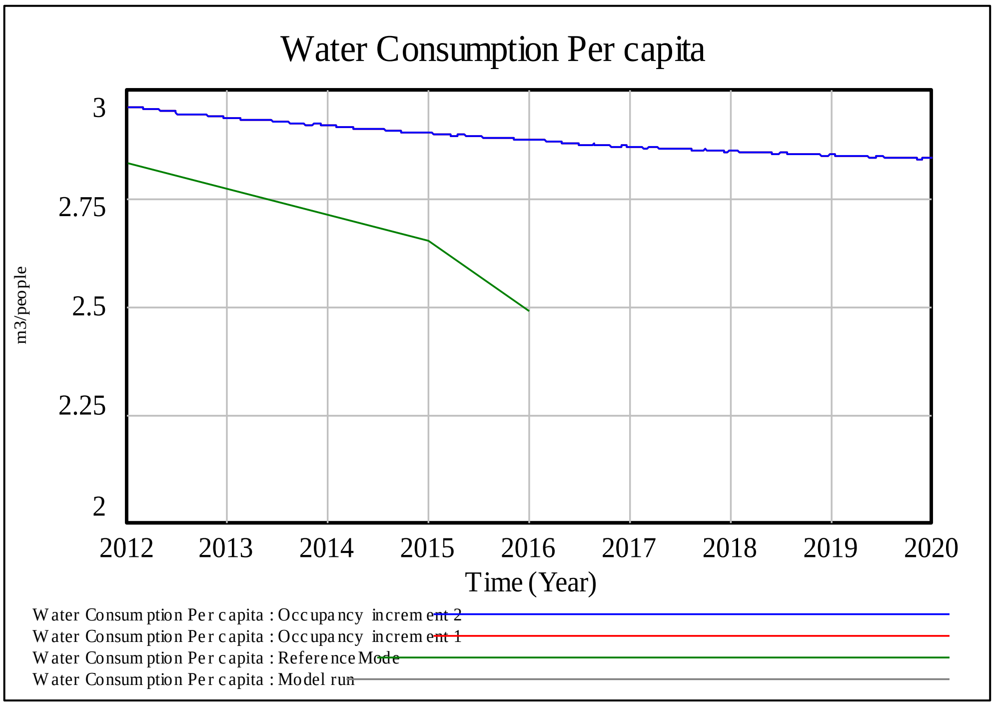

Figure 16. Water Consumption Per capita with a variation in occupation

Finding 2: Another factor that influence water consumption is awareness. The model shows that there exists a opposite relation between the level of awareness in the user with the water consumption variable. This means that as awareness increases, water consumption is reduced. In this context, the model shows a reinforcing loop R1, in which as the environmental literacy increases the level of awareness increases too, therefore the accumulated awareness effect is also greater. However, this relationship does not exhibit a great effect according to the model, as the water consumption reduction due to awareness is about 1 percent (1%) **(See Figure 17)**.

The literature mentions that the maximum reduction on water consumption due to awareness is of eight percent (8%)[42]. This low percentage of reduction (8%) is attributed

[42] Obtained from Defra Water Saving Campaign (Appelbom, 2009).

to the different demographic profile of the people in the universities and the high occupancy level which produces that environmental knowledge and campaigns have low levels of overall recognition (Appelbom, 2009). Moreover, the effect of awareness in water usage is low since the ratio of users that will gain awareness and that will change their behavior on water consumption is also low.

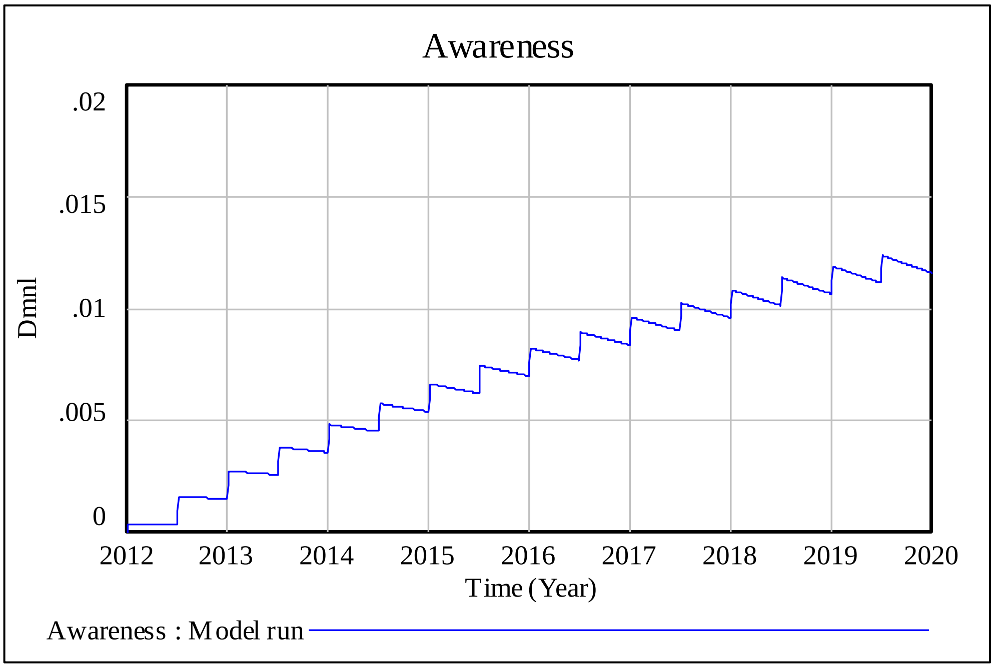

Figure 17. Effect of Awareness in water consumption

The model also shows that the accumulated awareness mainly depends on the frequency of campaigns. **Figure 18**, illustrates that as the frequency of campaigns increases, likewise the effect in water consumption. The initial frequency in the *Model run* is a campaign every six months. The first increment in the frequency is a campaign every three months and the second one exhibits a campaign every two months. The literature mentions that increasing the frequency of campaigns is expected to increase the promotion of awareness among users as they are constantly surrounded by information that encourages to develop positive attitude towards the environment. The increase on the frequency of campaigns produces low levels to forget awareness as it increases the recognition of the campaign amongst the segments of users (professors, students, staff).

