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Decommissioning and Rehabilitation of the Benambra Cu-Zn Mine Tailings Dam

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Summary The Benambra Tailings Dam received over 700,000 tonnes of pyrite rich potentially acid generating tailings which were stored under water. The paper provides an outline of the investigations conducted on the geochemistry of the tailings; the options evaluated for closure of the dam; and the conceptual design for wet closure. Sampling and analysis of the tailings has confirmed that the sub-aqueous disposal of the tailings has minimised the oxidation of the tailings and subsequent acid generation. A closure and rehabilitation strategy was developed to ensure the long term physical and geochemical stability of the tailings. The wet closure involved creating a permanent lake over the tailings and has necessitated the design of spillways and pipe siphons that must perform well into the future.

1. INTRODUCTION

Denehurst Limited established the Benambra mine in the remote and environmentally sensitive high country of northeastern Victoria in 1992. The processing of copper and zinc ores ceased in 1996 with the closure of the mine. During this period some 700,000 tonnes of pyrite rich, potentially acid generating tailings were discharged to a dedicated tailings dam where they were stored under a water cover.

The closure of the mine posed critical questions as to how the long term physical stability of a man-made structure, and the long term geochemical stability of the tailings, could be achieved without degrading the surrounding environment. Also, due to the remoteness of the site, a closure strategy with minimal long term maintenance requirements would be essential if it was to be practical. It was considered that to achieve long term stability two objectives would need to be met, these were:

1. to create a stable, sustainable landform that is consistent with the surrounding environment; and
2. to create an environment within the tailings mass that would ensure the long term geochemical stability of the tailings.

An additional issue for consideration in the long term closure planning of the tailings dam was the potential reactivation of the dam if mining operations recommenced in the future. There are limited suitable tailings dam sites within the vicinity of the known areas of mineralisation therefore the dam represents a significant economic resource.

This paper discusses the operational management of the dam, in particular the effectiveness of sub-aqueous storage of the tailings in preventing acid generation, and the adopted strategies to achieve the long term stability of the dam.

2. DAM CONFIGURATION AND THE SURROUNDING ENVIRONMENT

The Benambra Tailings Dam comprises a rockfill embankment of maximum height 20 metres situated in a small valley in the catchment of the Upper Tambo River. The embankment foundation incorporates a grout cut-off curtain tied to a clay cut-off key. To minimise seepage, a synthetic liner was placed over the upstream face of the embankment.

The tailings, and the associated water cover, extend over an area of approximately eight hectares with water depths varying between zero and six metres. Approximately 90% of the tailings are covered by at least two metres of water and the water cover has been maintained since tailings discharge to the dam commenced in 1992.

The embankment impounds a total catchment of 122 hectares with approximately 96 hectares of this catchment diverted around the embankment by the South Diversion Drain. A plan of the tailings dam and its immediate surrounds is shown on Figure 1.

2.1 Consequences of Failure

The drainage lines downstream of the dam (Straight Creek and the Tambo River) pass through approximately 50 kilometres of state forest with limited access, hence a failure would not be expected to cause loss of human life or immediate

significant economic losses. A failure which exposes large amounts of tailings may, however, lead to acid generation and mobilisation of metals into the streams and rivers. This may cause impacts on the sensitive alpine environment, economic losses to irrigators and other water suppliers, and damage to fisheries.

3. TAILINGS CHARACTERISATION AND DAM OPERATION

The major mineralogical components of a sample of tailings is shown in Table 1. The majority of the tailings sample is comprised of sulphide minerals, particularly pyrite.

Table 1. Tailings Mineralogy.

Mineral	% by weight
Pyrite	67.3
Quartz	13.0
Other silicates (Fe, Al)	7.6
Ferroan dolomite	4.6

Geochemical characterisation studies undertaken by Environmental Geochemistry International (EGI) concluded that the tailings have a very high nett acid producing potential (NAPP) with significant Acid Neutralising Capacity (ANC). This neutralisation capacity is most likely provided by ferroan dolomite in the tailings. EGI also concluded

that for tailings exposed to the atmosphere, ferroan dolomite will neutralise acid generated from sulphide oxidation for a lag period estimated at approximately 100 days after which acid may be released. EGI went on to state that there is potential for long term acid generation from the Benambra tailings.

Based on these conclusions it was recommended that the tailings be stored below water as the most effective way to exclude oxygen and thus prevent sulphide oxidation. Also, decommissioning of such a tailings dam would usually involve the development of a wetland or swamp environment on the surface to promote anaerobic conditions. In line with these recommendations, a layer of water has been maintained over the solid tailings since dam commissioning to minimise oxygen diffusion into the sulphidic tailings and thereby inhibit oxidation and the consequential generation of acid.

In early 1998, the water layer was in excess of two metres depth over most of the dam. Analysis results from tailings samples recovered from the dam in February 1997 are shown in Table 2. The elevated pH is consistent with the pH at discharge and, together with the high sulphide to sulphate ratios, suggests that the tailings have not oxidised significantly under the water cover.

