Development of a Probabilistic Model for Water Management on a Bauxite Mining Site

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Abstract

Water is a key resource for the mining industry all over the world. At Mineração Paragominas, water is used for dust control at mining area, bauxite washing in the beneficiation plant and product transport through the 244 km pipeline that links the mine to the refinery. There are currently four main water sources on the plant: a fresh water catchment at Parariquara river, two reservoirs to store water recovered from tailings, rainfall contribution on tailings dams and a reservoir to contain water from springs upstream the tailings dam. It is a complex system, strongly dependent on environmental influences like rainfall and evaporation during wet and dry season periods, alongside with operational conditions and impact of production level and solids content on tailings disposed at the dams. This paper describes the approach adopted in terms of water management at Mineração Paragominas, including the development of a probabilistic model, using Monte Carlo simulation, to integrate and simulate the main water inputs, outputs and storage levels. The scenarios obtained with the model were used to guide actions that improved the company's robustness in terms of water availability on short and medium terms.

Keywords: water management, Monte Carlo simulation, bauxite mining.

1. Introduction

Hydro's bauxite mine is situated approximately 70 kilometers from the municipality of Paragominas in northeastern Pará, on Miltonia Plateau 3. Mineração Paragominas began operating in March 2007 and today it mines about 16.4 million metric tons of ore per year, producing 11.4 million metric tons of bauxite annually, in a process aligned with the best environmental and operational safety practices.

At Mineração Paragominas (MPSA), operations are divided into three main stages:

- Bauxite mining;
- Mineral processing;
- Slurry transportation through pipeline.

The bauxite slurry is pumped from Mineração Paragominas to Alunorte refinery, where it will be dewatered and then transformed into Alumina through the bayer process. The productive chain is represented in Figure 1.

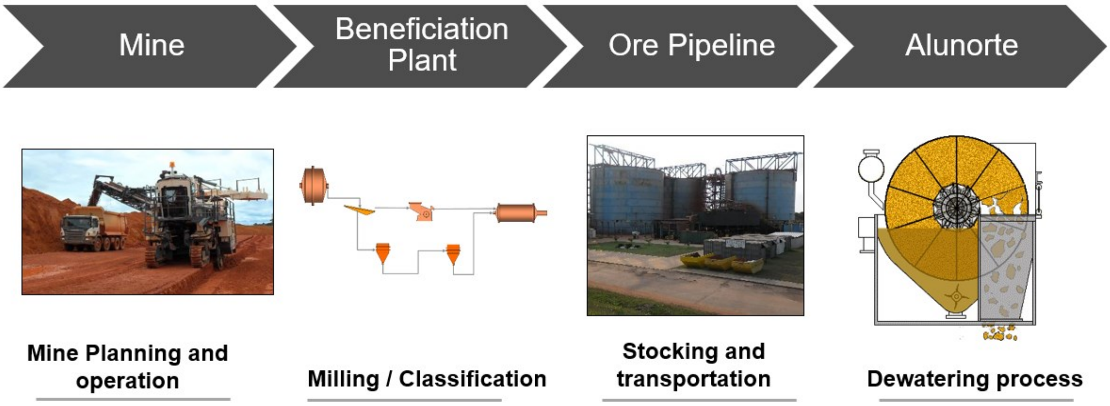

Figure 1. Productive chain.

During this whole process, water is an essential resource to allow production. At the mine area, it is used to control dust. At the beneficiation plant, it is used mostly in comminution and classification process. On the pipeline operations, it is used to transport the bauxite.

The water that goes on the product to Alunorte does not return to Mineração Paragominas, requiring then constant input of fresh water to compensate the losses and allow continuous operations. Besides that, there is also water leaving the system on tailings, as represented in Figure 2.

Figure 2. Water diagram.

As plant production increases, it requires a higher amount of water to run operations. However, the supply of this resource is limited and if not used wisely, it may not be enough. MPSA possesses a grant limiting the amount of water allowed to catch per day from Parariquara river, and to be able to capture this the first condition is to respect the remaining flow (ecological flow), which is the minimum flow that must pass after the collection point.

