

DECOMMISSIONING AND RECLAMATION OF THE SANTO ANTÔNIO TAILINGS MANAGEMENT FACILITY

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ABSTRACT

The Santo Antônio Tailings Management Facility (TMF) consist of an earth dam built for the purpose of forming a reservoir for the storage of tailings from the Kinross gold mining processing plant from the Morro do Ouro Mine located in the city of Paracatu, Minas Gerais, Brazil. The dam area is about 950 hectares, the highest section reaches 105 meters in height, and the crest length is 5.2km. This TMF was constructed in 1987 and currently is the biggest tailings dam in operation in Brazil. The Normative Resolution COPAM n.º 127/2008, applicable in Minas Gerais, establishes guidelines and procedures for environmental assessment during the mine closure phase and institutes the mandatory development of a closure plan. To satisfy the regulations Kinross started the development of the Santo Antônio Closure Plan with Pimenta de Ávila in 2013 and it was completed at a conceptual level in April 2014. The main purpose of this Plan was to identify, evaluate and propose sustainable closure solutions to promote physical, chemical and biological stabilization of the whole site, making it appropriate for future uses considering acceptable risk levels. The main environmental issues at the site were found to be related to the potential acid drainage generation from the tailings, the geotechnical challenges considering the tailings and downstream slope, and the integration of the closure process with the mine operations. The closure plan was segmented in two specific phases and the TMF was divided into separated components, and specific closure actions were developed for each one. In summary the closure solutions consist of reshaping the downstream slope, implementing a cover system, proposing a surface drainage system and revegetating the covered areas. Finally the closure solution components were integrated to provide a consistent plan for the overall site, and a post-closure monitoring program was developed. The closure plan will be presented to the Brazilian environmental agencies as well as to the local communities.

KEY WORDS

Tailings, dam, cover system, revegetation, future land use, long term stability.

INTRODUCTION AND SITE CHARACTERIZATION

This paper presents the conceptual plan for decommissioning and reclamation of the Santo Antônio Tailings Dam located at Morro do Ouro Mine owned by Kinross in the Municipality of Paracatu, Minas Gerais, Brazil. The Santo Antônio Dam is located to the north of the pit and beneficiation plant; it was constructed for the disposal of tailings from the flotation circuit of the ore processing plant and to store water; it has a total area of 950 hectares (Figure 1). The tailings solids content ranges from 35 to 40%. Tailings are discharged in the reservoir from one disposal channel located in an upstream basin. Tailings flow from the discharge point along the tailings surface and around a dividing berm into the pool area (Figure 1(a)). Fresh water from a well field is also stored in the pool and a barge pumping system returns the water to the ore processing plants, refer to Figure 1(a). Currently the Santo

Antônio Dam is 105m high, has a crest length of 5 km, contains 382 Mm³ of deposited tailings and 9 Mm³ of stored free water.



Figure 1. a) Tailings distribution in Santo Antônio Dam; b) View of Santo Antonio Dam in 2009; c) View of Santo Antônio Dam in 2014

The Dam started operating in 1987 and disposal of tailings is scheduled to end in the next 5 years. Until the end of the mine lifecycle forecast, in principle for 15 years from now, part of the reservoir would remain in operation for impounding and storing fresh water to provide processing water demand.

In fulfillment of legal obligations imposed by the environmental regulatory agency and in compliance with company internal procedures, Kinross prepared, with the support of Pimenta de Ávila Consultoria, the Conceptual Plan of Decommissioning and Reclamation for the Santo Antônio Dam. The main purpose of this project was contributing towards the sustainable development of the region through identification, assessment and proposal of closure solutions which would promote the environmental integrity (physical, chemical and biological stability of the entire site) and which are technically and economically acceptable to the Company and community enabling a future use of the area; the corporate and regulatory policies were also considered in the development of the plan. The major challenges associated with this project were related to the characteristics of the tailings, geotechnical issues, compatibility of closure of the dam with the mine operations and ultimately the large dimensions presented by the structure which is now the largest tailings dam in Brazil.

