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SCENARIOS FOR THE REUSE OF WATER GENERATED BY AIR CONDITIONERS FROM AN INSTITUTION

CENÁRIOS DE REAPROVEITAMENTO DA ÁGUA GERADA POR AR CONDICIONADOS DE UMA INSTITUIÇÃO

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Abstract: The article presents the modeling and development of a simulation model to evaluate the reuse of water generated by the conditioned air of a public higher education institution (IES). For this, the methodology of computational modeling and simulation was used: from the elaboration of a model, scenarios were constructed to carry out the analysis of the results. Among the analyzed aspects is the reduction of the financial impact, due to the reduction of the consumption of drinking water. To evaluate the possibilities, three scenarios were generated: a scenario based on the current situation, another called the Moderate scenario and finally the optimistic scenario. The results obtained through the simulation show that the reutilization process brings a significant financial gain. The simulated time horizon was ten years and Vensim software was used for the simulation development.

Keywords: Air conditioning. System Dynamics. Computational Modeling. Water resources. Sustainability.

Resumo: O artigo apresenta a modelagem e desenvolvimento de um modelo de simulação para avaliar o reaproveitamento da água gerada pelos ares condicionados de uma Instituição de Ensino Superior (IES) pública. Para isso, utilizou-se a metodologia de modelagem e simulação computacional: a partir da elaboração de um modelo, construíram-se cenários para realizar a análise dos resultados. Dentre os aspectos analisados está a redução do impacto financeiro, em função da redução do gasto com o consumo de água potável. Para avaliar as possibilidades, foram gerados três cenários: um cenário baseado na situação atual, outro denominado cenário Moderado e por fim o cenário otimista. Os resultados obtidos através da simulação demonstram que o processo de reaproveitamento, traz um significativo ganho financeiro. O horizonte de tempo simulado foi de dez anos e, foi utilizado o software Vensim para o desenvolvimento da simulação.

Palavras-chave: Ar condicionado. Dinâmica de Sistemas. Modelagem Computacional. Recursos Hídricos. Sustentabilidade.

1 INTRODUCTION

Water has been a constant concern of living beings since its creation, but the perspective began to change when man realized that the scarcity of this resource could mean risks to the continuity of the species, if the environment in general and some critical elements continue to exist. degradation process and rapid destruction. This reflection gained strength in Europe after the Second World War, when the degradation of the environment became more pronounced and from there, recovery initiatives gained momentum, which constituted a great commercial business (BERBERT, 2003).

In addition to being essential to human life and health, water is essential for ecological balance and economic and social development. As Grassi (2006) points out, water is a basic environmental component indispensable for the home of all known forms of life, in addition to being indispensable for the social and cultural development of humanity. Despite the importance of water for living beings, this renewable and non-inexhaustible natural resource has been suffering significantly from the actions of human beings, which modify their quality and quantity in space and time (CHRISTOFIDIS, 2002).

With the demographic and economic growth, the uses of water multiply and their demands grow rapidly, although the global quantity available is the same. Human supply, animal feed, industry, agriculture, navigation, electricity generation, fishing, sports, dilution and biodegradation of urban and industrial sewage are uses that are intensifying both globally and locally (GRASSI, 2006).

According to data from the National Water Agency (2013), the regulatory agency for the use of water resources linked to the Ministry of the Environment, almost one billion people worldwide do not have access to drinking water. According to the United Nations (UN), about four thousand children under 5 die every day from preventable water-related diseases, such as diarrhea, typhoid, cholera and dysentery. The statistics are the result of contamination of rivers, lakes and groundwater, with the discharge of untreated sewage. Also according to the UN, water will represent a major challenge due to its irregular distribution on the planet, added by its waste, pollution and degradation. The use of this asset has increased twice as much as the population growth rate in the last century, and in 2025, approximately 20% of the world population will live in areas with water resource problems (UN, 2002).

Brazil has 12% of the planet's freshwater reserves, but still faces chronic problems in the area of public health and economic development. Although the country is privileged in terms of water availability, its distribution over time and space is uneven, which generates situations of abundance in some regions of the country, such as the North, and situations close to scarcity, as in the northeastern semi-arid (NORONHA, 2006).