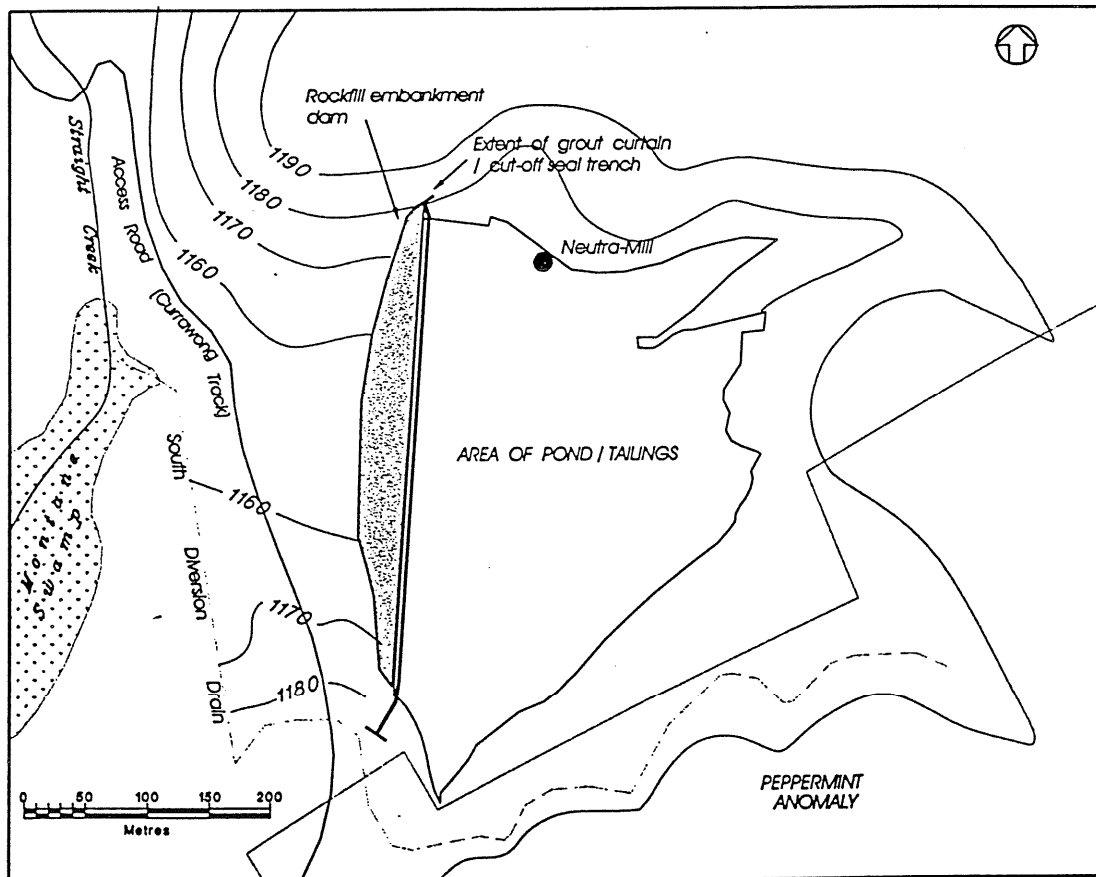


Figure 1. Plan of the Tailings Dam.

Table 2. Beached tailings analyses.

	Sample						
	1	2	3	4	5	6	7
Water depth over tailings (m)	0.1	0.1	0.1	0.5	0.5	1.5	0.1
Sample depth into tailings beach (m)	0-0.1	0.1-0.3	0.3-0.8	0-0.1	0.1-0.5	0-0.1	0-0.1
pH	11.2	9.1	8.4	10.5	10.9	12.4	12.3
Sulphate (mg/kg)	27.8	6.92	4.15	11.5	4.55	25.7	30
Sulphide (mg/kg)	217	341	333	320	332	272	17

4. CLOSURE AND REHABILITATION OPTIONS

4.1 General Issues

There were two fundamental closure options considered for the Benambra Tailings Dam. These were dry encapsulation or a wet cover. Dry encapsulation involves the construction of a solid earth or composite barrier over the tailings. The cover can be comprised of a variety of materials dependent on its design function. A wet cover requires the establishment of a water barrier over the tailings.

4.2 Dry Covers

Dry covers rely on minimising the diffusion of oxygen to the underlying tailings mass to inhibit the potential for acid generation.

The main issues with the establishment of a dry cover on the Benambra Tailings Dam are construction of the cover over the saturated, unconsolidated tailings surface and the sourcing of materials for cover construction.

4.3 Wet Covers

A wet cover involves the establishment of a permanent water layer or wetland over the tailings to prevent oxygen diffusion to the tailings.

Between 1988 and 1997, the Canadian MEND programme studied subaqueous disposal of tailings in four natural lakes in Canada. Reviews of these studies have been completed and confirmed earlier conclusions that subaqueous disposal of sulphide rich tailings would result in negligible rates of oxidation and a minimal loss of metals to overlying waters (Sly, 1996 and RAAS, 1992; Pederson et al., 1994 and 1997).

A wet cover is effectively a continuation of the management practices applied to the tailings over the life of the dam so far; that is, the minimisation of oxygen ingress to the tailings by the maintenance of a water cover. As discussed in Section 3, recent sampling confirmed that oxidation of the tailings has not occurred. The feasibility of maintaining the water cover is confirmed by hydrological studies where under the current configuration only in extremely dry years is there a small loss of water from the tailings dam pond. This occurs mainly as a result of evaporation but also due to leaks around the abutments and through the grout curtain.

4.4 Adopted Closure Strategy

Table 3 presents a comparison of the major issues for wet and dry covers on the Benambra Tailings Dam.

A dry closure method appears likely to risk inducing acid drainage generation. