IMPORTANCE OF HYDROELECTRIC POWER PLANTS IN THE NATIONAL ENERGY TRANSITION: A COMPLEX CASE STUDY HENRY BORDEN

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ABSTRACT

The transition to more sustainable energy sources is a subject of global discussion, with the goal of reducing dependence on fossil fuels and promoting responsible use of natural resources. In this context, ensuring water quality is also essential for the efficiency and sustainability of energy sources, particularly hydroelectric power, which predominates in electricity generation in Brazil. However, Brazil faces challenges related to the multiple uses of water, including water supply, navigation, and electricity generation. Water transfers between rivers have been a strategy to address conflicts arising from these multiple uses and enhance the utilization of hydroelectric plants. In this context, assessing the impacts of these transfers on water quality is crucial for ensuring sustainable development. This paper aims to perform numerical simulations of potential water transfers in order to increase electricity generation at the Henry Borden complex, in the State of São Paulo, Brazil, and to evaluate the impact on water quality. The results indicate the need for water treatment before the transfers.

Keywords: Energy transition, Sustainable development, Water transfers, Water quality index.

Introduction

The increasing warnings about the dangers associated with the use of fossil fuels have led to reflections and efforts towards energy transition, with international impact through global agreements[1]. The generation of electrical power has been a subject of discussion. Although Brazil's electrical matrix is relatively clean compared to the global average, with over half coming from renewable sources, the country is not immune to the transformation trend. This is because the right to a balanced environment is enshrined as fundamental, and there is a commitment as a signatory to international agreements aiming to reduce greenhouse gas emissions by 2030 and achieve climate neutrality by 2050. In the context of the energy transition, proper management of water resources to ensure supply, efficiency in energy generation, and the preservation of aquatic ecosystems is of paramount importance to promote sustainable development.

Multiple water use conflicts occur when multiple stakeholders compete for the use of a region's water resources, whether to meet the needs of water supply, agriculture, industry, power generation, recreation, environmental conservation, or other purposes. The process of transferring water between rivers and basins are also factors that contribute to the pollution of receiving bodies. Bearing in mind that most of the time, it has not been taken into account that the treatment of the water before the transfer. Ultimately, these conflicts can result in tensions and disputes over the allocation of water resources and how they are used[2].

It is worth mentioning that Brazil has faced problems with water availability in several regions, such as the Northeast and Southeast. Factors such as increased water demand and possibly climate change have affected the availability of water in certain locations[3].

However, one of the widely publicized projects is the transposition of waters from the São Francisco River, where some dams are located, such as Três Marias, Sobradinho, Itaparica, Moxotó, Paulo

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Afonso I, II and III, and Xingó, resulting in the formation of the lakes of Itaparica and Sobradinho. All this investment was made with one main objective: to generate electricity and enable irrigation in the region[4]. Currently, this project has been extended to capture water from the São Francisco River, located in the State of Pernambuco, and supply the municipalities located in the semi-arid region of Pernambuco and also the Metropolitan Region of Fortaleza[5].

In this study, the main objective is to assess water quality before and after river/basin transfers, given the importance of these transfers in enhancing the efficiency of hydroelectric power plants. We will use relevant data on the compounds and flows to calculate water quality indices of the rivers involved in the transfer process, focusing on the Henry Borden Complex as a case study. A power plant of significant importance is located in the Upper Tietê watershed in São Paulo, Brazil. With a total installed capacity of 889 MW, the plant has the Billings reservoir, which previously received water from the Tietê and Pinus rivers to enable its full operation. However, for ecological and social reasons, this transfer was suspended and is only allowed during floods in the city of São Paulo[6].

In this context, this paper contributes to the assessment of water quality in the Billings reservoir before and after the water transfer process, using a numerical model implemented in Java, which can be of great value for decision-making related to water transfer, with the aim of increasing the production of the Henry Borden Plant.

Materials and Methods

The Henry Borden Complex has unique characteristics in Brazil, due to the exceptional conditions of the Serra do Mar and its proximity to the metropolitan region of São Paulo. To achieve the results presented, some studies already developed related to the theme under study were used as a bibliographic base. Composed of two plants that take advantage of the energy generated by the fall of about 720 meters between the Billings reservoir, located on the plateau, and the foothills of the Serra do Mar. These plants, one external and the other underground, have a total installed capacity of 889 MW, which is equivalent to a flow of 157 m3/s from the Billings reservoir. However, in order to achieve this flow, the Billings dam depends on the reversal of part of the flow of the Tietê and Pinheiros rivers, since the direct contribution of the reservoir basin is insufficient[6].

The works of the reversal system were carried out in the 1930s and included the rectification of the Pinheiros River and the construction of the Pedreira and Traição elevators. Currently, the reversal system has a maximum capacity of 385 m3/s, but it is only activated in situations of risk of overflowing the Tietê and Pinheiros rivers[7]. In this system, the power of water is harnessed to drive turbines, resulting in the generation of electricity. This type of energy, which is renewable and ecologically beneficial, plays an important role in reducing greenhouse gas emissions and supplying the region with energy.

With the help of the NetBeans IDE, an algorithm was developed in the Java programming language to calculate the water quality index of the study points according to equations 1 and 2. It consists of the main steps: reading the input data, processing it, and outgoing data, as shown in Figure 1. In the pre-processing phase, a repository containing the data corresponding to the year 2017 was developed at the study site. These data cover all the parameters necessary for the calculation of the WQI of water. These parameters are obtained through measurement points located in the rivers and can be easily updated in the repository whenever new measurements are verified or published. Then, a

The package was created with several classes, which contain attributes that describe the values of each of the parameters (Coliforms, pH, BOD, phosphorus, nitrogen, dissolved oxygen, altitude and flow rate) and equations 1 and 2 to calculate the WQI, according to[8]. The first class traverses the repository to read the monthly values of each of the parameters, which in turn serve as input data for the algorithm.

$$C_0 = \frac{Q_{r1}C_{r1} + Q_{r2}C_{r2}}{Q_{r1} + Q_{r2}} \tag{1}$$

Where: C0 is concentration of the parameter in the mixture [mg/L]; Cr1 is concentration of the parameter in the main river (river 1) [mg/L]; Cr2 is the concentration of the parameter in the secondary river (river

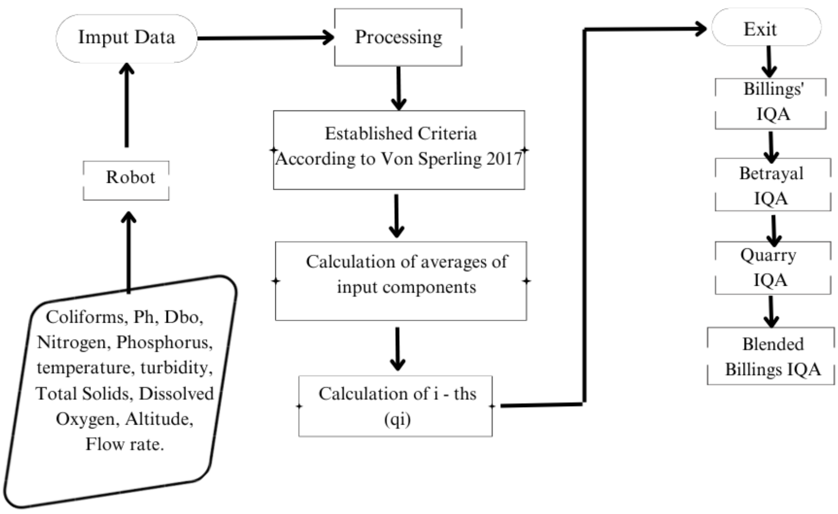

Figure 1: Algorithm developed

2) [mg/L]; Qr1: main river flow $[m^3/s]$; Qr2: secondary river flow $[m^3/s]$.

$$WQI = \sum_{i=1}^{n} q_i \omega_i \tag{2}$$

Where: is the amount of the i – the parameter as a function of its concentration or measurement; ω_i is the weight of the i – th parameter, assigned according to its importance for the overall conformation of water quality; i is the parameter number. Processing is carried out in the main class of the program, where calculations are executed via the following method.

- The mean values of the 9 parameters used in calculating the WQI are determined through Equation 1. Monthly averages are calculated based on all available measurements.
- The flow rate average is calculated per month based on the available daily measurements.
- The values of q_i are determined by using Equation 2.
- The water quality indices (WQIs) for each measuring point are calculated prior to conducting water transfers. The code utilizes the suitable equation[8].
- Finally, we calculate the monthly Water Quality Indices (WQIs) for the Billings Dam following the water transfer.

The software outputs data on the water quality indices of Billings, Betrayal, Quarry, and Billings before and after mixing. Post-processing was carried out using RStudio software. The algorithm is expected to serve as a useful tool for professionals and researchers in the energy sector for addressing energy planning issues.

Results and Discussions

First, the flows and the Water Quality Index (WQI) of the Billings Dam were analyzed before simulating the water transfers. Figure 2 shows Billings' flows and WQI throughout 2017. Based on Figure 2, it can be observed that in 2017, the period considered dry in the Southeast region, from May to October, presented flows that did not exceed the annual average. However, the month with the lowest flow was September, presenting a reduction of 51.9% in relation to the annual average. For the period

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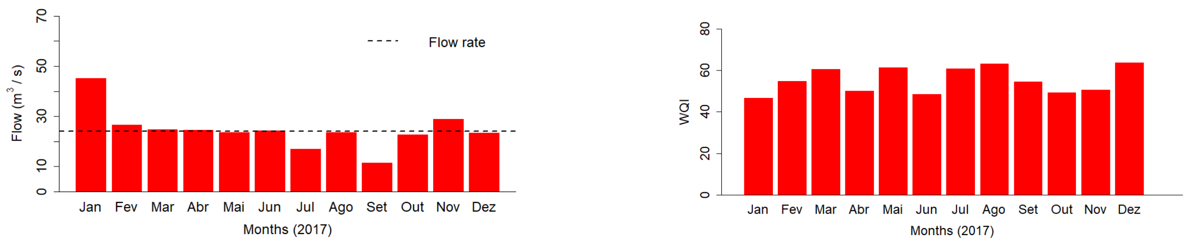
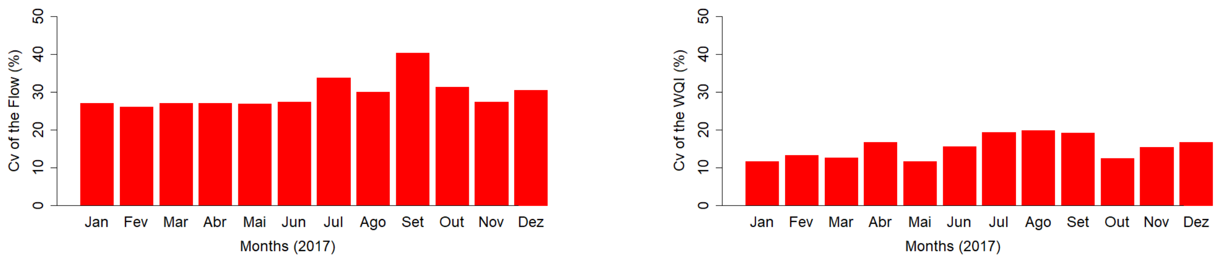


(a) (b)

Figure 2: (a) flow data; (b) WQI data prior to transfers

considered wet (November to April), the month of January recorded the maximum flow, with an increase of 88.84% in relation to the annual average.

After this study, the WQIs after the transfers for the year 2017 were analyzed, as can be seen in Figure 3. The simulations were performed for each month, adopting as hypothesis the transfer flows of Edgard de Souza and Ponte Nova. The flow combinations used for the transfers are: (1 and 1), (2 and 2), (2 and 4), (4 and 6), (6 and 6), (10 and 6), (20 and 7) and the maximum flows of Edgar de Souza and Ponte Nova of each month.



(a) (b)

Figure 3: (a) WQI as a function of the transfer flows for the dry period; (b) WQI as a function of the transfer flows for the wet period.

The values presented in Figures 3 show that, after water transfers, all mean values for the WQI can be classified as poor, while the flows present greater variability than the WQIs. In addition, it is verified that the months of July, August and September are the ones that present the greatest variation of the WQI. It is important to note that, even though it is the driest month, September also presents the greatest variation in flow.

Thus, it was observed that the transfer of water can lead the WQI to low values in both periods, in such a way that the water quality becomes bad or very bad. These results reinforce the relevance of the monthly analysis as a basis for decision-making related to water transfers for water supply and/or electricity generation in the Henry Borden complex.

Conclusion

The aim of this study was to highlight the importance of the Henry Borden Complex in the country's energy transition. From this, it is evident that the energy transition represents a propitious field for the generation of innovative ideas, being crucial the application of creativity to achieve the goals defined in the Paris Agreement. As illustrated throughout this article, there is no single solution to this challenge, since it encompasses the adoption of multiple technologies already existing, in the development phase or even those not yet conceived. Finally, it is believed that given the characteristics and conditions of power

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generation in the Henry Borden Complex, it is worth the treatment of donor rivers in order to ensure full power generation. Bearing in mind that the Complex is installed in a strategic point not only for the state of São Paulo, but for all of Brazil.

Briefly, the Henry Borden Complex plays an important role in the production of electricity, the provision of resources to the community, and flood management. However, the quality of the water stored in the reservoir emerges as a crucial factor that requires constant surveillance and actions to preserve the environment. This is essential to ensure the continuous and safe supply of drinking water in a sustainable manner for the population.

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