According to Mendonça and Leitão (2008), the availability of water in Brazil has become limited due to the compromise of its quality, a condition that becomes very serious when it is observed that about 60% of garbage deposits in the country are located next to rivers , lakes and sandbanks. The authors cite examples of Brazilian regions with problems in water supply, such as Greater São Paulo, where approximately half of the available water is affected by dumps, whose sanitary treatment is considerably inefficient, and Rio de Janeiro, where the supply of water for domestic and industrial use, due to increasing pollution by urban sewage. In the North region, where the largest fresh water reserve in Brazil is located (around 70%), it is where one of the most intense contamination of water resources is observed, in which pesticides are dumped by agricultural activities, mercury from mining and raw garbage.

In the arid and semi-arid regions of Brazil, water has become a limiting factor for urban, industrial and agricultural development, such as the drought polygon region in the Northeast (HESPANHOL, 2002). However, according to Hes Espanhol (2002), water scarcity is not an exclusive problem in arid and semi-arid regions. Many regions with abundant water resources, but insufficient to satisfy excessively high demands, also experience conflicts of use and suffer consumption restrictions, which affect economic development and quality of life.

Due to the scarcity of water, the importance of rational and sustainable use of this asset is growing, and one of the ways to better use it is through reuse. For Hes Espanhol (2002), water can be reused for several beneficial purposes, which depend on local characteristics, conditions and factors, such as political decision, institutional schemes, technical availability and economic, social and cultural factors. Bastos and Calmon (2013) cite the example of reusing water from air conditioners in a commercial building, in which it was shown that the reuse of water drained by the air conditioning system is economically viable, in addition to reusing water drinking water, which can be used for washing and maintenance of buildings and gardens. Among the potential forms of water reuse, Hes Espanhol (2002) mentions domestic sewage, which can be reused for drinking and non-potable urban use, for recreational activities such as canoeing, fishing, swimming, for recharging aquifers, and for agriculture. Industrial sewage, on the other hand, can be reused for the most diverse industrial processes.

The degradation of water and water resources is one of the serious global problems, according to the UN (2002), and expectations point to the worsening of the issue in the very near future. To curb this water scarcity, it is necessary to incorporate a philosophy of reuse in the management plans of public agencies and institutions, in the actions of the private initiative and in the daily habits of the population in general. With joint and integrated actions, we hope to contribute to the better use of this resource so important for human survival.

Thinking about the possibility of reducing the consumption of drinking water for cleaning Public Education Institutions (HEIs), this article aims to analyze scenarios for reusing water generated by air conditioners, evaluating the environmental and financial impact of the insertion of different lengths of air. water from the air conditioners.

To achieve the research objective, a computational model will be built using the Systems Dynamics methodology (Dynamic Systens). According to Daellenbach and Mcnickle (2005) the dynamic methodology of systems (SD) allows the study of the behavior of systems over time, in order to allow the evaluation of the consequences of certain decisions. The data were collected directly at an HEI in the central region of Rio Grande do Sul. Therefore, the proposed research problem is the following: What is the environmental and financial impact of adopting the reuse of water generated by the conditioned air of an HEI?

To answer the research problem, techniques from the area of systems dynamics were used. The use of tools in the area of support systems for decision-making seeks to add quality to the decision-making process, because, even today, many of the decisions about the management of water resources are based only on the experience of managers. (CHANG; WEI, 2000).

In this impetus, the justification for carrying out this research is due to the high use of air conditioning by users of the HEI. According to Fortes, Jardim and Fernandes (2015), the prospect of using water from the cooling system of air conditioning units is an apparently viable alternative, seeking to reconcile the use of water and the reduction of costs involved by high water consumption. Introducing IES managers to new decision-making possibilities regarding the use of water from Companhia Riograndense de Saneamento (CORSAN), several advantages can be cited when the decision maker uses some modeling process for decision making, such as the communication of new ideas to use less public resources (LACHTERMACHER, 2018).

Regarding the structure, it should be noted that this article is divided into five sections: this first section has an introductory character about the theme addressed; the second section contains the theoretical framework that supported the study. The third section, in turn, shows the research method adopted while the fourth section details the simulation model developed. The fifth section presents the results obtained and ends with the conclusion in the sixth section accompanied by suggestions for future investigations.

