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INFLUENCE OF GROUNDWATER DEPLETION ON A GEOTECHNICAL STRUCTURE

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Abstract: The increase in the water table and the increase in pressure inside the dam massif conditioned the reduction of the Safety Factor and, consequently, indicates a condition of instability. The objective of this article is to evaluate the behavior of the water table in the massif of the tailing dam under the influence of closure. The evaluation consisted of the technical analysis of the instrumentation history for the interpretation of the graphs, performing the transparency between these data and subsidizing the choice of boundary conditions for the flow analyzes carried out by the Slide2D software. The results visualized in the graphs and in the percolation analysis indicate that the water table depleted the traffic after the decommissioning stage of the structure, before the stabilization stages and hydrological and hydrogeological control. The study points out that the decrease in the water table is associated with decommissioning and, above all, tailings management during dam operation. Although a hydrological and hydrogeological control stage was carried out 4 years after decommissioning, this had the objective associated with closing the structure, once the internal conditions were controlled.
Keywords: Phreatic; Dam; decharacterization; Depletion

INTRODUCTION

ANM Resolution No. 95, of February 7, 2022, defines an uncharacterized mining dam as a structure that does not permanently receive input of tailings and/or sediments from its core activity, which no longer possesses characteristics or performs its function. dam, according to the technical project, comprising, but not limited to, the following completed stages: i. decommissioning; ii hydrological and hydrogeological control and, iii stabilization.

In view of this, this article aims to present the influence of the behavior of the water table in the tailings dam massif during and after the decharacterization stages.

The structure's initial dike was built in 1992, with the crest at an elevation of 1056 m, with the aim of receiving the fine tailings slurry and heightening upstream with the compacted tailings itself. The last elevation took place in 2012, with the crest at an elevation of 1115 m.

The foundation of the structure is represented by a horizon of colluvial soil. Underlying this horizon is the schist saprolite, associated with the rocks of the Nova Lima Group.

The operation of the structure consisted of launching tailings from the left abutment, therefore, the beach was formed in this region towards the right abutment. Thus, the lake was kept away from the crest of the dam. The operation ended in 2016, when the dam was decommissioned, that is, it no longer received tailings input.

Auscultation of the structure, during active and passive monitoring, comprised 21 water level indicators, 10 piezometers, 1 flow meter, 11 surface landmarks, prisms and 1 rain gauge.

Table 1 summarizes the main technical characteristics of the dam:

General information	
Construction – Stages	- Departure Dike: massive on El. 1,056.00 m - Increases by amount
Construction date	1992
Height	80 m
Extension of the crown	1.351 m
Reservoir area	360.000 m²
Volume	12.535.000 m³
Section Type	- Starting dike: compacted soil - Raising over tailings: compacted/sterile soil
Internal drainage	-- Raised dam: bottom drain

Table 1 – Structure characteristics

Source: Authors (2023)

The execution of the Dam's decharacterization project consisted, in short, of the following construction stages: (a) decommissioning, (b) reinforcement downstream of the structure through the expansion of a Waste Pile and (c) regularization and waterproofing of the reservoir with material clayey (impermeable).

METHODOLOGY

The analysis of groundwater depletion in the dam, increased by the upstream method, will focus on the post-decommissioning and post-decharacterization stages through a numerical model and instrumentation analysis.

The permeability parameters, presented in Table 2, of the dam materials come from tests and calibration with instrument readings. KS being the maximum permeability of the material, when 100% saturated, K1 the horizontal permeability and K2 the vertical permeability.

Material	Color	KS (m/s)	K2/K1
Colluvial soil		5e-07	1
Shale Saprolite		1e-08	1
Tailings/Reservoir		9e-06	1
Reject Raising		1e-05	1
Friable itabirite		1e-08	1
Quartz Coin		1e-08	1
Phyllite Saprolite		1e-08	1
Sterile		0.01	1

Table 2 – Permeability Parameters

Source: Authors (2023)

Percolation analyzes were conducted using the Steady State FEA Finite Element Method, using Slide2 Software, developed by the Canadian company RocScience. The program is used to model water flow and the distribution of pore pressures in porous media through numerical analysis. The model section will be the most critical of the bus, represented by Figure 1, without water table.

The boundary conditions used for the numerical model were the piezometric level (PZ08) in the most critical section and the unit flow rate of the bottom drain (VW01). We also chose to use the boundary condition, in the extreme left tailings in relation to PZ08, Zero Pressure in both scenarios at elevation 1090m.

Table 3 summarizes the scenarios and boundary conditions used.

The coefficient of variation is greater in the internal flow, which indicates greater data variability in relation to the average. In this sense, using the average in both boundary conditions will represent a more appropriate scenario.