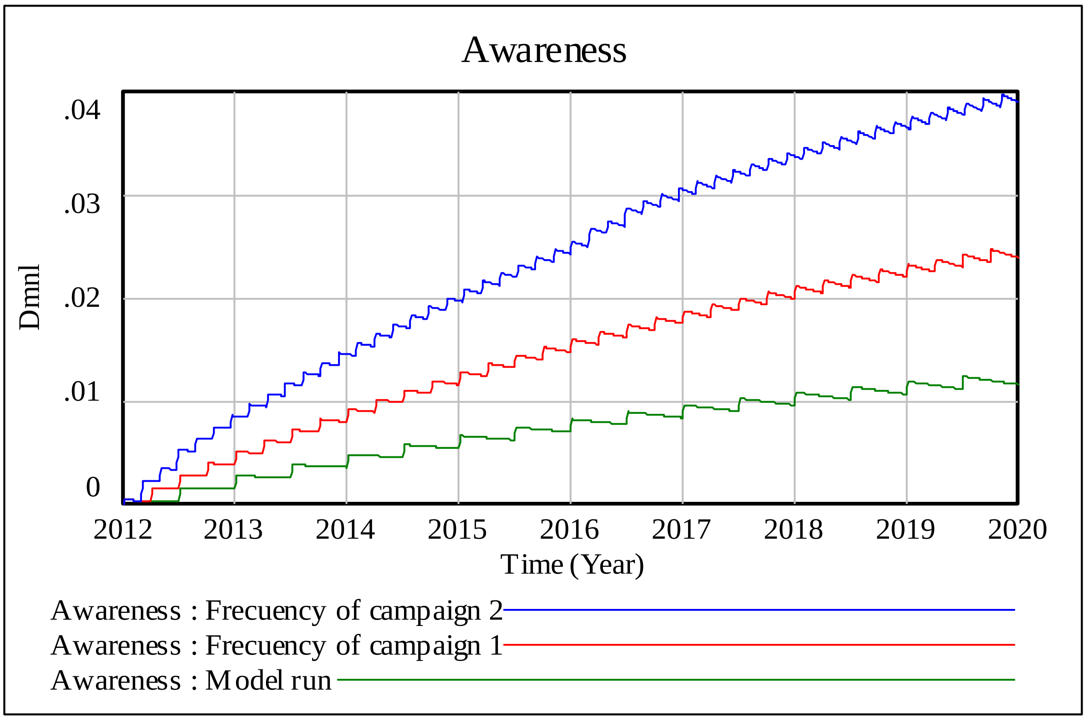

Figure 18. Effect of awareness in water usage using different campaign frequencies

Finding 3: Water cost influences water consumption and infrastructure efficiency. The feedback loop R3 created in the model **(See Figure 19),** show how if water consumption increases, the water bill will also increase. This effect, causes a change in water consumption due to changes in infrastructure efficiency. According to EPA (2009), a water bill that increases over time could influence in that building owners could look for an improvement, in water efficiency characteristics, in their buildings or homes.

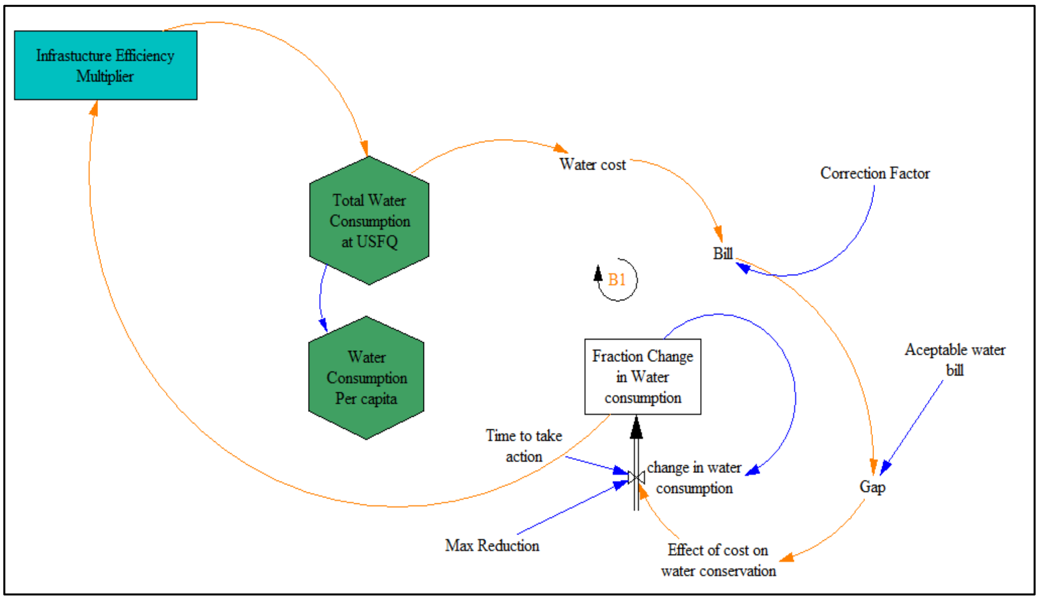

Figure 19. Water bill effect on water consumption: Balancing loop B1

However, **Figure 20** exhibits how the water bill has no effect on water consumption in the USFQ. This behavior can be attributed to the low cost that is paid every year for water bill in the university. As the water bill paid by the university is lower than the value of the bill accepted, the relation between bills is less than one. Therefore, no change on water consumption is observed.

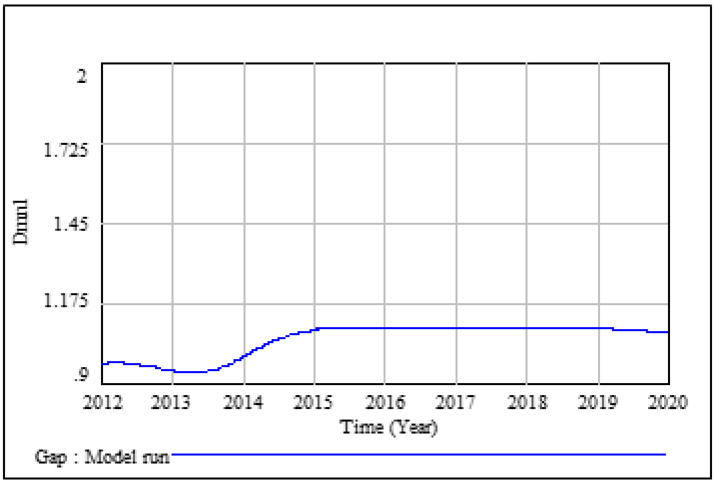

Figure 20. Gap[43] between water bill and acceptable water bill.