At full production, the plants can produce about 11,5Mt of bauxite a year and to do that, nowadays, it requires more water than just the quantity established on the grant. Therefore, demanding extra water sources to complement the amount catched from Parariquara. This extra water may come from three reservoirs, called B5, B6 and BCs (Figure 3).

Figure 3. BCs and B5 reservoirs, respectively.

Water availability in both Parariquara and reservoirs is strongly dependent on rainfall and evaporation rates, as can be seen in Figure 4, which shows that the volume of B5 reservoir is directly proportional to the rainfall rates.

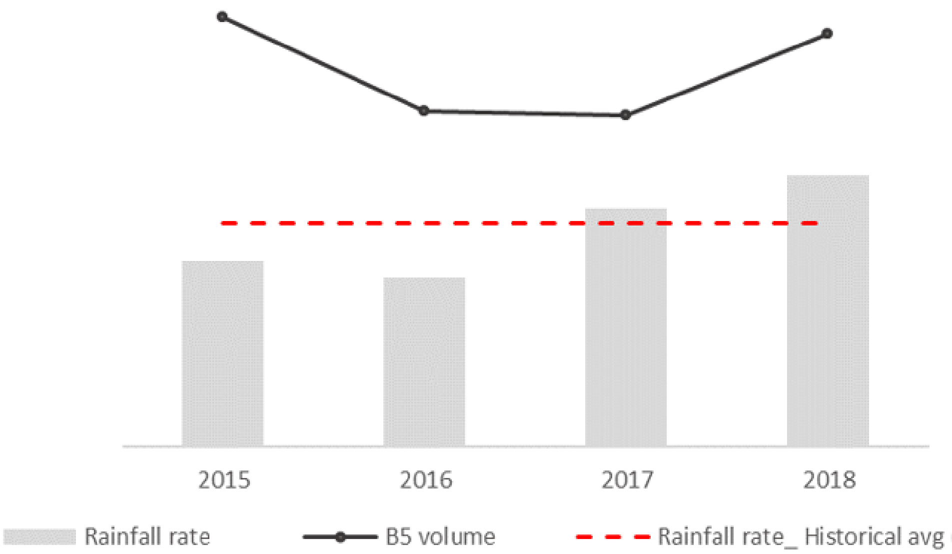

Figure 4. B5 volume x rainfall rates.

As humans have no control over nature, it becomes impossible to predict for sure if it will rain or not and the amount of rain on the following years. Therefore, not being possible to know exactly if there will be enough water in the reservoirs on the future. However, based on data from the past it is possible to have an estimation of it.

Due to the high need of having enough water available to run operations, it became necessary to find a manner to evaluate the risks associated with a possible lack of water, and based on this evaluation, define a specific water management strategy to minimize the risks.

The manner found was to develop a model that would be able to generate output predictions of different water scenarios based on simulations using data from the past.

2. Methodology

The first step to build the water management model was to develop a deterministic model and proceed with reservoirs modelling. This first model was developed to calculate the amount of water needed for a certain production level. It takes into account many different parameters that influence the amount of water needed, such as mass recovery, solid content (in both bauxite slurry and tailings), ore moisture and pipeline flowrate. Figure 5 shows a flowchart that summarizes the outputs obtained from the deterministic model.

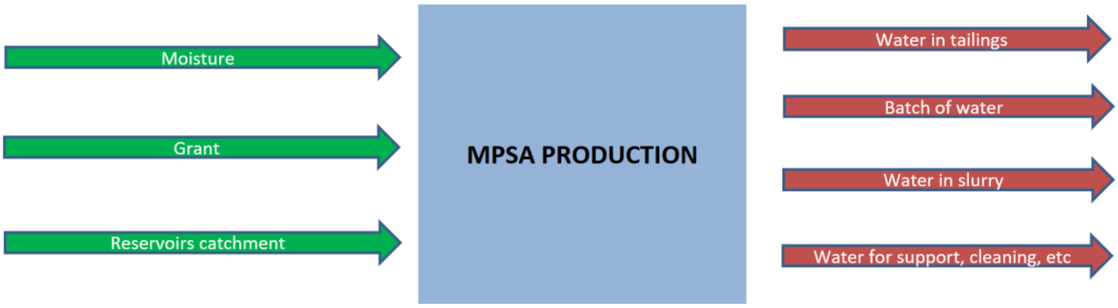

Figure 5. Deterministic model.