The influence of decommissioning and decharacterization on the depletion of phreatic water in the massif is also observed in analyzes and graphic interpretations of instruments, such as: water level indicators, piezometer and bottom drain meter. Figure 2 shows the location of the instrumentation analyzed and the main components of the structure:

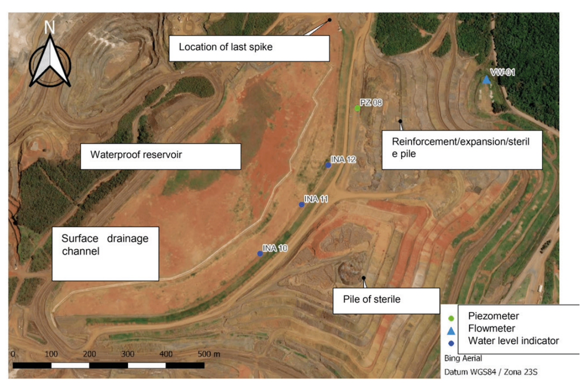

Figure 2 – Instrumentation map

Source: Authors (2023)

To complement the analyses, a correlation matrix will be presented that indicates the similarity of behavior between the instruments in the case study discussed in this article. The method used will be Pearson's correlation, a

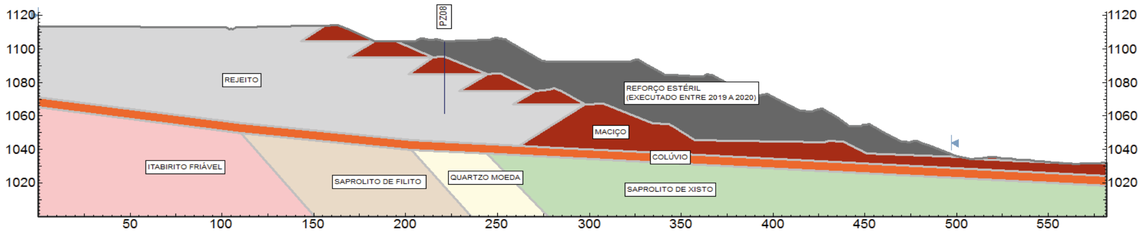

Figure 1 - Critical section of the Dam

Source: Authors (2023)

Scenarios	NA quota (m)			Flow (m³/h)		
	Average	Standard deviation	Coefficient of variation (%)	Average	Standard deviation	Coefficient of variation (%)
Post decommissioning (2016 to 2017)	1.063,32	0,25	0,02	16,42	3,85	23,43
Post decharacterization (2021 to 2022)	1061,00	-	-	1,48	0,6	90,99

Table 3 – Adopted boundary conditions (water level)

Source: Authors (2023)

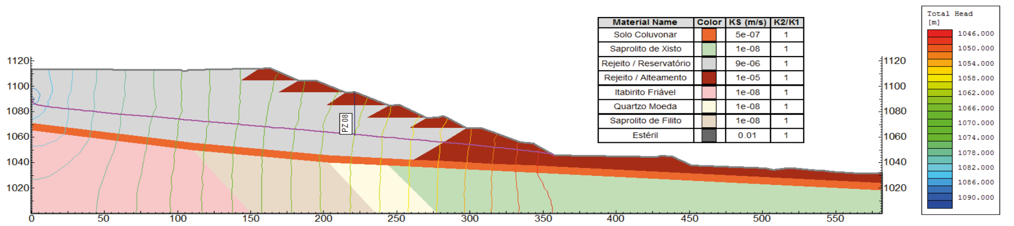

Figure 3 – Flow analysis (post decommissioning scenario)

Source: Authors (2023)

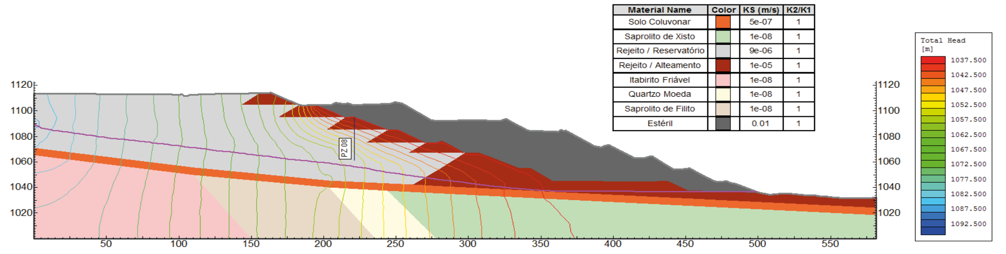

Figure 4 - Flow analysis (uncharacterized scenario)

Source: Authors (2023)

statistical measure that evaluates the linear relationship between two quantitative variables, specifically the instrument elevation, flow rate and rainfall.