2 THEORETICAL REFERENCE

In contemporary society practically all the processes in the routine of the citizens, make use, directly or indirectly, of water resources. The growing problem of scarcity of water resources, added by the economic crisis, causes institutions to seek alternatives for the sustainable use of water, such as techniques for using the water generated by air conditioners.

For Senguer et al (2016) it is estimated that the existing water deficit picture will be expanded (SAUTCHUK, et al., 2004), and due to these predictions, it is necessary that people take attitudes to preserve these finite resources , as for example, the reuse of water (MACÊDO, 2007). In this section we will show that, because of its usefulness, water is considered a finite, scarce resource of economic value. Its importance is so great that it can define the development that a region, country or society can achieve.

2.1 Water Resource Management

Water is an essential element of life and is necessary for almost all human activities, being also a component of the landscape and the environment. It is a precious, priceless asset that must be preserved and protected at all costs. It can be used in several areas such as: electricity generation, industrial and domestic supply, irrigation of agricultural crops, navigation, recreation and also for assimilation and removal of sewage. (SETTI et al., 2001).

The development of economic activities and the great population growth have been causing serious problems to water resources. In light of this, public and civil agencies came together to create specific legislation and policies, with the objective of supporting the participatory and decentralized management of water resources (LIMA, CADEIAS E CUNHA, 2017).

The management of water resources in Brazil is guided by the National Water Resources Policy (PNRH) instituted by Law No. 9,433, of January 8, 1997, known as the Water Law, which created the National Water Resources Management System (SINGREH)). In this way, an integrated and participative management is advised, which mainly aims to guarantee the availability of water to the current and the next generations, in quality standards appropriate to the respective uses. (Lima; Cadeias e Cunha, 2017).

For the implementation of the PNRH, the National Water Agency (ANA) was created, instituted by Law No. 9,984 of 2000. It is characterized as a regulatory body, linked to the Ministry of the Environment (MMA), responsible, above all, for the implementation, operation, control and evaluation of management instruments and other functions inherent to water resources (ANA, 2011).

The Hydrographic Basin Committees have the legal mandate to determine water management in accordance with the government, and play an important role in this participatory management system. Among other competencies within their area of expertise, they are responsible for approving the appropriate application of the Basin Water Resources Plans, which allow integrating and articulating the other instruments of the Policy (ANA, 2011).

When there is a large supply of water, we can treat it as a free asset, with no economic value. As demand grows, conflicts between water uses and users arise, leading to scarcity. Right now, it needs to be managed as an economic asset, and it must be given a fair value. Scarcity can also occur due to so-called qualitative aspects, when pollution affects water quality and raises values to levels that are inadmissible for certain uses. (SETTI et al., 2001).

The rational use of water resources aims to ensure that water fulfills its role in the economic development and social welfare of the population, and is sufficient to continue to be a factor in balancing ecosystems. In order to enable this development, goals and structured planning, scientific studies must be carried out in order to provide control and use of water at minimum satisfactory quality standards, by its current and future users. To reach such a level of development, deep knowledge of risks and damage in different areas and groups is necessary to understand, plan and avoid possible damage to the local ecosystem. (POLETO, 2008).

2.2 System Dynamics

Systems Dynamics (DS) studies the behavior of systems over time. It has roots, among others, in systems theory, general systems theory and control theory. These theories provide a basis for holistic thinking, mentioned in some areas of literature. The first publication on General Systems Theory (TGS) took place in 1945, by biologist Ludwig Von Bertalanffy, in which he affirms that TGS treats living systems as always open systems, in contrast to the Systems Theory that it deals with in particular closed systems, focused on automation, systems engineering, cybernetics and computer technology (VENSIM, 2018).

Developed in the 1950s by engineer Jay Forrester, the dynamic systems methodology (DS) had its first application in an analysis by an American company, which verified fluctuations in sales. The Systems Dynamics (DS) methodology, according to Costa (2004), emerged when Jay W. Forrester was working on an article called “Industrial Dynamics, Major Breakthrough for DecisionsMakers” for the book “Industrial Dynamics”. In Jay's research, there was a need to use computers to run some simulations, with the help of his friend Richard Bennett to code the necessary equations. Through the need to run complicated codes, Richard created the simulator called SIMPLE (Simulation of Industrial Management Problems with Lots os Equations). This simulator was the starting point for Systems Dynamics. Today, there are several softwares, such as Stella, iThink, PowerSim and VenSim, that can be used in computers for the implementation of systems models.