[43] The Gap calculated is dimensionless because it is the result of dividing the water bill to the acceptable water bill, which have the same units

Finding 4: The model was used to link it to the energy consumption at USFQ, in order to find the nexus between them. As mentioned earlier, energy is used during the treatment and distribution of water. According to CONUEE (2011), in a typical potable water system, the pumping system represents up to 95% of the energy consumption in the distribution lines. In Latin America, the literature mentions that 0.95 kWh are required for each cubic meter of transported water[44]. Additionally, there are other energy consumptions, which are a consequence of the operation of pipes and domestic pumps in the distribution systems of the users. According to Watergy Mexico (2011), a domestic piping system requires approximately 0.47 kWh for each cubic meter of water transported. **Figure 21** shows the amount of indirect energy that has been consumed by the university, from 2012 to 2016, due to water transportation. Indirect energy consumption, is defined as the energy consumed in transportation of water needed at USFQ. This indirect water consumption is not reflected on the energy bill but it causes great impact on urban environments as increases the rate of depletion of energy reserves and generates pollution and impacts the ecosystems (WWF,2011). To calculate this, an energy-water index of 1. 57 kWh/m^3 was used[45].

[44] This value represents the average energy required for water transport, in the region. This value could vary among countries.
[45] Obtained from the Energy Report (Corporacion Electrica del Ecuador,2014).

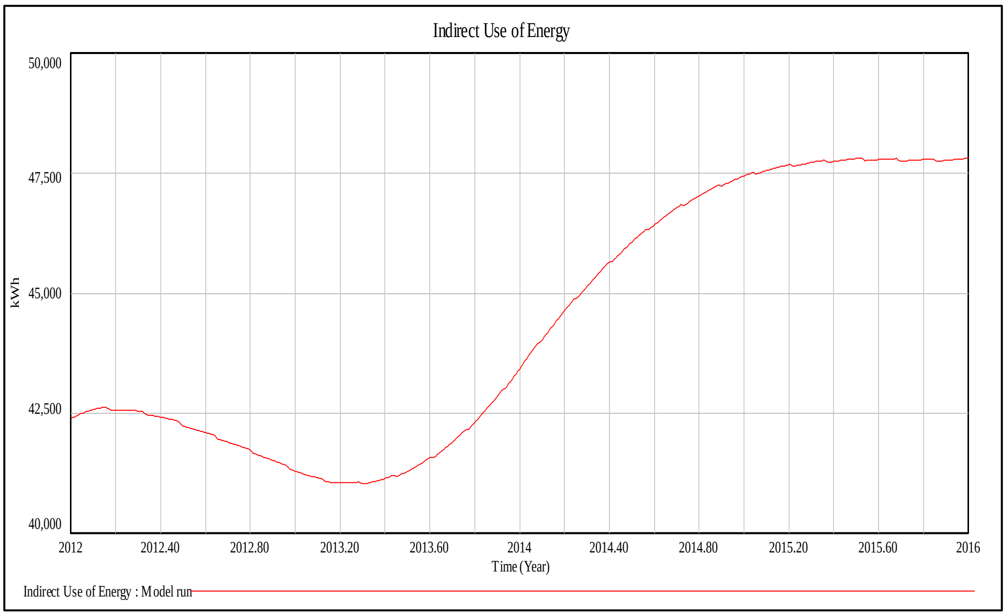

Figure 21. Indirect use of energy due to water transportation

Finding 5: Figure 22 shows how the efficiency of appliances can impact water consumption. The figure indicates that by implementing more efficient appliances in the bathrooms in the main campus which as mentioned earlier are less efficient than the bathrooms located in Hayek building., there is a reduction in water consumption. The change consists on replace the toilets and sinks for more efficient ones. This means replacing the toilets and sinks that use 0.006 m^3per flush and 0.00273 m^3, respectively, with sinks and toilets that consume 0.0026 m^3per flush and 0.0017 m^3, respectively. In response to the replacement of appliances, the total water consumption shows a reduction of 15.67%. Flor (2016) mentions that more efficient appliances can help to decrease water consumption by accelerating the benefits of using new and better technology.

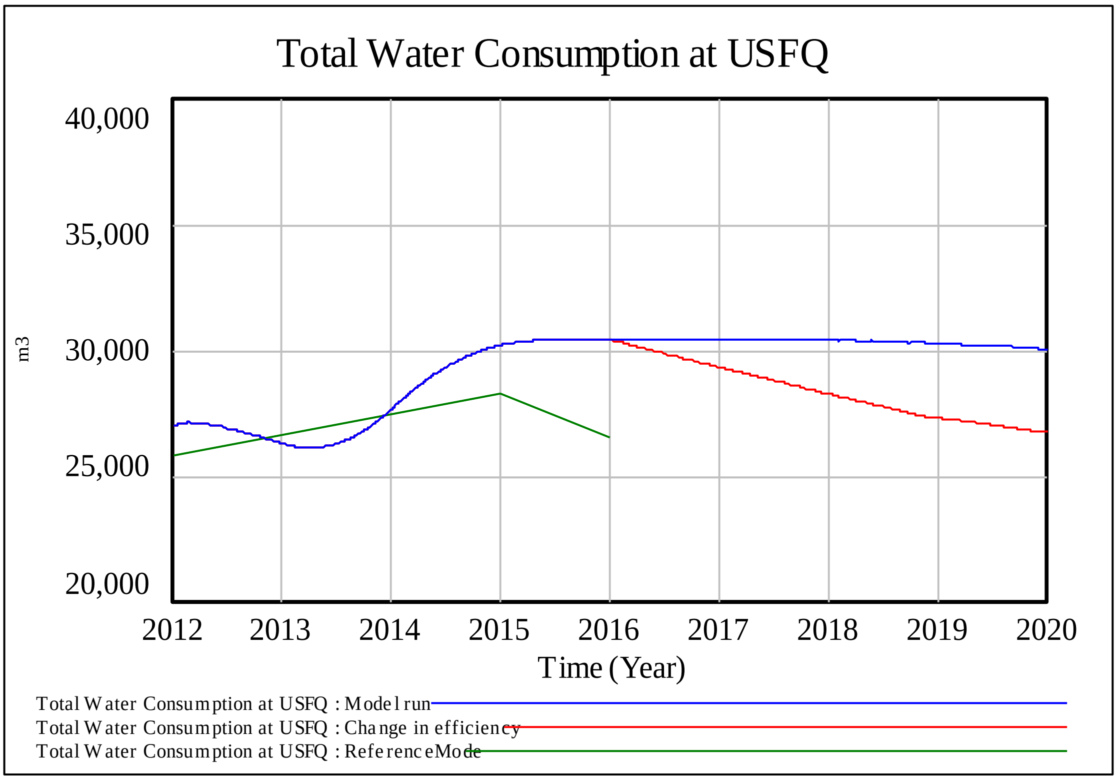

Figure 22: Model variation: improving efficiency characteristics of appliances

Finding 6: As mentioned earlier, during the water audit period it was identified that the bathrooms at Hayek building are more efficient than the ones at the main campus. Under this consideration, a model variation was created in order to see how total water consumption changes if the level of occupancy of the bathrooms also changes. To reflect this effect, the occupancy in the restrooms of Hayek building was increased in 20%, meanwhile the occupancy in the restrooms of the main campus was reduce in the same percentage (20%). In response to this change, the total water consumption show a reduction of 5.37% **(Figure 23).**

