Hydrogeochemistry Tailing Model to Evaluate Future Water Quality – Mina Vazante MG, Brazil

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ABSTRACT

Aroeira dam received for the last 10 years, zinc silicate tailing material (willemite $Zn_2(SiO_4)$ from the mill plant (USICON) of Vazante Mine. Votorantim Metals is nowadays developing a Feasibility Project of Zinc-Ambrosia oxidized sulphide zinc deposit, located in the nearby municipality of Paracatu / MG. This new ore deposit is subdivided into two parts (North and South Cava), and the North Cava has 800,000 tons of oxidized sulphide zinc ore. The financial feasibility of the ore exploitation of this new deposit requires the disposal of the new tailings into Aroeira dam. Work recently carried out by Votorantim Metals technicians using acetic acid leaching test in several samples of tailings had values for lead and cadmium relatively high. However, test results from the same samples using water leaching test (using distilled water) had values of the same parameters (Pb and Cd) below the detection limit of the analytical methods for most of the samples. Considering the above issues presented here in terms of the solid waste metal leaching, Ambrosia tailing characteristics should be considered in the final tailing disposal. In addition, the actual tailings are low in sulfide and have large neutralizing capacities, so decreasing in pH conditions are not expected. The work presented here aims to demonstrate through a hydrogeochemical model, using geochemical waste material characterization data and the software PHREEQC the environmental impact of disposal of Ambrosia mining waste into Aroeira tailings dam. The study developed here required the water sampling and tailing geochemical characterization according to MABA, NAG, water leaching test, and SPLP and the use of these results together with the dam physical characterization for the development of a future water quality model for this reservoir. Results obtained from this work allow someone to state that the disposal of Ambrosia tailings will not impact the local water resources.

Keywords: Water quality prediction, Hydrogeochemical modeling.

INTRODUCTION

Aroeira dam received for the last 10 years, zinc silicate tailing material (willemite $Zn_2(SiO_4)$ from the mill plant (USICON) of Vazante Mine. Votorantim Metals is nowadays developing a Feasibility Project of Zinc-Ambrosia oxidized sulphide zinc ore deposit, located in the nearby municipality of Paracatu / MG. This new ore deposit is subdivided into two parts (North and South Cava), and the North Cava has 800,000 tons of oxidized sulphide zinc ore. The disposal of the new tailings into Aroeira dam is fundamentally important for the financial viability of this new project. Considering the above issue presented here in terms of the solid waste management, Ambrosia tailing characteristics should be considered in the final tailing disposal. So, Aroeira tailing dam will receive new solid waste coming from Ambrosia ore deposit and also coming from other zinc mine (Extremo Norte mine). The first one is an oxidized sulphide lead and zinc ore deposit and the last one is a zinc silicate ore deposit hosted in a geological carbonate formation. The aim of this work is to demonstrate, using a PHREEQC model, that the current tailing dam can receive this new tailing material (Ambrosia deposit and Extremo Norte mine) without significant changes in the water quality of the current conditions of this reservoir.

METHODOLOGY

The water sampling of the tailing pond was carried out on July/2014 by the technicians of HidroGeo & Amplo consulting companies with the help and support of an employee from Votorantim Metals who was the boat operator for the water sampling collection. The water sampling was based on the Brazilian technical standards ABNT NBR 9897 - Planning sampling of liquid effluents and receiving bodies and ABNT NBR 9898 - Conservation and sampling techniques of liquid effluents and receiving water. This technical norm presents the fundamental aspects that should be followed during any water sampling campaign. All the technical aspects related to water sampling were strictly executed by field technicians.

The methods of analysis of water samples were those recommended by the Standard Methods for the Examination of Water and Wastewater, in its 21st edition of 2005. Some methodologies of the Environmental Protection Agency (EPA) were also adopted regarding the collection and analysis of industrial effluents and receiving waters.

Water and tailing sampling

Eight water samples were collected at four points inside the Aroeira tailing dam at two depths as shown in Table 1 below. To collect these samples field technicians used the Van Dorn bottle. Table 1 presents the identification and characteristics of the sampling points, and the depth of the collection. Tailing samples of the future waste material that will be discharged into the Aroeira reservoir were obtained from metallurgical plant, provided by Votorantim Metals for geochemical characterization.