ALTERNATIVES FOR FUTURE USE

Options were developed for the post-closure use of the Santo Antônio Dam considering the attributes of the area, intentions of post-operational use, landscape adequacy and possibility of transfer of custody. It is also important to maintain physical, chemical and biological stability in the long term. The assessments focused mainly on three options:

- Environmental conservation,

- Environmental conservation associated with scientific research oriented to local college institutions, and
- Agricultural use.

All alternatives were assessed through a qualitative classification methodology envisaging technical, environmental, economic and socioeconomic variables. A point score was assigned to each aspect and the alternatives were compared by obtaining a sum of the scores for all aspects per alternative. The highest score reflects the most preferred alternative. Table 1 shows the scores that each alternative received for each aspect evaluated, considering the implementation phase of the closure solution and during future land use.

Considering the risks and restrictions associated with the structure and the results shown in Table 1 the future preferred use for the area is mixed use of environmental conservation and scientific research aiming to boost the research and learning infrastructure of local college centers by promoting technical and academic knowledge applied to mining activities and establishing the township as a regional academic pole. Subsequent to the implementation of closure and post-closure monitoring the area will be destined to environmental conservation which is in alignment with economic zoning established for Paracatu Municipality; the actual involvement of the community will be part of the next stage of the closure project, referred to as the basic project development stage.

GENERAL DECOMMISSIONING GUIDELINES

Considering the challenges associated with the structure the following strategy was adopted: the structure was divided in two different areas, namely the reservoir and downstream slope. The closing process was also divided into two stages: Stage 1 occurring during the Mine operation and considering the partial closing of the dam, and Stage 2 considering the full closure of the dam concurrent with the decommissioning of the entire mine site.

Guidelines for Closure of Downstream Slope

The downstream slope of the structure at closure should have a slope and geometry that will provide stability for long-term conditions. Long-term stability considers physical stability, control of erosion processes and restoration of vegetal cover. Thus it was essential to assess, in an integrated way, the geotechnical aspects, surface drainage and re-vegetation.

Table 1: Comparative Analyses between Future Use Alternatives

CLOSURE PLAN - FUTURE LAND USE - SANTO ANTÔNIO TAILINGS MANAGEMENT FACILITY - MORRO DO OURO MINE					
PERIOD: CLOSURE					
VARIABLE	FACTOR	ASPECTS ANALYSED	Alternative A	Alternative B	Alternative C
			Environmental Conservation	Environmental Conservation and Scientific Research	Agricultural Use
TECHNICAL	Physical Stability	Effort in geotechnical works for ensuring physical stability	5	5	1
		Effort in drainage works for ensuring physical stability	5	5	1
		Effort in revegetation works for ensuring physical stability	5	5	9
	Chemical Stability	Effort in works for ensuring chemical stability (Surface and Groundwater, Soil and	5	5	5
	Flood of the Project	The structures attend the flood for closure condition	9	9	9
ENVIRONMENTAL	Impact	Degree of impact resulting from implementation	9	9	1
ECONOMIC	Implantation	Agility in implementation	5	5	1
	Period of Implantation	At the end of useful life/During operation/Progressive	9	9	1
SOCIOECONOMIC	Access	Existing accesses are positive for the future use	9	9	9
	Transfer of Custody	Agility in the process of transfer of custody	5	7	1
SUBTOTAL FOR IMPLANTATION			66	68	38
PERIOD: POS CLOSURE					
VARIABLE	FACTOR	ASPECTS ANALYSED	Alternative A	Alternative B	Alternative C
			Environmental Conservation	Environmental Conservation and Scientific Research	Agricultural Use
TECHNICAL	Physical Stability	Promote physical stability in long term	9	9	1
	Chemical Stability	Promote chemical stability in long term	9	9	1
ENVIRONMENTAL	Biological Stability	Promote biological stability in long term	9	9	1
	Impact	Degree of impact during regular use	9	9	1
	Landscaping Adequacy	Promote landscape integration	9	9	1
ECONOMIC	Monitoring and Maintenance	Condition: Walk way/Passive care/Active care	5	5	1
SOCIOECONOMIC	Employment	Promote employment	1	5	9
	Community	Aim to attend a community necessity	1	9	5
		Encourage an specific community potential	1	9	5
	Income	Provides Income for economy and community	1	5	9
	Health and Human Well-Being	Promote well-being and health for the community	5	5	1
SUBTOTAL FOR POS CLOSURE			59	83	35
Alternative A	Environmental Conservation			125	
Alternative B	Environmental Conservation and Scientific Research			151	
Alternative C	Agricultural Use			73	
BEST ALTERNATIVE				B	

Several alternative downstream slope configurations were evaluated and the major challenge was minimizing the large volumes of material required for re-sloping. The criteria for selection of the preferred alternative focused on long-term physical stability and the feasibility of constructing this alternative; the following geometry for the closure of the downstream slope was selected:

- Slopes between berms with an inclination of 1V:1.7H corresponding to an overall slope equal to an overall slope angle of 1V:3.2H;
- Horizontal berms parallel to the crest, 6m wide with longitudinal slope of 0.5% and cross slope of 5.0%. These berms are spaced at 7.0m vertical height.
- Surface drainage system on the berm consists of compacted laterite (30 cm layer) flowing to downslope concrete channels spaced at 400m along the entire slope. The drainage system design was based on a return period of 1:1000 years;
- Slope stability safety factors must be above 1.5 as required by Brazilian standards. The safety factors were assessed for three sections of the dam: right side abutment, central section and left side abutment. In all analyses carried out the values found were above the required by the Brazilian standards (See Figure 2);



Figure 2: Sections of Analyses of Stability and safety factors found for the closure condition.

- The erosional loss of soil for the proposed configuration was calculated as 4.52 ton/ha/year using the RUSLE methodology and considering vegetal cover around 60-80% ($C=0.03$);
- The volumes of cut, fill, material handling, implementation of drainage systems and re-vegetation of the slope face were estimated for purposes of cost comparisons.

The alternatives considered for geometry and drainage at closure of the downstream slope of the Santo Antônio Dam aimed at maintaining physical stability and also to control erosion in the long term. The

re-vegetation plays a critical role in reaching these goals and also results in landscape integration. In the short term the re-vegetation of the slope aimed at the slope stability and control of erosion processes. In the medium and long term it is expected that the area will be integrated into the native vegetal appearance of the area.

To maintain low levels of soil loss the selection of species was based on the following criteria:

- Low vegetation height or herbaceous size;
- Medium depth root penetration;
- Fast growth and considerable production of biomass;
- Adapted to conditions of local water availability (precipitation);
- Providing good rates of ground cover favorable to erosion control and slope stability.

Based on these criteria and the proposed embankment geometry different options of grass, small size leguminous and some shrubs were assessed to form a 60-80% cover of the downstream slope with grass and 25% with shrubs. Field experiments in the area were carried out for 10 species and the ones presenting the best performance, Bermuda and Pensacola grass, were recommended for utilization at the closure stage (Figure 3).



Figure 3: Result of experiment carried out in the field with Bermuda Grass

The full closure of the downstream slope is scheduled to be implemented and completed during Stage 1 of Decommissioning.

Guidelines for Closure of the Reservoir

The concepts for closure of the dam beach and reservoir area required the assessment of storage of water in the pool area, the unit water demand, the chemical stability of tailings, implications of conventional and multilayer cover systems and the geotechnical characteristics of tailings. As the Santo Antônio Dam is a multi-use structure for disposal of tailings and impounding of water, the

technical closure solution adopted considered the storage volumes available in the reservoir, the volume required to regulate flow rates and prevention of discharging tailings liquid into the environment. The volume available in the reservoir should be sufficient to store the water volume required to meet the water demand, the volume of tailings to be deposited until the end of the structure life cycle and still maintain a volume available for the tailings surface decommissioning measures.

As to the chemical stability of tailings the data provided showed that tailings with different characteristics have been disposed of in the dam throughout the operation. The composition of the tailings requires that the area should be covered in order to result in environmental conditions satisfying the applicable legislation and standards.

A cover system must isolate the tailings from the environment by controlling the ingress of oxygen and must also limit the water infiltration to minimize the generation of leachate. Due to the climatic conditions in the region and the large extent of the area, dry cover options were assessed using multi-layered cover systems that include a conventional hydraulic barrier and store and release components.

Conventional hydraulic barriers use layers of clayey material with low hydraulic conductivity to minimize infiltration and maximize surface runoff and evaporation. Despite being a very simple type of cover it requires strict quality control during construction to establish a uniform low permeability layer on the whole area. Still in the long term degradation of the layer may occur with increase of permeability and loss of efficiency chiefly associated with occurrence of cracks.

The store and release type of cover is a multilayer system with specific functions. The upper layer formed by vegetation (top soil) is used to enhance evapotranspiration; the intermediate layer formed by lightly compacted silty soil, called “store and release”, accumulates infiltration water during the rainy period and releases it by evapotranspiration during the dry period. A third layer of clayey soil was included to act as a hydraulic barrier thus reducing entrance of oxygen.

Simulations of the behavior of the two types of cover were carried out assessing infiltration and maintenance of saturation of materials using the Vadose/W program considering climate, vegetation and geotechnical parameters. Figure 4 shows the variation of the degree of saturation in the profile used for the simulations in Vadose /W over one year. During this interval, the degree of saturation in the store-and-release layer ranged between 35 and 100% and the hydraulic barrier layer remained saturated during the entire period of the simulation, showing its efficiency. At the layer of tailings the saturation remained above 85%, which prevents the inflow of oxygen.

The higher the thickness of the store-and-release layer the lower was the infiltration rate. Considering the results obtained for the store-and-release cover associated with a hydraulic barrier this became an alternative for use in the decommissioning of the Santo Antônio Dam. Despite being more robust, this type of cover presents higher physical stability over time and it is efficient in reducing water infiltration and minimizing oxygen entrance.

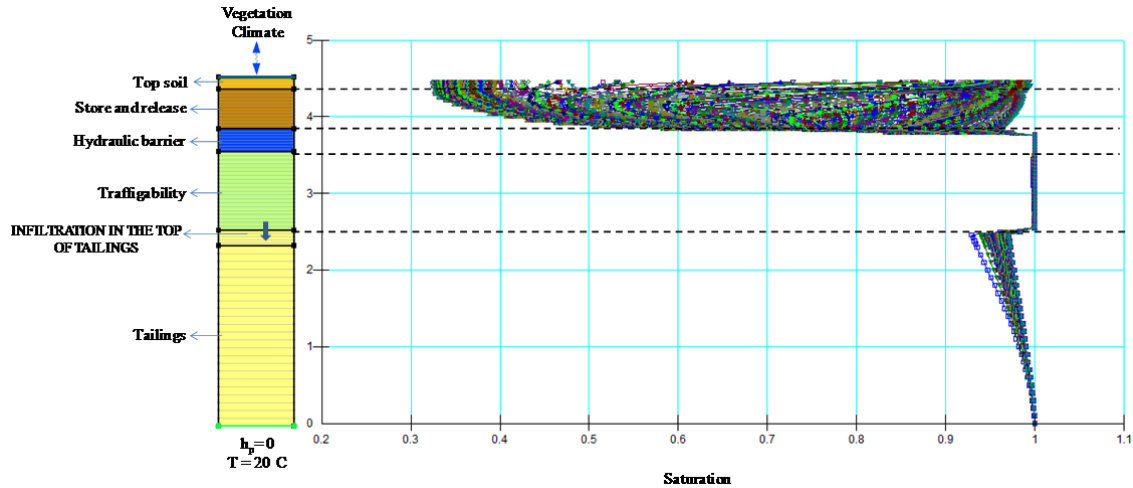


Figure 4: Result of Modeling of Store and Release Cover

For Stage 1 Closure (ending with disposal of tailings until the decommissioning of the Mine) the suggestion was, conceptually, to construct only one trafficability layer of variable thickness and minimum value of 1m in the upstream region and near the left side abutment on top of tailings. The implementation of such a trafficability layer would allow equipment traffic on top of the tailings surface and promote the re-sloping of the surface to direct surface water flow. This cover will only partially cover the tailings surface as the pool will be maintained during this period for the supply of the processing plant water demand. The presence of the lake inevitably implies variation of the water level which could cause damage to the cover system if it were fully implemented. Stage 2 considers the emptying of the reservoir lake by pumping the water to the exhausted mine pit; placement of a full cover system consisting of a store-and-release layer (formed by saprolites) over a hydraulic barrier layer (formed by low permeability clayey material). A topsoil layer will be placed on top of the multi-layered cover.

The numerical modeling used to design the cover system presents limitations related to the simulation of certain field conditions such as, for instance, occurrence of cracks, heterogeneity of materials and their permeability. Thus further studies, such as filed trials, will be required for the development of a final closure plan.

The tailings are discharged at a solids content between 35 and 40%, followed by sedimentation and subsequent self-weight consolidation as the successive layers are deposited over the years the years. A one-dimensional consolidation analysis was developed for the numerical modeling of filling of the reservoir, sedimentation and self-weight consolidation plus consolidation caused by the surcharge of the cover system. This provided a first approach to the effects of the partial and full closure of the future surface elevations and where material will be required to cover depressions which will be formed due to consolidation of the tailings over time to avoid the formation of ponding.

The limiting factors for the revegetation of the area are the instability associated with the consolidation of the tailings, the tailings substrate composition, which is a poor soil due to the absence of organic materials and the possible residual presence of arsenic. The selection of species was based on the assessment of several studies carried out in the field by Kinross with research institutions which

addressed the local chemical characteristics and their influence on the establishment of species, the influence of the presence of one soil layer in the cover system and a survey of species that presented good adaptation to the area. The implementation of a cover system is beneficial to the selection of species as it avoids the migration of possible contaminants to the soil surface by providing better conditions for the development of vegetation and maintaining the arsenic levels within the limits set forth by the applicable legislation. Table 2 below shows a summary of species which presented positive results in the assessed studies with good growth rates and good adaptation to local conditions.

Table 2: Summary Table of Species assessed by Previous Studies

Size		Melo 2006- Species for Phytoremediation	Neri 2011-Species of occurrence by natural regeneration	Assis 2006-Species well adapted to the coverage systems	
Herbaceous	Gramineous	Low	<i>Lolium multiflorum</i>	<i>Axonopus marginatus</i> <i>Andropogon bicornis</i> <i>Aristida ekmaniana</i> <i>Digitaria ciliaris</i>	-
		Shrub	-	<i>Sabicia brasiliensis</i>	-
	Leguminous	Low	<i>Stilozobium aterrimum</i> <i>Arachis pintoii</i>	-	-
		Shrub	<i>Stylosanthes humilis</i> <i>Crotalaria spectabilis</i> <i>Sesbania virgata</i> <i>Leucaena leucocephala</i>	<i>Stylosanthes viscosa</i>	<i>Acacia holosericea</i>
Arboreal		<i>Eucaliptus grandis</i> <i>Corymbia citriodora</i>	<i>Simarouba amara</i> <i>Maprounea guianensis</i>	-	

The recommendation arising out of such assessments was that the re-vegetation of the Santo Antônio Dam reservoir should occur only in Stage 2 of Closure after the implementation of the final cover system and a layer of organic soil (top soil) of approximately 20 cm. Considering the results of the field studies, the short-term goals and the restrictions existing in the area, the recommendation was to plant only small sized herbaceous species. Subsequently when the reservoir area physical stability is assured arboreal size species may be added. It is expected that, along with the development of the vegetation and gradual increase of diversity of species the return of local fauna and fauna may also occur so that little by little the closed area will be integrated with the local landscape and biological diversity will be reestablished.

Guidelines for Closure Stages

Figure 6 illustrates the design for closure expected for the 1st and 2nd Stage of Closure. Figure A shows the 1st Closure Stage consisting of the partial closure of the dam with the implementation of the trafficability layer on the tailings surface, the presence of the lake and the reshaping of the downstream slope. Figure B shows Stage 2 closure consisting of the total closure of the dam with the implementation of a full cover system and re-vegetation.