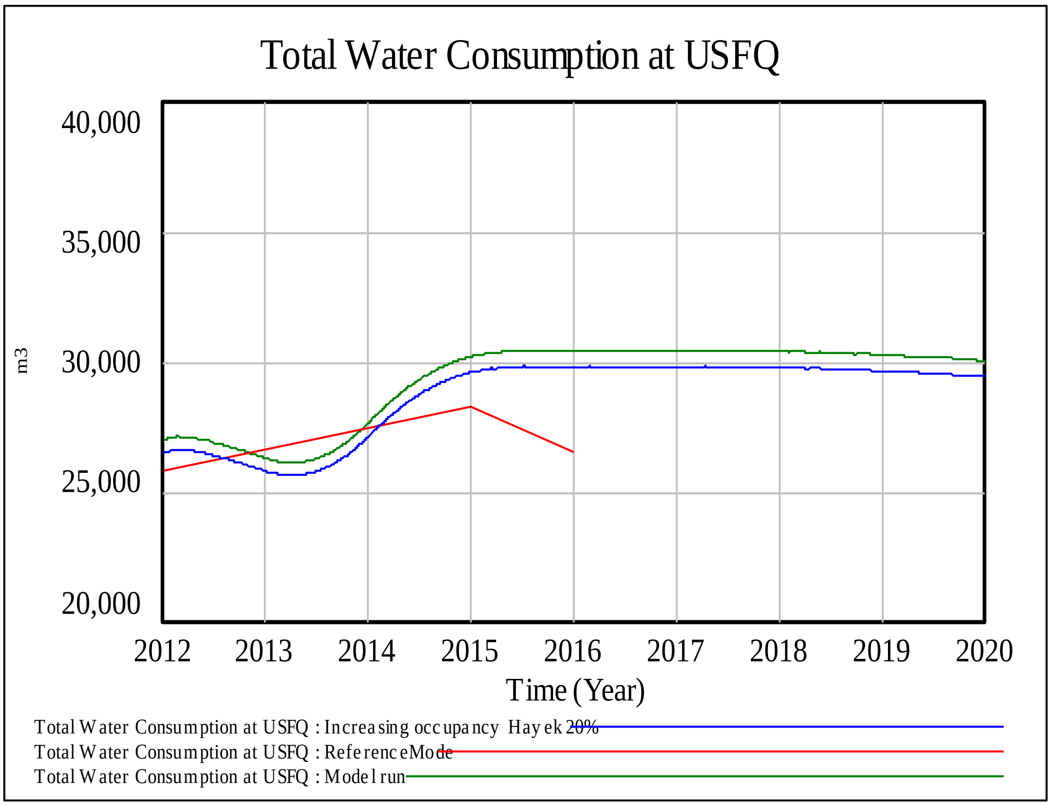

Figure 23: Model Variation: Increasing the occupancy of the restrooms in Hayek building

SECTION 5: DISCUSSION AND CONCLUSION

Water consumption is a complex variable influenced by different factors related to social, economic, and technological aspects. The behavior of the model showed that the variables that affect water consumption in the university are: occupancy, awareness, and efficiency of appliances. Each of these variables affect water consumption in a different way. Occupancy is the major factor that influence total water consumption at USFQ (EPA,2009). However, the model showed that occupancy does not influence water consumption per capita. According to (Hunt & Rogers, 2014), water consumption per capita is marginally influenced by occupancy rates. This is due to the fact, that supplies increase relative to occupancy and that the daily personal activities of user in educational buildings are quota of water individual uses.

The model also showed that awareness has a small effect on water consumption reduction as it only contributes with 1.16% in reductions. However, as shown in the model, an increment on the frequency of environmental campaigns could increase the accumulated effect of awareness in water usage (Selvam & Nazar, 2011). The model showed that if the frequency of campaigns is doubled[46], the effect of awareness doubles too (2.45%). According to Flor (2016), campaigns help to increase the level of awareness in a community, as they increase the number of people that will change they behavior.

Additionally, the model exhibited that water bill has little effect on water consumption reduction. One of the main findings of this study was that the university water bills do not reflect the actual consumption of water in the USFQ. The amount paid for water in the university could be consider as low if compared with the amount paid by other services,

[46] Doubling the frequency of campaigns means: one campaign occurs every three months instead of one every six months)

like energy, for example. These low bills cause users to be less aware about how much water they consume. This leads to the conclusion that the users got used to the average amount paid monthly for water consumption.

Also, findings from the model show that efficient infrastructure and technology are a promising sector for reducing water consumption, resulting in an opportunity to develop water policies that can afford water reduction of almost 18% after implementation[47] (Berkeley, 2010). **Finding 5** above, showed how the replacement of more efficient restrooms a reduction of 15.67% on the total water consumption could be achieved. Also, **Finding 6** exhibits how if the level of occupancy in the Hayek building increases in 20%, a reduction of almost 6% in total water consumption could be achieved. These findings suggest that efficiency should be consider for policies to reduce water consumption. The installation of more efficient technologies, in the buildings of the university, could work as a strategy to reduce water consumption, as it forces the end users to use devices that use less amounts of water.

Moreover, the model exposed how energy and water are linked. The analysis show that an average of 250 000 kilowatts of energy are consumed every year for water transport to the university. This finding reveals the importance of using alternative sources of water like recycling water or rainwater to reduce resources utilization and reduce environmental impacts of water consumption. Alternative water sources help to decrease the amount of wastewater discharges, reducing pollution. In this way synergies between

[47] The literature mentioned that the average time to the implementation of policies related to changes in efficiency of infrastructure take 2-3 years.

water and energy systems offer opportunities to compound benefits of developing new technologies.

Additionally, it is important to mentioned that the group sessions and water audit provided key information to understand the behavior of water consumption at USFQ. The water audit showed that the appliances at the main campus are less efficient that the ones at Hayek. However, it also showed that the restrooms at the main campus, have higher occupancy than the ones at Hayek. During the water audit, it was identified that the university does not have hydrosanitary plans of its facilities, nor individual water meters in buildings. This made it difficult to understand how the water distribution system works in the university.

System dynamics approach was a useful methodology that enables to understand the structure and dynamics of a complex system like water consumption. Also, system dynamics helped as a rigorous modeling method that enables to build formal computer simulations to used them as a first stage to design possible water efficient policies in the future. Finally, System dynamics allowed to accomplish the objectives of this study to identify the dynamics of water consumption and finding the main variables that influence water consumption at the university. As we saw in the model, integrated analysis and modeling of the water consumption requires the simulation of many human and social systems and their complex interactions and dynamics. This study could be utilized as basis for developing water policies in the university.

SECTION 6: FUTURE WORK AND RECOMMENDATIONS

a) Further research, on the relationships between water consumption, consumer behavior and technology will provide a better understanding of how water consumption works at the USFQ.

b) Hydrosanitary information is required in order to have a better understanding of how the water distribution system works at the university.

c) The model can be used as a first stage to design a Water Conservation Plan that provides viable policies to be applied in the university.

d) The measures that can be implemented are the following:

   -Installation of water meters in each university building in order to have a better understanding of the levels of consumption in the university and which buildings use bigger amounts of water.

   -Implementation of more efficient technology in the most occupied restrooms could contribute to important water reductions.

   - Increasing the occupancy on the Hayek restrooms also represent an opportunity to reduce water consumption.

   -Increasing the level of awareness in the university by promoting more frequent campaigns could help to increase the ratio of population aware about water saving.

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Appendix A: Group Session Methodology

The information below describe the activities that were used for the groups session. It is important to mention that the activities that were used during the sessions are an adaption of the original methodology proposed.

Variable Elicitation

Context:
Early in the modeling process

Purpose:
To facilitate consensus---based group discussion about the model problem and boundaries. It elicits key variables that become the input for other activities.

Status:
Best practices

Primary nature of group task:
Divergent

Time:
Preparation time: 0 minutes
Time required during sessions: 20 minutes
Follow-up time: 0 minutes

Materials needed:
1. Markers
2. Stacks of plain paper
3. Chalk/whiteboard markers

Inputs:
None

Outputs:
Prioritized list of variables

Roles:
- Facilitator with moderated expertise in SD and small group facilitation.
- Modeler with moderated expertise in SD

Steps:
Part I

1. The facilitator gives each participant sheets of blank paper and markers.
2. The facilitator writes a task focusing question on the whiteboard or flipchart, such as “What are the key variables affecting the process and outcomes of the [project name] project?”
3. The facilitator asks participants to write as many problem-related variables as the can on the sheets of paper. Participants are given a few minutes to work individually on their lists.
4. Once the have finished the individual exercise, the facilitator uses the same process used in the hopes and fears script to put all individual variables on the board. When a variable name is open to several interpretations, the facilitator asks for a brief description or definition of the variable, including the units in which the variable can be measured.
5. The facilitator writes the variable name on the board, including any additional information in parenthesis.

Part II

6. The facilitator asks the participants to prioritize the variables by simple voting mechanisms. Individuals can vote for as many variables as they want. The number of votes for each variable is also written down on the board.
7. The facilitator makes a summary of the variables on the board, while the recorder captures the products of the process either photographically or in a word processor.
8. The facilitator suggests which variables can be considered stocks as they are mentioned. If the participants agree, the facilitator can add the words “level of” to these variables.

Evaluation criteria:
Identification of key variables and stocks.

Authors:
Andersen and Richardson

Date created:

History:
Originally described in Luna-Reyes et al (2006)

Appendix B: Water Audit

Section B1. Water Audit Guidelines

Table 5 and 6, exhibit the questions that were used to conduct the interviews to the cleaning staff manager and the two people from the cleaning staff , during the water audit.

Building Manager	
Question	Answer
What type of toilets does the commercial building have (low flush, differentiated flush, etc.)? What is the flush volume of the toilets?	
Are there any initiatives for saving water in the installations within the building such as aerated tabs?	
At what time of the days there is no activity in this commercial building? During this time is there any facility that is programmed to consume water?	
Is this building naturally ventilated?	
Have there been any recent refurbishments in this building, if so, could you provide any more information?	
Do you use water for gardening? How many times per month do you water the plants? What irrigation systems do you use?	

Table 5: Building Manager Interview Guideline

Cleaning Staff	
Question	Answer
How many times do you clean the bathrooms and kitchens per day?	
Please describe which activities you use water for and approximately how much? (if easier, ask how many buckets he/she Uses)?	
Are you responsible for using the dishwashers? How many times in a day do you use it? Does this vary and if so, how?	

Table 6: Cleaning Staff Interview Guideline

Table 7, presents which kind of information was collected in the water audit.

Water Consumption Management and people counting.				
Project Title: Date, Time: Location:				Completed by: Reviewed by:
Location (Floor)	Area (Kitchen, bathroom, laboratory)	Time interval	How many people enter the area?	Observations (Are there any initiatives of water efficiency? Are there any indications of water wastage by staff? (Faucets left running, using excessive water in the kettle etc.)

Table 7: Audit Guidelines

Section B2. Water Audit Collected Data

Table 8, presents the information collected regarding water consumption of appliances.

Area	Location	Toilet Technology	Water Requiremnt m^3 per flush	Efficiency [48]	Urinary Technology	Water Requiremnt m^3 per flush	Sink Technology	Water Requiremnt (m^3/s)	Efficiency[49]
BAÑO HOMBRES	BIBLIOTECA FRENTE	sensor	0.006	Inefficient	automatico	0.002	SENSOR	0.06	Inefficient
BAÑO HOMBRES	BIBLIOTECA	sensor	0.006	Inefficient	automatico	0.002	SENSOR	0.02	Inefficient
BAÑO HOMBRES	DAVINCI PB	sensor	0.006	Inefficient	pulsor	0.002	SENSOR	0.09	Inefficient
BAÑO MUJERES	HAYEK	palanca	0.006	Inefficient	n/a	0.002	TAMBOR	0.08	Inefficient
BAÑO HOMBRES	HAYEK	palanca	0.006	Inefficient	automatico	0.002	TAMBOR	0.08	Inefficient
DUCHA MUJERES	HAYEK	giratorio	N/A	N/A	n/a	0.002	N/A	0.02	Inefficient
DUCHA HOMBRES	HAYEK	giratorio	N/A	N/A	n/a	0.002	N/A	0.02	Inefficient
BAÑO MUJERES	HAYEK	palanca	0.0048	Moderate	n/a	0.002	TAMBOR	0.10	Inefficient
BAÑO HOMBRES	HAYEK	palanca	0.0048	Moderate	automatico	0.002	TAMBOR	0.10	Inefficient
BAÑO MUJERES	HAYEK	presion	0.0048	Moderate	n/a	0.002	SENSOR	0.09	Inefficient
BAÑO HOMBRES	HAYEK	presion	0.0048	Moderate	automatico	0.002	TAMBOR	0.00	Inefficient
BAÑO MIXTO	EUGENIO ESPEJO	palanca	0.006	Inefficient	n/a	0.002	TAMBOR	0.00	Inefficient
BAÑO MUJERES	BIBLIOTECA FRENTE	sensor	0.006	Inefficient	n/a	0.002	SENSOR	0.06	Inefficient
BAÑO MUJERES	BIBLIOTECA	sensor	0.006	Inefficient	n/a	0.002	SENSOR	0.02	Inefficient
BAÑO MUJERES	DAVINCI PB	sensor	0.006	Inefficient	n/a	0.002	TOUCH	0.07	Inefficient
BAÑO HOMBRES	DAVINCI 3ER P	sensor	0.006	Inefficient	pulsor	0.002	TOUCH	0.09	Inefficient
BAÑO MUJERES	DAVINCI 3ER P	sensor	0.006	Inefficient	n/a	0.002	SENSOR	0.09	Inefficient
BAÑO HOMBRES	MAXWELL 2DO P	palanca	0.006	Inefficient	automatico	0.002	TAMBOR	0.04	Inefficient
BAÑO MUJERES	MAXWELL 2DO P	palanca	0.006	Inefficient	n/a	0.002	TAMBOR	0.09	Inefficient
BAÑO HOMBRES	EINSTEIN PB	sensor	0.006	Inefficient	n/a	0.002	SENSOR	0.08	Inefficient
BAÑO MUJERES	EINSTEIN PB	sensor	0.006	Inefficient	n/a	0.002	SENSOR	0.05	Inefficient
BAÑO MUJERES	DARWIN	palanca	0.006	Inefficient	n/a	0.002	TAMBOR	0.07	Inefficient
BAÑO HOMBRES	DARWIN	palanca	0.006	Inefficient	automatico	0.002	TAMBOR	0.11	Inefficient

Table 8: Water Consumption of Appliances

[48] Compared to a Benchmarking System proposed by the University of Birmingham (Hunt and Rogers, 2014). Efficient toilets require=0.0026 m^3/flush, Moderate=0.0045 m^3/flush

[49] Compared to a Benchmarking System proposed by the University of Birmingham (Hunt and Rogers, 2014). Efficient sinks require :0.0017 m^3/person day

Section B3. Water Audit Collected Data

Table 9 and 10, present the information collected in the water audit and which was used to calculate the Occupancy Factors of the restrooms in the main campus and Hayek building.

Area	Location	Toilet Technology	Number of Toilets	Sink Technology	Number of Sinks
BAÑO HOMBRES	BIBLIOTECA FRENTE	SENSOR	3	SENSOR	3
BAÑO HOMBRES	BIBLIOTECA	SENSOR	3	SENSOR	3
BAÑO HOMBRES	DAVINCI PB	SENSOR	3	SENSOR	5
BAÑO MUJERES	HAYEK	PALANCA	3	TAMBOR	3
BAÑO HOMBRES	HAYEK	PALANCA	3	TAMBOR	3
DUCHA MUJERES	HAYEK	GIRATORIO	2	N/A	N/A
DUCHA HOMBRES	HAYEK	GIRATORIO	2	N/A	N/A
BAÑO MUJERES	HAYEK	PALANCA	4	TAMBOR	3
BAÑO HOMBRES	HAYEK	PALANCA	2	TAMBOR	2
BAÑO MUJERES	HAYEK	PRESION	7	SENSOR	8
BAÑO HOMBRES	HAYEK	PRESION	6	TAMBOR	6
BAÑO MIXTO	EUGENIO ESPEJO	PALANCA	1	TAMBOR	1
BAÑO MUJERES	BIBLIOTECA FRENTE	SENSOR	3	SENSOR	3
BAÑO MUJERES	BIBLIOTECA	SENSOR	3	SENSOR	2
BAÑO MUJERES	DAVINCI PB	SENSOR	5	TOUCH	5
BAÑO HOMBRES	DAVINCI 3ER P	SENSOR	3	TOUCH	5
BAÑO MUJERES	DAVINCI 3ER P	SENSOR	5	SENSOR	5
BAÑO HOMBRES	MAXWELL 2DO P	PALANCA	4	TAMBOR	5
BAÑO MUJERES	MAXWELL 2DO P	PALANCA	4	TAMBOR	5
BAÑO HOMBRES	EINSTEIN PB	SENSOR	5	SENSOR	4
BAÑO MUJERES	EINSTEIN PB	SENSOR	5	SENSOR	5
BAÑO MUJERES	DARWIN	PALANCA	2	TAMBOR	2
BAÑO HOMBRES	DARWIN	PALANCA	2	TAMBOR	2

Table 9: Number of Appliances

Area	Location	Time	Men	Women
BAÑO HOMBRES	BIBLIOTECA FRENTE	9:55:00 AM	23	0
BAÑO HOMBRES	BIBLIOTECA	10:30:00 AM	23	0
BAÑO HOMBRES	DAVINCI PB	11:32:00 AM	20	0
BAÑO MUJERES	HAYEK	12:40:00 PM	0	19
BAÑO HOMBRES	HAYEK	12:40:00 PM	25	0
DUCHA MUJERES	HAYEK	N/A	0	0
DUCHA HOMBRES	HAYEK	N/A	0	0
BAÑO MUJERES	HAYEK	1:11:00 PM	N/A	11
BAÑO HOMBRES	HAYEK	1:11:00 PM	7	0
BAÑO MUJERES	HAYEK	1:45:00 PM	N/A	11
BAÑO HOMBRES	HAYEK	1:45:00 PM	9	0
BAÑO MIXTO	EUGENIO ESPEJO	9:00:00 AM	2	1
BAÑO MUJERES	BIBLIOTECA FRENTE	9:55:00 AM	0	14
BAÑO MUJERES	BIBLIOTECA	10:35:00 AM	0	16
BAÑO MUJERES	DAVINCI PB	11:35:00 AM	0	15
BAÑO HOMBRES	DAVINCI 3ER P	12:28:00 PM	15	0
BAÑO MUJERES	DAVINCI 3ER P	12:28:00 PM	0	22
BAÑO HOMBRES	MAXWELL 2DO P	2:20:00 PM	49	0
BAÑO MUJERES	MAXWELL 2DO P	2:20:00 PM	0	28
BAÑO HOMBRES	EINSTEIN PB	2:14:00 PM	101	0
BAÑO MUJERES	EINSTEIN PB	2:14:00 PM	0	88
BAÑO MUJERES	DARWIN	3:03:00 PM	0	9
BAÑO HOMBRES	DARWIN	3:03:00 PM	12	0

Table 10. Number of people entering the restrooms

Section B4. Water Audit Collected Data

Images **1-4** present the different appliances audited in the restroom areas.

Image 1. Urinary kind in the Hayek building

Image 2. Toilet kind in the USFQ installations

Image 3. Urinary kind in the main campus building

Image 4. Sink kind in the USFQ installations

Section B5. Water Audit Collected Data

Images **5 and 6** exhibit the number of bottles filled with the water distribution machines at the end of the day (8pm).

Image 5. Water distribution machine at the main campus building.

Image 6. Water distribution machine at Hayek building.

Section B6. Water Audit Collected Data

Images **7 and 8** exhibit two examples of the appliances audited in order to identify the water requirements of the laboratory areas and the kitchen areas respectively.

Image 7. Dentistry machine that requires water

Image 8. Dish washing machine

Section B7. Water Audit Collected Data

Table 11, shows the information gathered during the water audit in order to identify the water requirements withing the different laboratory areas.

Laboratory	Water Requirement (m3/week)
Environmental Engineering	0.3
Environmental Engineering (2)	0.1
Food Engineering	0.65
Nutrition	0.08
Biotecnology	0.2
Biotecnology (2)	0.85
Biotecnology (3)	0.3
Ecology	0.15
Chemistry	0.5
Photography	0.1
Mechanics	0.15
Biology	0.2

Appendix C: Session Groups 1 &2 (Brainstorming)

The pictures below present the ideas discussed during the group sessions. The brainstorming present every idea or variable mentioned by the audience and that were discussed during the sessions.

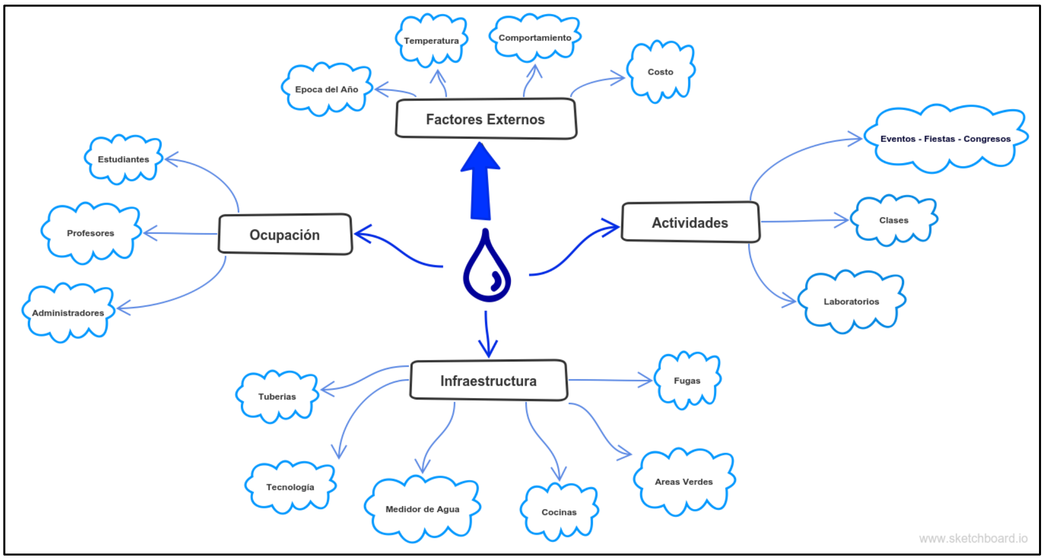


Figure 27: Variables connected to water consumption discussed on group sessions

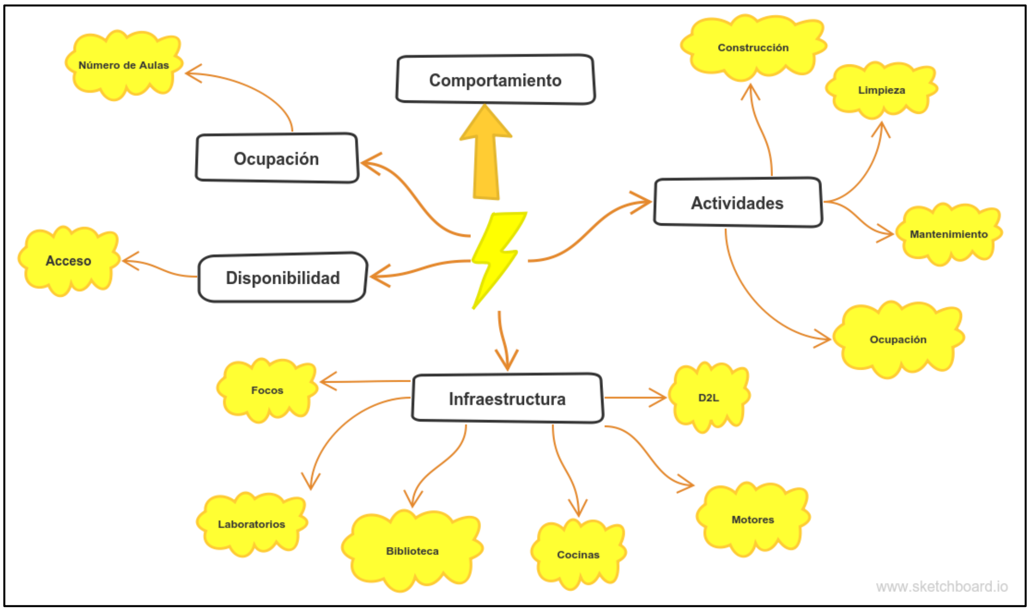


Figure 28: Variables connected to energy consumption discussed on group sessions

Appendix D: Modelling Occupancy

Section D1: Number of Students

Table 12, show the data used in order to calculate the number of students entering the university.

University Enrollment Rate				
		2013	2014	2015
Area	**Urban**	30.30%	27.90%	26.20%
	Rural	10.40%	8.20%	8.60%
Natural Region	**Coast**	22.50%	19.10%	17.30%
	Mountain range	28.10%	26.70%	26.70%
	Amazon	10.10%	8.00%	8.50%

Table 12. University Enrollment Rate (Senecyt, 2016).

Section D2: Number of Students

Table 13, show the data used to calculate the number of students withdrawing college each year.