System Dynamics allows the study of the behavior of systems over time, allowing the evaluation of the consequences of our decisions. For this reason and the need to study the impacts of recycling vegetable oils in a future time horizon, it was decided to use it in computer modeling and simulation. DS helps us to build models of most known systems, with the support of some software for the use of personal computers, we can simulate the behavior of these systems over time (VENSIM, 2018).

A DS model can be defined as the structure resulting from the interaction of policies. This structure is formed by two main components, which are stocks and flows. Ford (2009) defines DS as a combination of stocks and flows that use a computational structure to be simulated. Inventories refer to the model variables that are accumulated in the system and the flows are the decisions or policies of the system. These components can be organized in the form of cause and effect relationships, called balance or reinforcement feedback and are subject to time lags in the system under analysis.

Several authors use this methodology to analyze issues related to the environment and sustainability, among which the studies by Abeliotiset al. (2009); Dyson and Chang (2005); Kum et al. (2005); Simonetto (2014). Sufian and Bala (2007).

3 RESEARCH METHOD

For the development of this article, the systems dynamics methodology, applied by Law (2015), was used, using the computational modeling technique to serve as a basis for the execution of the desired simulations. According to Lisboa (2009), a model is the simplified representation of a real system, with the objective of reproducing the functioning of the existing real system. The complexity of a real system is influenced by several variables involved in the decision-making process. For Belfiore and Fávero (2012) due to the great complexity of this system, it is necessary to simplify from a model, so that the main variables involved in the system.

Six steps make up the modeling process. In the problem definition stage, the objectives to be achieved and the possible ways to solve the model are clarified. In this step, the limitations of the model are also defined. The construction of the computational model consists of a set of mathematical equations, derived from the logic between the variables created in the Vensim-PLE software by the researchers, in order to improve the efficiency of the system under study, in addition to offering subsidies for the borrower to decision identifies its limitations. The model solution is responsible for generating the output variables of the research, where they will be used to analyze the results. The evaluation of the model will happen through electronic spreadsheets and tests in laboratories, this step is important to try to leave the model with a greater proximity to the real system, it is in this stage that the variables will be tested and analyzed. After the evaluation, the model will be simulated in the Vensim-PLE software and finally the final evaluation stage consists of verifying whether the objective has been achieved.

To perform the analysis of the results of the computer simulation, the Vensim software will be used. Vensim has the characteristics of improving real systems, being widely used to develop and analyze models of system dynamics. Through the tools and their extensions, it presents the user with a high quality analysis, with dimensions that absorb and check reality. Different variables can be interconnected, assigning different weights in addition to providing the user with an environment for creating flexible models. Another benefit of the software is that it is free and can be used in classrooms or other educational environments.

The development of the model will be presented in the next session.

4 MODEL DEVELOPMENT

In the face of the economic crisis experienced by Brazil, budget cuts happen more frequently, and it is up to the Institutions to find strategies to reduce the costs necessary to maintain their full functioning. Among the expenses necessary to supply and meet the needs of users of a Higher Education Institution, is water. Because of this, the proposal for sustainable development becomes feasible, which is development capable of meeting the needs of users in the current situation, ensuring the ability to meet the needs of future generations.