Tailing samples from the Aroeira reservoir were collected at the same time that water samples were collected (Table 1).

Table 1 List of water and tailing sampling points at Aroeira reservoir

Point	ID	Date	Hour	Location: coordinate UTM SAD 69 Zone 23		Sample Depth (m)
1	ARO 01	07/02/2014	12:31	307906	8012222,	0.5
	ARO 02		13:30	307906	8012222	2.0
2	ARO 03	07/02/2014	14:27	307597	8012347	0.5
	ARO 04		15:00	307597	8012347	2.5
3	ARO 05	07/02/2014	15:27	307689	8012245	0.5
	ARO 06		15:50	307689	8012245	6.5
4	ARO 07	07/02/2014	16:30	307746	8012169	0.5
	ARO 08		16:50	307746	8012169	8.5

The parameters temperature, pH, dissolved oxygen (DO), electrical conductivity (EC) and redox potential (Eh) were measured in situ with a multiparameter equipment Hanna HI9828. The equipment was calibrated daily as part of the protocol (QA / QC) for data collection in the field.

The samples were filtered and preserved in the field with membrane of 0.45 μm to determine the dissolved metals (Figure 1).

Figure 1 Photo of the water sampling and filtering procedure in the Aroeira tailing dam.

Tailing Geochemical characterization (Mill plant, Vazante tailing, Extremo Norte tailing, Ambrosia tailing)

Geochemical characterization for acid generation (static tests) and metal leaching potential were performed in all tailing samples. For acid generation it was used modified acid base account (MABA) and net acid generation (NAG) and for metal leaching it was used synthetic precipitation leaching procedure (SPLP) and a Brazilian version of TCLP test that uses diluted strong acids and acetic acid at pH 5 (ABNT NBR 10,005) and another Brazilian test that uses water leaching procedure for characterization of solid waste (ABNT NBR 10,006). All these metal leaching tests were used to better understand the potential metal leaching capacity of sample at normal and extreme condition of water pH. Results and comments are presented in the next section.

Underneath there is a schematic profile representing the sampling points along the main axis of the tailing dam (Figure 2).

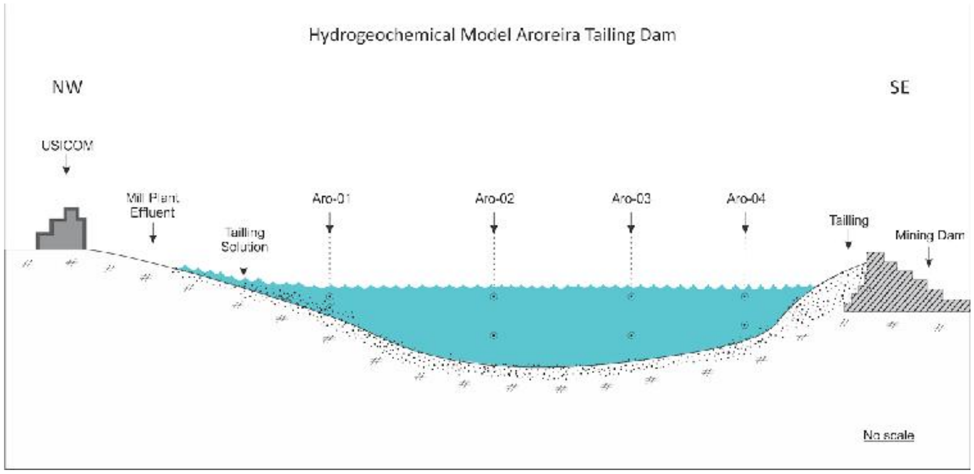

Figure 2 Schematic representation of the sampling points of water and tailings from Aroeira dam.

Conceptual Site Model (CSM)

To be able to develop a hydrogeochemical model using PHREEQC it is necessary to develop a conceptual site model (CSM) based on the tailing's water balance and solutions chemical composition. Five solutions were considered in this model and they are the following: Solution 1- Underground mine effluent; Solution 2- Mill plant effluent; Solution 3- Rainfall precipitation; Solution 4- Tailing water; and Solution 5- Tailing spillway. These solutions are represented in the following CSM figure (Figure 3). Groundwater contribution was not relevant for this case; therefore, it was not considered in the CSM presented here.