Variable		Percentage of dropouts			
		No		Yes	
		n	%	n	%
Pre-university variables					
Gender	Male	702	87.8	98	19.2
	Female	418	87.8	58	17.2
Age (years)	18 to 20	225	94.1	14	15.9
	21 to 48	895	86.3	142	18.7

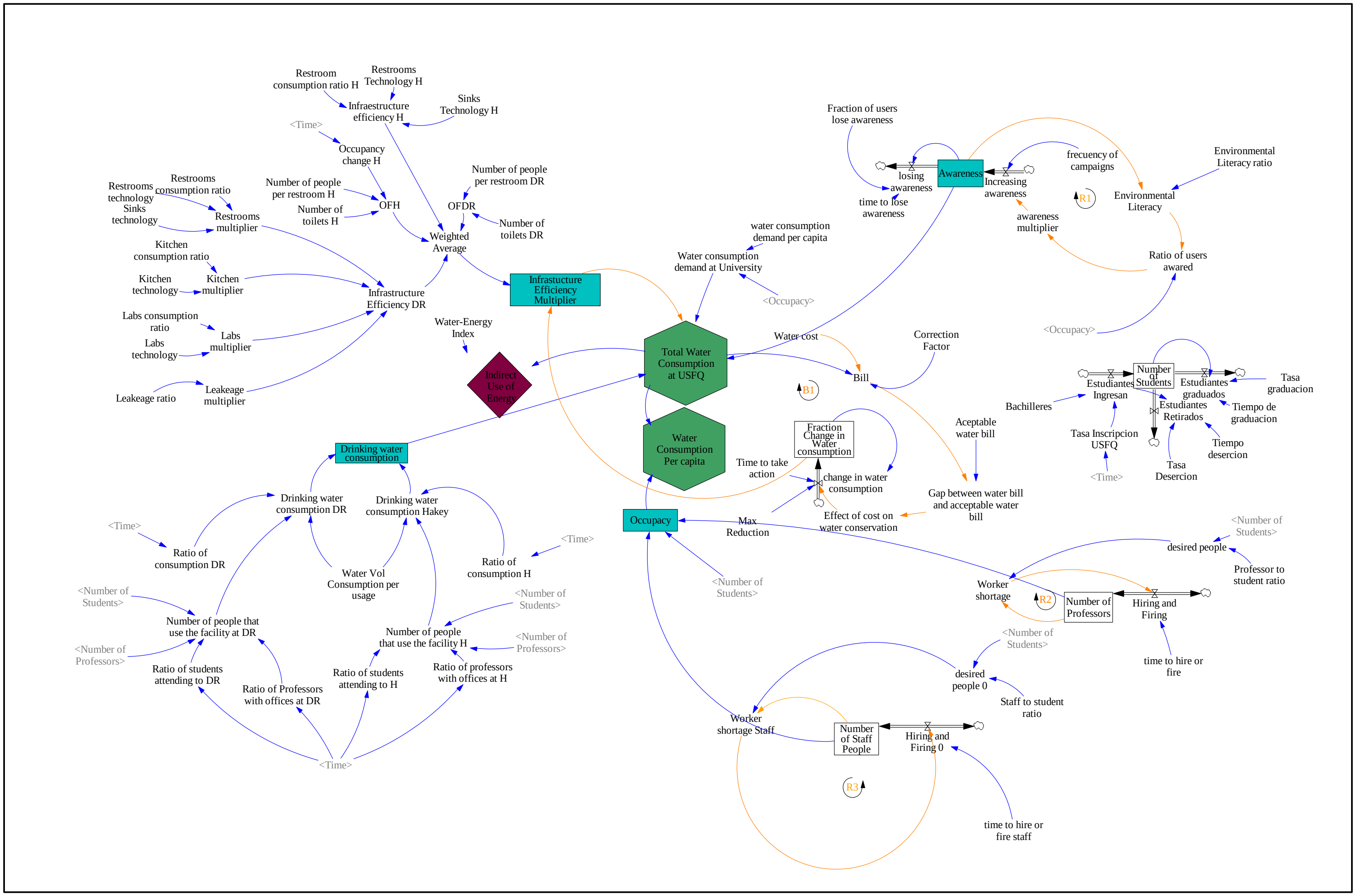
Table 13. Rate of college dropout (Senecyt, 2016).

Appendix E:

Table 11, exhibits the data used for building the references modes of 'Number of Students" and 'Number of Professors".

Year	Number of Students	Number of Professors
2012	7998	971
2013	7559	859
2014	8634	981
2015	9230	1097
2016	9158	1165

Table 11: Number of Professors and Students at USFQ: (Innovation Office USFQ, 2017)



Restroom consumption ratio H
Restrooms Technology H
Infraestructure efficiency H
Sinks Technology H
<Time>
Occupancy change H
Number of people per restroom DR
Restrooms technology
Restrooms consumption ratio
Sinks technology
Restrooms multiplier
Number of people per restroom H
OFH
Number of toilets H
OFDR
Number of toilets DR
Weighted Average
Kitchen consumption ratio
Kitchen technology
Kitchen multiplier
Infrastructure Efficiency DR
Infrastucture Efficiency Multiplier
Labs consumption ratio
Labs technology
Labs multiplier
Water-Energy Index
Leakeage ratio
Leakeage multiplier
Indirect Use of Energy
Total Water Consumption at USFQ
Water Consumption Per capita
Drinking water consumption
Drinking water consumption DR
Drinking water consumption Hakey
<Time>
Ratio of consumption DR
Water Vol Consumption per usage
Ratio of consumption H
<Time>
<Number of Students>
Number of people that use the facility at DR
<Number of Professors>
Ratio of students attending to DR
Ratio of Professors with offices at DR
<Number of Students>
Number of people that use the facility H
<Number of Professors>
Ratio of students attending to H
Ratio of professors with offices at H
<Time>
Fraction of users lose awareness
losing awareness
Awareness
Increasing awareness
frecuency of campaigns
time to lose awareness
awareness multiplier
R1
Environmental Literacy ratio
Environmental Literacy
Ratio of users awared
water consumption demand per capita
Water consumption demand at University
<Occupacy>
<Occupacy>
Water cost
Bill
Correction Factor
B1
Fraction Change in Water consumption
Time to take action
change in water consumption
Aceptable water bill
Gap between water bill and acceptable water bill
Effect of cost on water conservation
Max Reduction
Occupacy
<Number of Students>
Number of Students
Estudiantes Ingresan
Estudiantes graduados
Tasa graduacion
Bachilleres
Estudiantes Retirados
Tiempo de graduacion
Tasa Inscripcion USFQ
<Time>
Tasa Desercion
Tiempo desercion
<Number of Students>
desired people
Professor to student ratio
Worker shortage
R2
Number of Professors
Hiring and Firing
time to hire or fire
<Number of Students>
desired people 0
Staff to student ratio
Worker shortage Staff
Number of Staff People
Hiring and Firing 0
R3
time to hire or fire staff