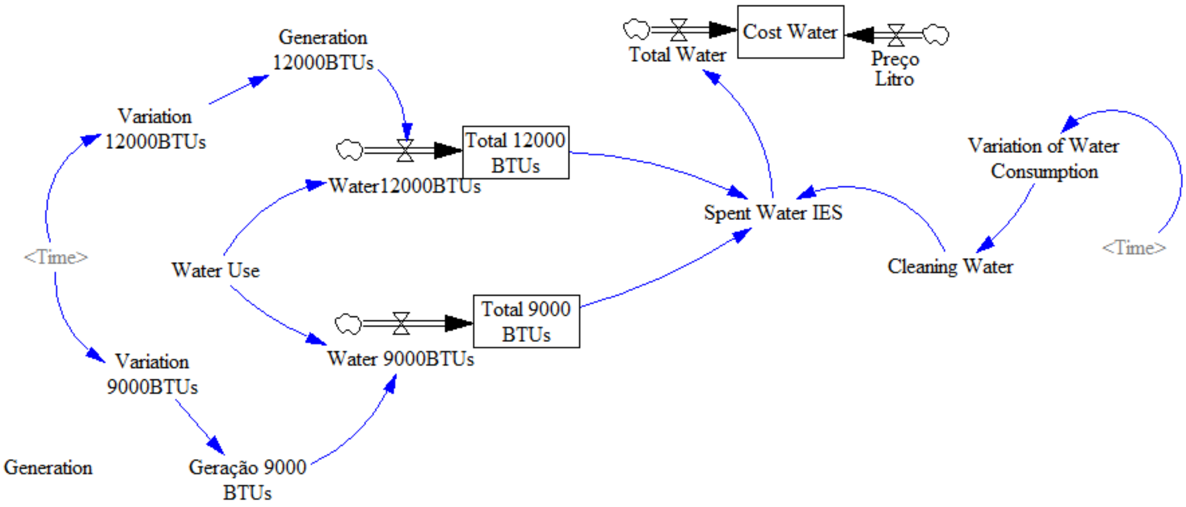
Air conditioning devices, which are used on a large scale in IES buildings, generate dripping water, derived from the humidity of the condensed air when the device cools the air in the internal environment. The article aims to analyze the use of water generated by air conditioning. According to MOTA (2011), on average an air conditioner with 12000 BTUs generates around 300 milliliters of water per hour or 0.3 liters per hour, while the 9000 BTUs generate half of this amount. In order to reinforce this data, a collection of approximately ten air conditioning units from the HEI partner of the study was carried out, reinforcing the data presented by the author mentioned in this paragraph.

The institution has about one hundred air conditioners with a power of 120000 BTUs, three hundred with a power of 9000BTUs and two hundred in maintenance or not installed. These were not considered to perform the modeling. The devices are switched on an average of 14 hours a day and approximately 22 days a month.

The cost of m³ of water varies considerably, with Companhia Riograndense de Saneamento (CORSAN) charging about R $ 0.005 for the liter of water. The average in Brazil of the liter of water is around R $ 0.0035. In order to reinforce the cost of water consumption in the HEI based on the study, 36 water bills were collected from the different buildings of the HEI, enabling researchers to understand the logic of the water consumption / expenditure of the institution.

The developed model has computational and mathematical characteristics, widely used in managerial situations where the quantities are represented by decision variables and the relationships between the variables, by mathematical expressions / equations (LACHTERMACHER, 2018). The model generated for this research is formed by three stock variables, "Total 12000 BTUs", "Total 9000 BTUs", "Water Cost", which represent the accumulations of data in relation to water and the cost involving water consumption. The model forms four flow variables, “Agua1200BTUs”, “Agua9000BTUs”, AguaTotals ”,“ PriceLitro ”. The flows are flows controlled by equations and for this reason they are represented by an icon similar to "a tap over a pipe", representing the transport of resources in the system. They total eight auxiliary variables, whose purpose is to feed the inputs of the model flows. The variables "Variation 12000BTUs" and "Variation 9000BTUs" are responsible for representing the average water loss generated by the conditioned air, together with the variables "Generation 12000BTUs", "Generation 9000BTUs" and "Water Utilization", which represent the quantity of total water collected by the two air conditioning models. The “Harnessing Water” variable will be used to differentiate the scenarios developed. Through different percentages applied to it, water collection differs, modifying different water reuse strategies. The model developed is represented in figure 1.

Figure 1 - Developed Model



Source: Authors (2020)

The model complements a “shadow” type variable called “time”, where it will be possible to project the time horizon, for the study we will study the impact of decisions for ten years. Where the “time” variable is connected, there will be a temporal change in its input values. A computational model depends on mathematical equations to accurately execute its logic in the simulation. For this model, the equations shown in frame 1 below were developed.