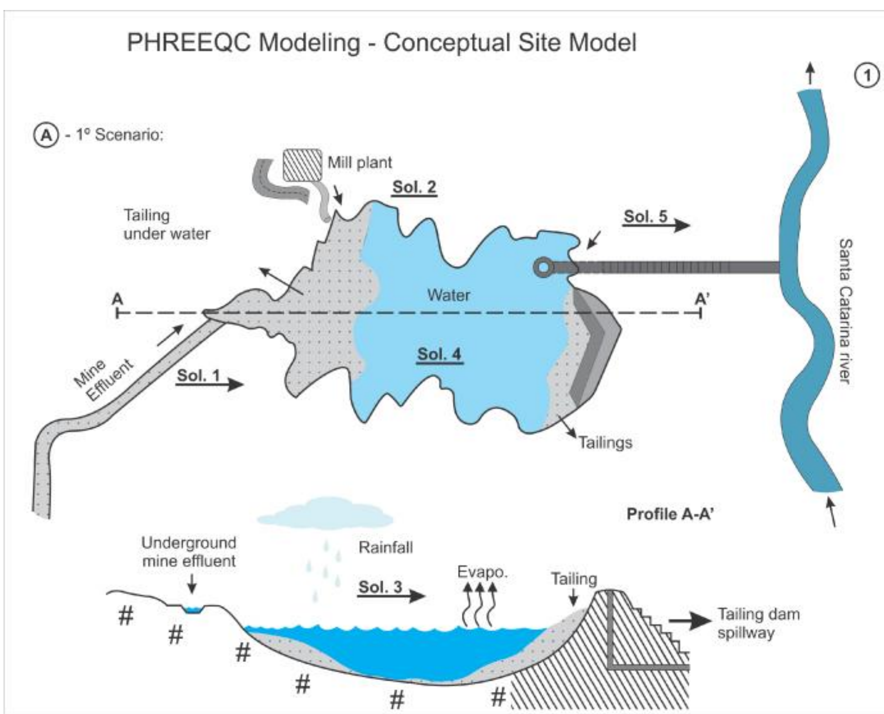

Figure 3 Conceptual site model (CSM) representing a map and a profile of the site, and no scale.

PHREEQC input data

The PHREEQC used in this paper took MINTEQ database to run the model and the input data is basically the water quality of each solution that compound the system to be modelled and the percent volume of each solution, then three scenarios were simulated. The first one was the current tailing scenario where the underground mine effluent mix with the mill plant effluent to make the tailing water composition. The other two scenarios are derivatives of the first one, where just the second solution (solution 2), coming from the mill plant effluent would change considering the new type of ore material that will be processed there.

Hydrogeochemistry model calibration

To be able to calibrate the model the following approach was used. Based on the CSM tailing water chemical composition (solution 4) is derived from the mix of solution 1 (underground mine effluent) and solution 2 (mill plant effluent). Therefore, in this work, solution 4 was used to calibrate the mix of solution 1 and 2. Once, the results obtained from the model come out very similar to the results obtained from solution 4 the model was considered calibrated and it was run for the other two scenarios where solution 2 would change in function of the new ore material or mix of ore that would be processed in the mill plant. So, the only solution that will change from scenario 1 to 2 and 3 is solution 2 (Table 2).

Table 2 Hydrogeochemical calibration of PHREEQC using current scenario of the tailing dam

Solutions	*Solution ID*
Solution 1	Underground Mine Effluent (sampling point ARO 09)
Solution 2*	Current mill plant tailing; Ambrosia; Mix of tailings (Ambrosia, Vazante and Extremo Norte)
Solution 3	Annual precipitation water quality
Solution 4	Tailing dam water quality (Average of sampling points)
Solution 5	Spillway of the dam (sampling point ARO 10)

* Solution 2 will change in function of the 3 scenarios.

RESULTS AND DISCUSSION

Geochemical characterization of the tailing samples

The potential to generate acidity conducted from static tests can be interpreted by various types of graphical forms. In this study, it was chosen one type of interpretation often used for this purpose (INAP, 2009; MEND, 2009) (Figure 4).

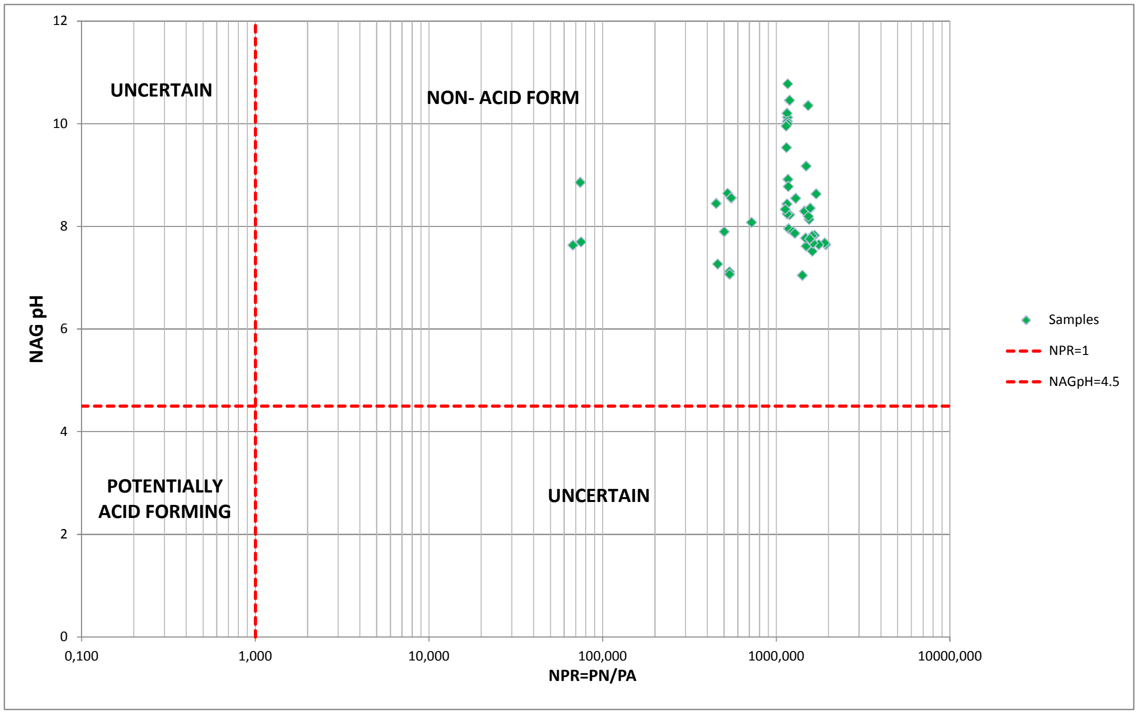

Figure 4

From the results obtained in the MABA and NAG tests presented above it can be concluded that it is very low and unlikely that these tailing samples already displaced or that will be disposed into the Aroeira reservoir will generate acidity. These results are consistent with the mineralogical composition of the rocks that generated Vazante tailing samples that are metamorphosed carbonate sediments, as marls and dolomites, intercalated with phyllites. The geological formation of this zinc deposit is a classical karst environment. In addition, underground water flow in the underground mine is super critic with a water flow rate of 10,315 m^3/hr.

Results of metal leaching test according to the North American standard SPLP, using diluted strong acid at pH 5, (US EPA 1312) presented very similar numbers and the only parameter that showed the greatest potential for leaching was just lead (values varied from 3.74 mg/L to 10.43 mg/L). For modeling purpose neither SPLP test nor the Brazilian acetic acid leaching test results (ABNT NBR 10,005) were used because they do not accurately represent tailing physical chemical conditions. Water leaching results from a mix of tailings at the following proportion 10% (Ambrosia Mine); 40% (Extreme North); 50% (Vazante Mine), used for modeling purposes, is presented in the underneath table (Table 3).

Table 3 Water leaching test in mixed tailings.