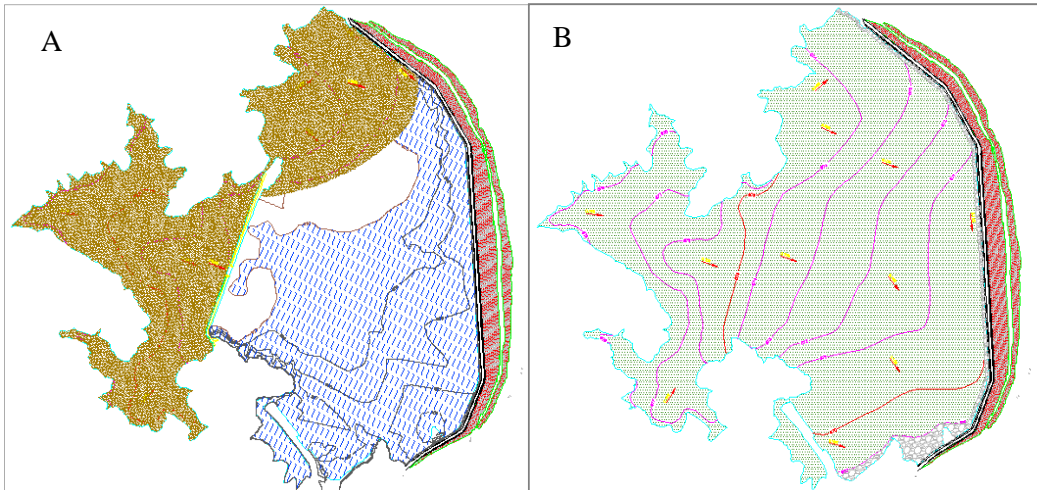


Figure 6: Schematic illustration of conceptual closure stages of Santo Antônio Dam:

A) Stage 1: Partial Closure: Presence of lake, placement of trafficability layer and reclamation of downstream slope

B) Stage 2: Full Closure: Implementation of full cover system and revegetation

MONITORING

Monitoring will be used to obtain information before the implementation of closure components as well as the success of the implemented closure actions and the need (or not) for maintenance. Initial monitoring was planned for a 5-year period however it should also continue after that until acceptable conditions set forth by the legislation and required for closure will be reached. The Santo Antônio Dam Monitoring and Maintenance Plan considered:

- Monitoring the physical stability (by visual inspections and instrumentation),
- Monitoring of chemical stability (assessment of quality of ground and surface waters and quality of soil), and
- Monitoring of biological stability (assessment of reestablishment of species and evolution of vegetal cover).

During the proposed monitoring the need for maintenance should be assessed although no major problems are expected. Corrective actions will be implemented as necessary. Monitoring should be more frequent just after the implementation of closure actions and may become more sporadic as the conditions stabilize and the requirements agreed upon with the supervising agency are approached.

SUCCESS INDICATORS

Success indicators for closure of Santo Antônio Dam were established that are aimed at verifying the performance of the proposed decommissioning and reclamation measures. Such indicators will enable Kinross to perform maintenance and other actions to maintain stability and ongoing performance of the components. Some of the suggested indicators are:

- ✓ Reduction of soil loss on the downstream slope;

- ✓ Surface and groundwater quality;
- ✓ Increase diversity of species of flora on site, mainly native species; assessment of integration of reclaimed areas with the local landscape.

FINAL CONSIDERATIONS

The concept of continuous planning for closure is in alignment with the best practices adopted by developed countries. In Brazil the requirement of the company's commitment to closure of a mine is a relatively new development due to the recent legislation on closure.

The Santo Antônio Dam Closure Plan was developed in a conceptual (initial) form and its main purpose was the identification of applicable closure alternatives while seeking the balance between the technical, environmental and socioeconomic variables. It was done based on information available at the time of preparation.

For the next phase of the project new information will be produced and will be used in relation to the adopted cover system, the proposed timetable and actual community involvement. Therefore some of the proposed approaches may be adjusted and changed.

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