The correlation value varies from -1 to 1, and the closer to the extremes, the stronger the correlation. Positive correlation values indicate that the instrument series vary in the same direction. On the other hand, negative correlation values indicate that the series vary in opposite ways.

Correlation measures can be classified as:

- Strong Correlation - correlation values between -0.7 and -1 and between 0.7 and 1
- Moderate Correlation - correlation values between -0.4 and -0.7 and between 0.4 and 0.7;
- Weak Correlation - correlation values between -0.4 and 0.4.

DATA ANALYSIS

FLOW ANALYSIS

The flow networks obtained are presented in Figures 3 and 4 for the post-decommissioning and post-decharacterization scenarios, respectively:

The flow networks obtained with the boundary conditions used make it possible to visualize the reduction of the water table in the main section of the structure. In the analysis of the post-characterized scenario, the equipotential lines indicate a reduction in the potential load from PZ08 onwards. Therefore, the horizontality of the water table is observed, which indicates that the hydraulic gradient is close to 0 and, consequently, minimizes the occurrence of piping in the massif.

INSTRUMENTATION

FLOWMETER

The flow meter will be analyzed using the average monthly readings associated with the sum of monthly rainfall. That said, Figure 5 presents the temporal analysis graph of both quantities, covering the period from 2012 to 2022.

From the graph, one can observe the increase in the bottom drain flow, in 2012 to 2013, shortly after the last raising of the dam, reaching flow peaks in the order of 60 m^3/h. Then, a decline was noted until the end of 2015 with a reduction rate of approximately 82%.

At the beginning of 2016, the high rainfall during the period contributed to the increase in the average, reaching values in the range of 25 to 30 m^3/h. From this period until the end of 2019, the flow reduction rate was 95%. The post-decommissioning period is characterized by a sharp reduction in the bottom drain flow, with little or no influence from rainfall and with values below 1 m^3/h,

In the post-decharacterization period, the graph shows flow behavior without major variations, as already observed in previous periods. During this period, the average flow is 1.48 m^3/h.

Figures 6 and 7 for the years 2018 and 2022, respectively, indicate the decrease in the flow meter flow:

Figure 6 - Flow Meter

Source: Authors (2018)

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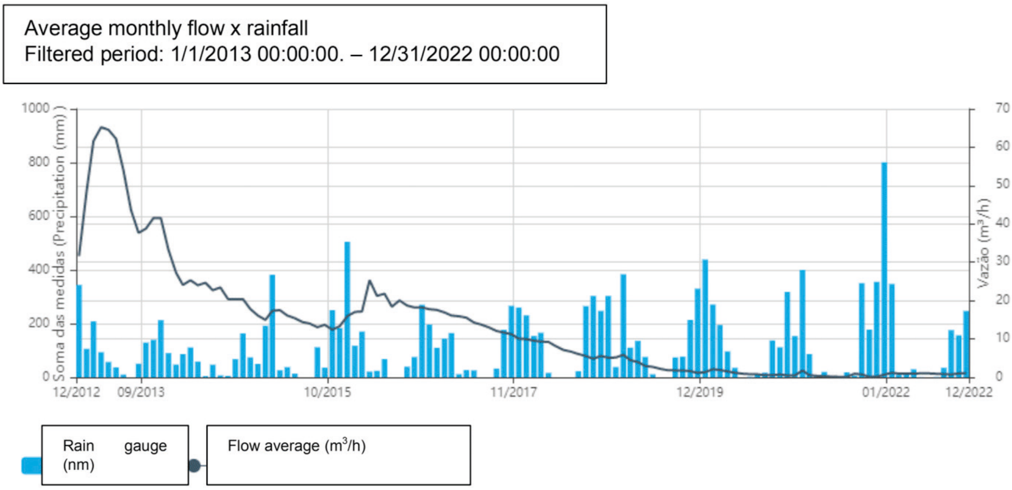

Figure 5 – Graph of the sum of monthly rainfall and average bottom drain flow

Source: Authors (2023)