Frame 1 - Model of equations

Agua12000BTUs = Harnessing Water * Generation 12000BTUs
Agua9000BTUs = Water Use * Generation 9000 BTUs
Total 12000 BTUs = Water12000BTUs
Total 9000 BTUs = Water9000BTUs
Spent Water IES = Clean Water- (Total 12000 BTUs + Total 9000 BTUs)
Water Cost = Total Water * Price Liter

Source: Authors (2020)

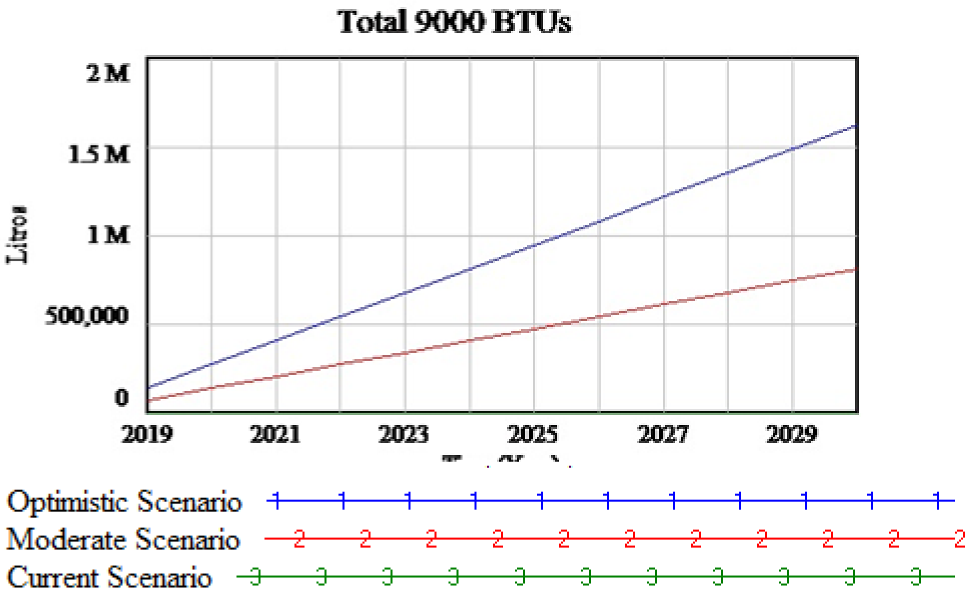
To analyze the model, three scenarios were generated: the first represents the current model, where the HEI does not collect the water generated from its conditioned air, serving as a comparative basis and allowing researchers to analyze which scenario obtains the best result; in the second, two proposals were generated, initially developing an average scenario, where 50% of the water will be collected; and finally, an optimistic scenario that will analyze the collection of 100% of the water generated by the conditioned air. The analysis of the scenarios and their results will be presented in the following section.

5 EXPERIMENT AND RESULTS

After defining the scenarios for carrying out the experiment using the model, simulations are performed. The simulations were performed using the Vensim simulator (VENSIM, 2018) in a computational structure with a 2.5 Ghz Intel Core (i5 2450) processor, 4 Gb of RAM and the simulation execution time for the three scenarios was in order millionths of a second. The model will allow interested parties to generate other simulations, and may create different scenarios since the model was built with the objective of offering better decisions to reuse the water generated by the conditioned air.

Figure 2 shows the total water consumed in the HEI until 2030, the scenario with the highest consumption is the current scenario, reaching a total consumption of approximately 8,540,000 liters of water in ten years. The scenario with the least impact on consumption is the positive scenario, saving about 300,000 liters of water per year, when compared to the current scenario, when compared to the median scenario, it will save approximately 1,300,000 liters of water. The median scenario, which will collect 50% of the water, will enable savings of approximately 1,420,000 liters of water when compared to the current scenario.