Once the amount of water required to run operations is defined, it is necessary to calculate if there is enough water available in the reservoirs. It can be done through a model which considers several parameters, such as historical series of rainfall, water spring, evaporation and infiltration to calculate the useful volume in the reservoir. Figure 6 shows the water gains sources and its losses.

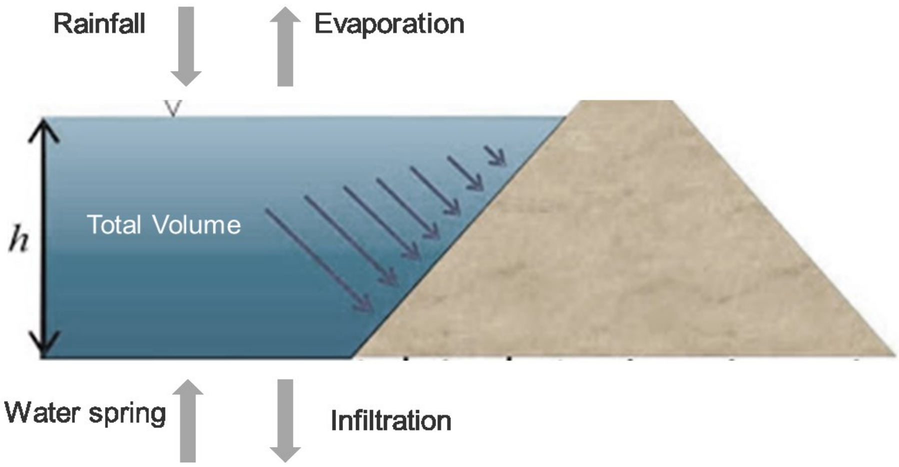

Figure 6. Reservoirs modeling.

Useful volume = Total volume + $(Q_{rainfall} + Q_{water\ spring}) - (Q_{evaporation} + Q_{infiltration})$

Where:
Q Flowrate, m^3/d

It is also important to understand the hydrology of the region. For example, the rainfall rates at MPSA possesses a strong correlation to the season, where there is a huge volume of rainfall during the rainy season and very low during the dry season. Figure 7 shows the minimum and average rainfall rates (historical data) as well as the ones occurred in 2018. The red area represents rates lower than the critical year (which is when presented the lowest level). The yellow area represents a rainfall lower than the historical average and the green one represents above.

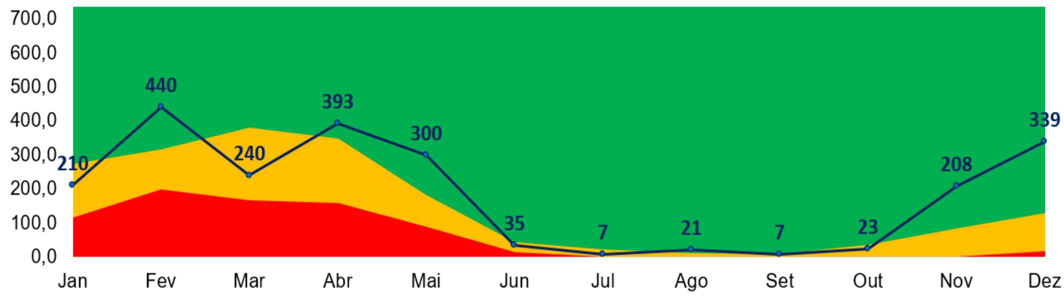

Figure 7. Rainfall rates 2018.

The deterministic model was a good starting point, but it was limited because it uses averages. Especially when simulating the behavior of nature, averages are not the best option as, for example, could rain only half of the average in the next year and then, the model would fail to simulate the risk of water shortage. Because of that, it was necessary to develop a probabilistic model.

To develop the water management model, it was necessary to purchase a software that could run simulations. The software @Risk executes risk analysis through Monte Carlo simulation to show multiple possible results and inform the probability of their occurrence. The program performs calculations and allow track back multiple possible future scenarios; Then, it informs the probabilities and associated risks for each scenario. It allows to evaluate the risks, and based on that, make the best decisions possible in uncertain situations.

The probabilistic model considers the probability distribution of each variable that has impact on water balance, such as mass recovery, ore moisture, solids content in tailings, etc. So, the model understands all the possibilities and their probability of occurrence. Figure 8 shows the probability distribution of mass recovery, for example, where the blue bars are the histogram of the data and the red curve is the best distribution curve.

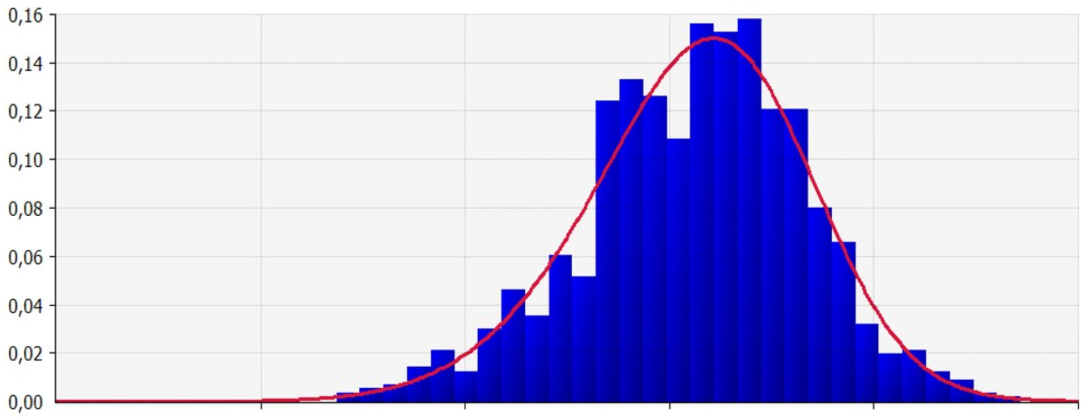

Figure 8. Probability distribution for mass recovery.

For rainfall, water spring and evaporation there is a seasonality that the model needs to understand. Because of that, a time series modeling was performed. Figure 9 shows the series modeling for rainfall. This series contain the real rainfall rate since 2006 (blue curves), where the valleys represent the dry season (low rates) and the peaks represent the rainy season (high rates), The grey curve was the predicted rainfall simulation for 2019, with the probability of occurrence.

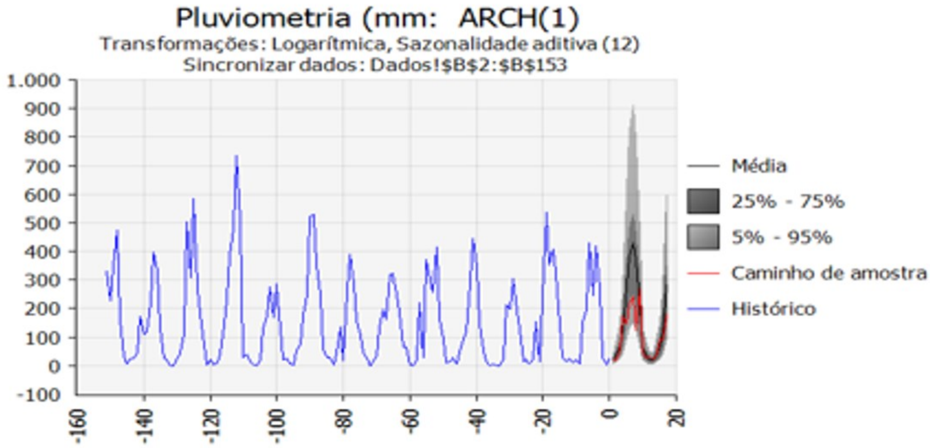

Figure 9. Time series modeling for rainfall.

3. Results and Discussion

Once the probabilistic model was created, different scenarios could be generated and simulated. Such as the ones indicated below. Those scenarios, in combination, provided useful information to the organization regarding the best water strategies to be taken to minimize the risks of water shortage.

3.1 Probability of Reducing River Catchment due to Ecological Flow

MPSA possesses a grant that limits the amount of water that can be catched from Parariquara river per day, however, to be able to catch the full quantity established on the grant, there is an ecological flow that must be respected. After running model simulation, as can be seen in Figure 10, it was found that if kept a maximum catchment rate allowed per day, during 8% of the time the ecological flow would not be respected. For this reason, during 8% of the time water collection needs to be reduced to attend the remaining flow requirements.

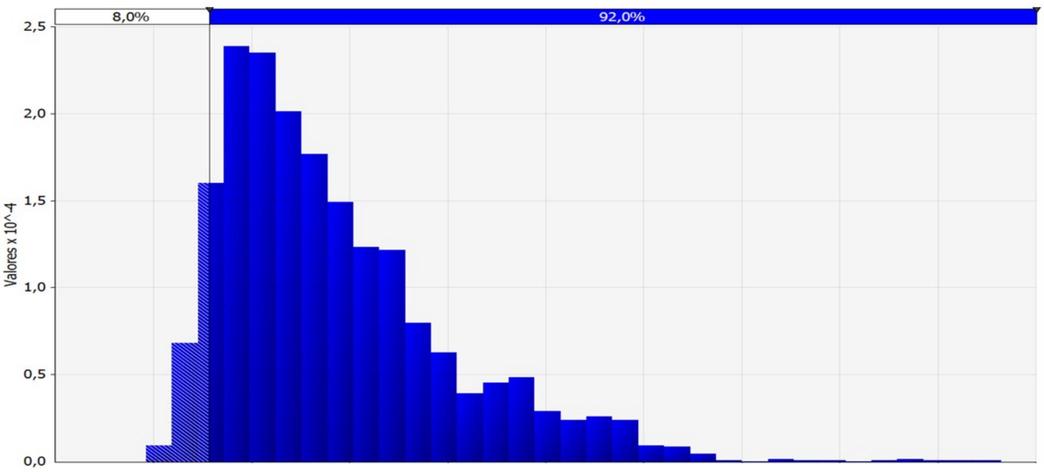

Figure 10. Ecological flow probability.

3.2 Probability of Reservoirs Catchment (Monte Carlo Simulation)

This reduction of water from the river is compensated with water from the reservoirs, which leads to this simulation, that aims to identify the amount of water required from the reservoirs to enable the plant run at a specific production level. An example of output from the model is indicated in Figure 11.