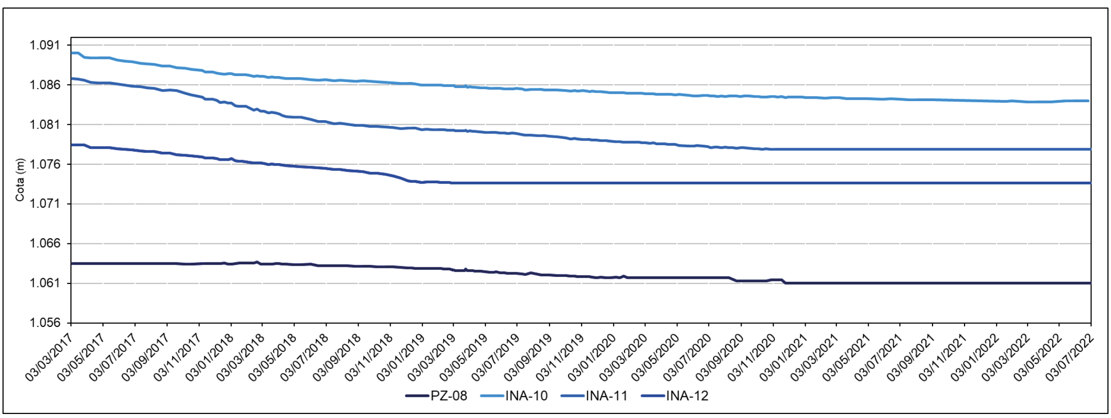

Figure 8 – Time analysis graph

Source: Authors (2023)

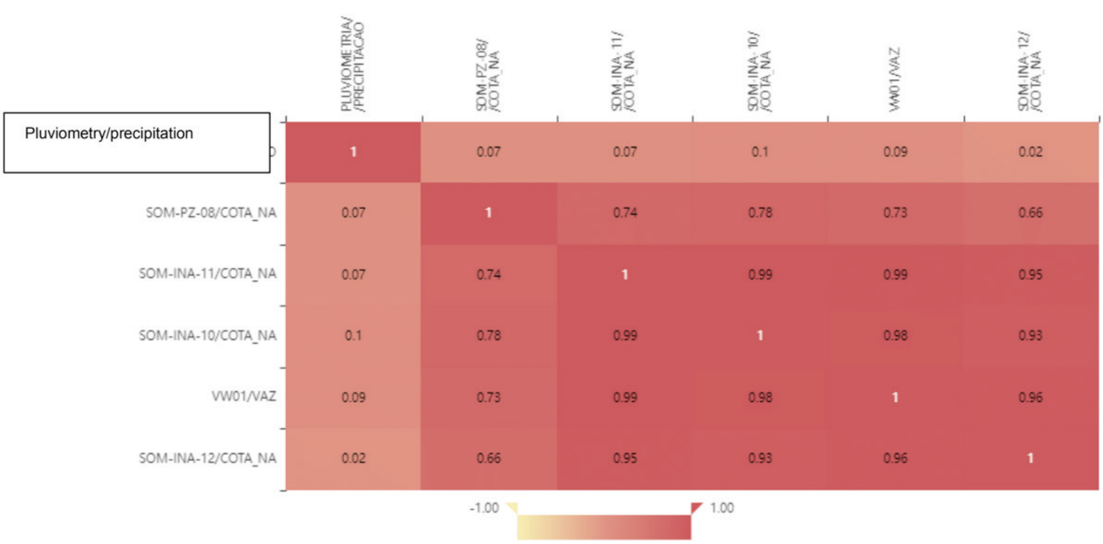

Figure 9 - Correlation Matrix

Source: Authors (2023) h

Figure 7 - Flow Meter

Source: Authors (2022)

WATER LEVEL INDICATORS AND PIEZOMETER

The same panorama observed in the behavior of the bottom drain flow meter is noted in the water level and piezometer indicators. Therefore, Figure 8 presents graphs of instrument readings from different sections of the structure and referring to the period after decommissioning until decharacterization.

In line with the bottom drain flow, the water table of the instrumentation installed in the dam mass decreased after decommissioning. The last instrument readings were considered "dry", that is, they did not show a water column.

Given the waste disposal system before decommissioning, it is possible to observe that INA 12 depleted first due to its proximity to the spiking point, then INA 11 and, subsequently, INA 10, this being located in the region closest to the lake in in relation to the other instruments analyzed.

CORRELATION MATRIX

Additionally, Figure 9 presents the correlation matrix of the instruments analyzed in the period from 2017 to 2022.

In this context, it is observed that for the period analyzed, a moderate to strong correlation is obtained between the instruments, that is, there are similarities between the phreatic line and the bottom drain flow in the decreasing behavior.

When analyzing rainfall with the other instruments in the correlation matrix, it is stated that precipitation does not immediately influence the reading of the instruments. The correlation obtained is classified as weak.

CONCLUSIONS

It is known that the disposal of tailings in the reservoir influences the behavior of the water table. In this context, the hydraulic segregation of waste in the structure contributed to the results observed in the bottom drain flow and water level indicators.

Although the reservoir waterproofing stage and the implementation of the surface drainage system were completed in 2020, this stage was linked to the effective closure of the structure, since the internal drainage conditions became controlled after decommissioning.

The water table of the uncharacterized structure, according to the graphs and numerical modeling, was depleted and a horizontal behavior was maintained, even in periods of high rainfall. Therefore, the decharacterization steps were effective in maintaining stable internal conditions and, consequently, the stability of the geotechnical structure.

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