Element	*Unit*	*T_1*	*T_2*	*T_3*	*T_4*	*T_5*
Al	mg Al/L	<0.005	<0.005	0.046	0.,027	0.036
As	mg As/L	<0.01	<0.01	<0.01	<0.01	<0.01
Ba	mg Ba/L	0.243	0.228	0.264	0.241	0.273
Cd	mg Cd/L	<0.001	<0.001	<0.001	<0.001	<0.001
Pb	mg Pb/L	<0.01	<0.01	0.03	0.02	<0.01
CN	mg CN-/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cl	mg Cl-/L	<2.0	<2.0	<2.0	<2.0	<2.0
Cu	mg Cu/L	<0.003	<0.003	0.006	<0.003	<0.003
Cr	mg Cr/L	<0.01	<0.01	<0.01	<0.01	<0.01
Fe	mg Fe/L	<0.05	<0.05	<0.05	<0.05	<0.05
Mn	mg Mn/L	<0.03	<0.03	<0.03	<0.03	<0.03
NO_3	mg N_NO_3/L	<0.05	<0.05	<0.05	<0.05	<0.05
pH solution (ratio 2:1)	-	9.04	9.08	9.17	9.1	9.18
Ag	mg Ag/L	<0.003	<0.003	<0.003	<0.003	<0.003
Se	mg Se/L	<0.01	<0.01	<0.01	<0.01	<0.01
Na	mg Na/L	8.08	8.23	7.54	7.67	7.57
SO_4	mg SO4/L	24.1	23.7	27.1	27.8	23.7
Zn	mg Zn/L	0.006	<0.005	0.013	0.011	0.006

The only trace metal with significant water leaching values was lead (Pb = 0.03 and 0.02 mg/L). However, this order of magnitude of values obtained for lead (i.e., decimals ppm) is not considered high because of the dilution factor that should be also counted for in this analysis.

Water quality of each solution is presented in the table underneath (Table 4). The water percent volume is presented right after (Table 5). It is noticeable that the solution 1 coming from the underground mine effluent is the biggest percent volume and probably will play major role in the final tailing water composition (solution 4) considering its volume.

Table 4 Water quality input data for PHREEQC model for Aroeira tailing dam at different scenarios.

Element	*Solution 1 (mg/L)*	*Solution 2 (mg/L)*		
		Scenario 1 Current tailing	**Scenario 2 Ambrosia tailing**	**Scenario 3 Mixture of tailings**
Alkalinity	191	200	200	200
Al	0.033	0.005	0.0025	0.005
Cd	0.0005	0.0005	0.0005	0.0005
Ca	33.7	15.6	11.64	11.26
Cu	0.0015	0.0015	0.0015	0.0015
Fe	0.025	0.050	0.025	0.025
Mg	20.8	6.71	9.4	6.75

Mn	0.015	0.03	0.024	0.0225
N(5)	0.57	0.11	0.025	0.025
pH	7.0	9.1	8.2	9.23
K	0.87	1.3	3.6	1.17
pe	4.57	4.0	4.0	4.0
Pb	0.005	0.005	0.005	0.005
Zn	0.04	0.0106	0.1649	0.019

Considering that there is no gain or loss of water from or to the groundwater in the tailing dam area, the tailing reservoir (Solution 4) is made out of approximately 92% of water coming from the underground mine effluent and 8% of water coming from the mill plant (Table 5). The percent of water coming from rainfall precipitation is not significant therefore it was neglected in this study in particularly.

Table 5 Percent volume of each type of solution used in the hydrogeochemical model.

Solutions	*Volume (m^3/year)*	*Solution ID*	*Percent Volume (%)*
Solution 1	90,436,000.00	Underground mine	91.87
Solution 2	168,340.87	Mill plant	8.10
Solution 3	70,927.57	Rainfall	0.03
Solution 4	2,080,297.39	Tailing water	-
Solution 5	85,759,000.00	Spillway	-

PHREEQC output data

The current tailing pond is basically composed of water from the underground mine (sol. 1 = 91.87%) and solution waste from the beneficiation plant (USICON) (sol. 2 = 8,10%). The mixture of these two solutions must generate another solution very similar in composition to the water dam (sol. 4). The PHREEQC output data for the three modeled scenarios are shown at Tables 5, 6 and 7 below. Scenario 1 is considered in this exercise the calibration operation. It is remarkable that pH from the underground mine effluent raised com 7.3 to 8.4 after being displaced in the tailing dam (sol. 4). This fact means that solution alkalinity coming from the inlet increases in more than 10 times. PHREEQC model was able to consistently represent the field data. For most of the other parameters the different in concentration were not higher than 35%, so this represents a fair agreement between field data and model results , only trace metal such as: Fe, Mn, Zn and Cu that had very low concentration presented relative difference higher than 35% (Table 6).

Table 6 PHREEQC Output data for scenario 1 (model calibration)

Elements	*MIX of Sol. 1 and Sol. 2 (mg/L)*	*Water tailing Sol. 4 (mg/L)*	*Relative difference (%)*
Al	0.033	0.0211	36.6
Ca	33.37	28.79	13.7
Cd	0.0005	0.0005	0.0
Cl	1.00	1.00	0.0
Cu	0.002	0.003	50
Fe	0.025	0.050	100
K	0.861	1.436	20.6
Mg	20.60	20.25	24.6
Mn	0.015	0.030	6,2
Ni	0.005	0.010	100
Pb	0.005	0.005	0.0
Zn	0.040	0.023	42.5
pH	7.3	8.40	1.8

Once we got the model calibrated in relation to the tailing water (solution 4), the next step was to run the same model framework in terms of solution volume but now solution 2 would change accordantly to the water leaching from the tailing material generated by the mill plant. Result obtained demonstrates that the addition of tailing from Ambrosia ore deposit to the reservoir will not change significantly water quality of Aroeira tailing dam (Table 6). Sensitivity analysis was done further on to demonstrate that even when someone double the metal leaching results obtained from the geochemical test, simulating a more conservative scenario, final modeling results in the tailing dam still similar to the one obtained here (results not presented). Aluminum and zinc concentration was lower in the current tailing solution and it is probably due to some sorption of this metal with ferryhydrite or another form of iron oxyhydroxides.

For the other scenarios the same procedure as the previous one was used. The system framework was kept the same, except the water composition of solution 2. Now this solution was obtained from a mix of tailing water leaching composition (Table 6). Again the difference between the mix of solution 1 and 2 was close to the standard solution 4 that we use to evaluate the model results. In this particular case sodium and sulfur different was even higher than before and this must be related to field tailing water composition tailing characterization procedure. The mix of sample definitely was not processed with sodium sulphide and sodium carbonate.

Table 6 PHREEQC output data for scenarios 2 and 3

Elementos	*MIX Sol. 1 e Sol. 2 (mg/L) Scenario 2*	*MIX Sol. 1 e Sol. 2 (mg/L) Scenario 3*	*Água Barragem (Sol. 4) Reference (mg/L)*
Al	0.061	0.0611	0.021
Ca	27.39	27.315	28.79
Cd	0.001	0.001	0.001
Cl	2.0	2.0	1.0
Cu	0.003	0.003	0.003
Fe	0.002	0.002	0.050
K	2.177	1.788	1.436
Mg	17.65	17.21	20.25
Mn	0.032	0.032	0.030
Ni	0.010	0.010	0.010
Pb	0.010	0.010	0.005
Zn	0.076	0.076	0.023
pH	8.25	8.25	8.40

CONCLUSION

All tailings evaluated (current mill plant tailing; Ambrosia tailing; Mix of tailings, Vazante and Extremo Norten tailings) did not show potential to generate acid drainage and have low potential for metal water leaching. They also have very similar geochemical behavior comparing to the waste currently disposed at the bottom of the Aroeira tailing dam. The hydrogeochemical modeling performed in this study using a computational tool PHREEQC, was used to demonstrate this behavior and it reflected the boundary conditions presented above. The solution 1 from the underground mine, due to its large volume (92% of the total water volume), will dominate the water quality of the Aroeira tailing dam and other tailings solutions from the processing plant, solution 2, (i.e., mix of Ambrosia and mix waste) will not be able to change the current quality of the reservoir. Therefore, water quality in the Aroeira dam will not turn into acid and no significant metal solubility from tailing displaced in the dam to the water will occur. So, it is possible to conclude that this new disposal of tailings will not cause any harm to the local environment.

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