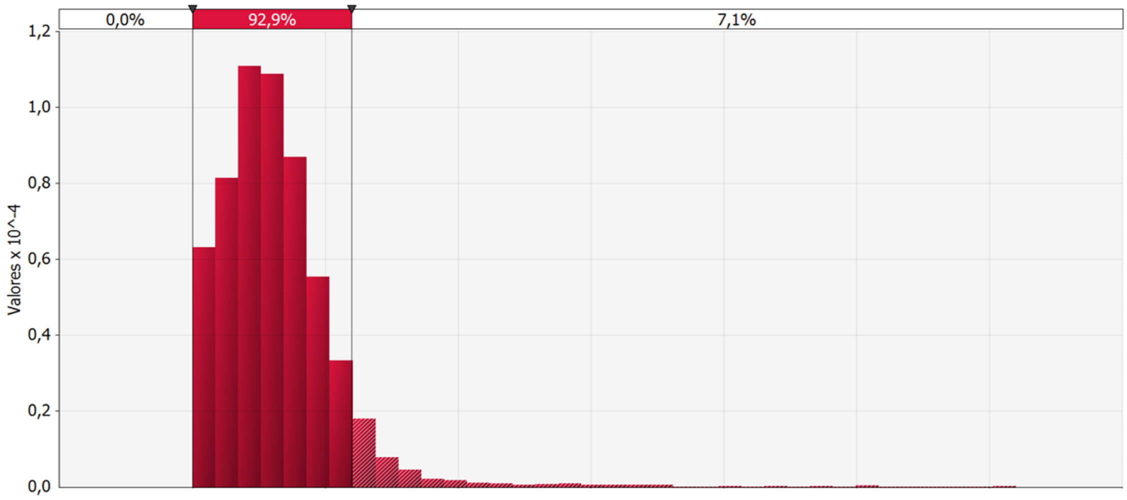

Figure 11. Required amount of water from reservoirs.

3.3 Probability of Water Shortage

Once it is known the amount of water available at the river for catchment and the amount of water needed from the reservoirs, next step is to find out if there will be enough water in the reservoirs. Through this simulation it is possible to identify this and the risks of water shortage for specific production levels, as displayed in Figure 12.

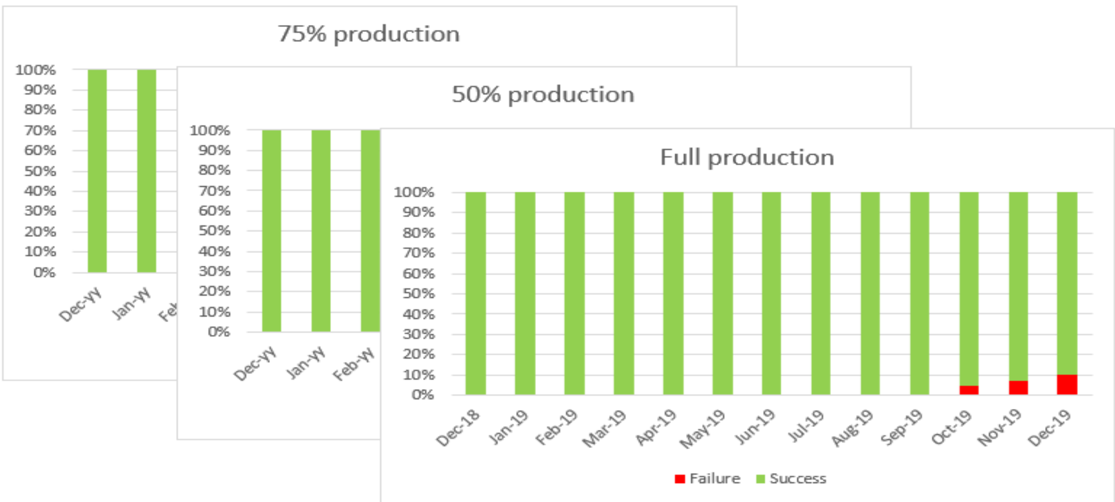

Figure 12. Probability of water shortage.

4. Conclusion

Water is a key resource to Mineração Paragominas business. The bauxite exploited from the mine site needs water to be processed and transported to the refinery. As production level tends to increase at the plant, a higher water consumption is expected to attend all the process needs. However, water is a finite resource and there is a limit of Parariquara river catchment that needs to be respected by MPSA. Also, water availability is highly dependent on rainfall and evaporation rates, being these variables directly associated with the risks of water shortage.

Although it is impossible to predict for sure the nature behavior, it is possible to obtain good indications on how weather will behave based on historical data. Taking that into account, a simulation model has been developed internally at MPSA. This model is capable of generating different probability scenarios when assessing the risks of water shortage at the plant, which provided valuable information for the water balance work team to decide the best strategy to minimize the identified risks.