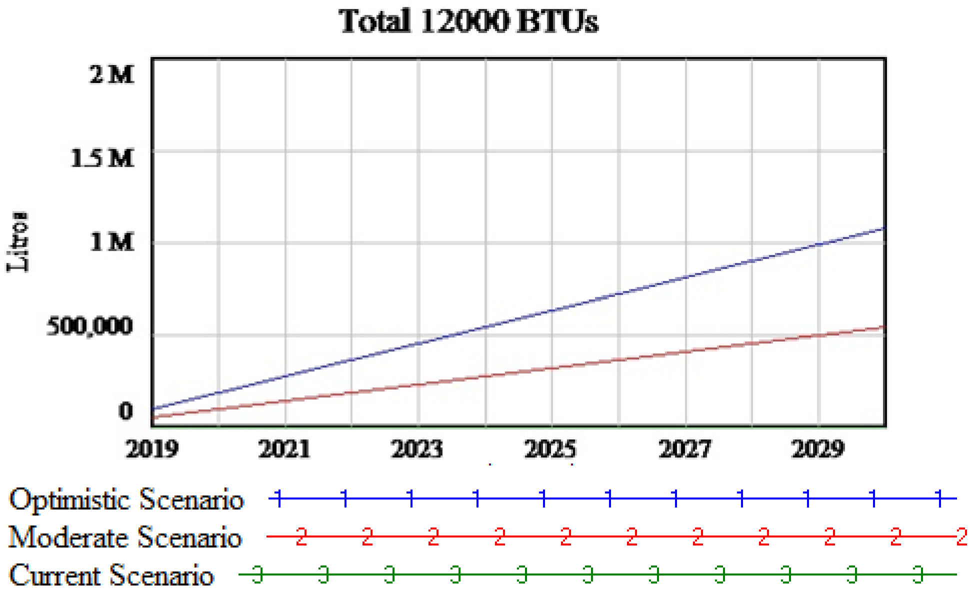
Figure 2 - Water Total 9000BTUS



Source: Authors (2020)

Figure 3 shows the total water consumed in the HEI until 2030, the scenario with the highest consumption is the current scenario, reaching a total consumption of approximately 8,540,000 liters of water in ten years. The scenario with the least impact on consumption is the positive scenario, saving about 300,000 liters of water per year, when compared to the current scenario, when compared to the median scenario, it will save approximately 1,300,000 liters of water. The median scenario, which will collect 50% of the water, will enable savings of approximately 1,420,000 liters of water when compared to the current scenario.

Figure 3 - Water Total 12000BTUS

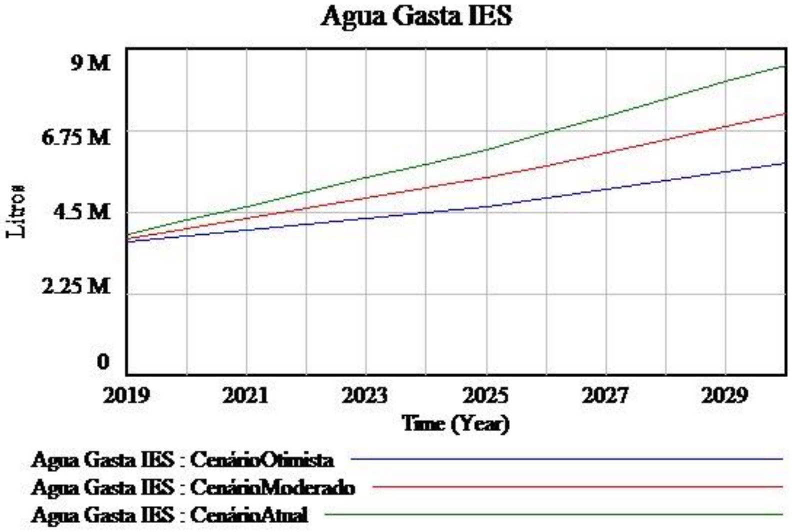


Source: Authors (2020)

Figure 4 shows the total water consumed in the HEI until 2030, the scenario with the highest consumption is the current scenario, reaching a total consumption of approximately 8,540,000 liters of water in ten years. The scenario with the least impact on consumption is the positive scenario, saving about 300,000 liters of water per year, when compared to the current scenario, when compared to the median scenario, it will save approximately 1,300,000 liters of water. The median scenario, which will collect 50% of the water, will enable savings of approximately 1,420,000 liters of water when compared to the current scenario.

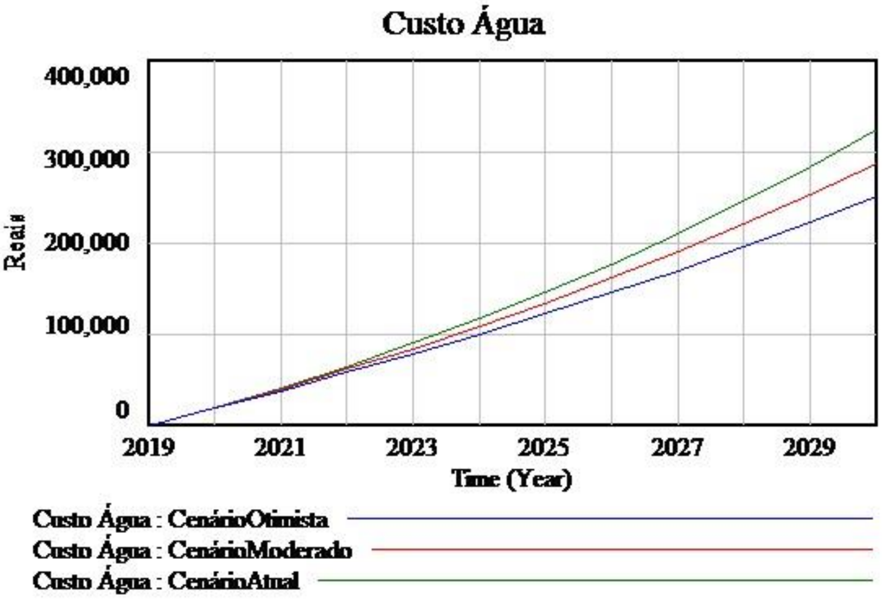
To check the expenditure generated by water consumption, the graph shown in figure 5 was generated. It is noted that until the year 2022, the strategy presented by the researchers will obtain practically the same expenditure as the current scenario. But in 2023 the optimistic scenario will already show savings of approximately R $ 10,000.00, arriving in 2030 there will be savings of up to R $ 110,000.00, enabling IES to invest this money in other areas with greater needs. The median scenario also showed savings, spending up to 2030 R $ 287,340.00, while the current scenario spent approximately R $ 324,000.00.

Figure 4 - Spent Water IES



Source: Authors (2020)

Figure 5 - Total Cost



Source: Authors (2020)

The results reinforce the importance of finding new alternatives to save public money, in a way making it possible to invest the economy in other emerging areas.

6 FINAL CONSIDERATIONS

The concern about water scarcity extends to many of the Brazilian Metropolitan Regions. Although Brazil has a large percentage of the world's water resources, many regions live with water resources of the order of two hundred cubic meters per inhabitant per year, generating critical conditions of supply and conflicts in the use of water. It is necessary to invest in objective measurement, evaluation and research programs, as well as in motivation and personal training programs.

Therefore, the main objective of this article was the development, verification, evaluation and experiment of computer simulation models with the purpose of evaluating groups of scenarios for the reuse of water generated by conditioned air.

For the development of the simulation model, the concept that Systems Dynamics models are composed of stock, flow variables, both endogenous variables, was taken into account. One of the central objectives of the Systems Dynamics methodology is to have a model that can simulate real behavior. That is, the source of problems in a system is an inherent part of the model developed.

The Systems Dynamics methodology helped to map the structures of the developed system, seeking to examine its interrelation in a broad context. Through the developed simulation, the applied dynamics intends to understand how the system in focus evolves over time and how changes in its parts affect its behavior. From this understanding, it was possible to diagnose and predict the system, in addition to making it possible to simulate more scenarios over time.

With specific regard to the results obtained, for the scenarios evaluated, the optimistic scenario presented the best results, offering savings of approximately R $ 11,000.00 reais per year. The median scenario will also offer financial savings when compared to the current scenario, reinforcing the importance of taking advantage of the water generated by the air conditioners of the Higher Education Institution that is a partner in the research.

The relevance of this is not limited only to the creation of an alternative for the more conscious use of water, but also to the fact that there is an alternative for the use of water generated by air conditioners. Water, as previously described, is a resource that needs to be increasingly rationally used, as its available useful quantity decreases every year.

One of the main limitations of this investigation refers to the fact that the model was developed to analyze a public institution, which may prevent the generalization of the findings to other private HEIs. Another limitation refers to the cost of water, since there is a discrepancy in the annual amounts paid for water by the HEI. As future work, we intend to add variables to the model, such as, for example, the cost to create the water collection devices, in addition to analyzing the environmental bias, such as the amount of water collected by the air conditioners.

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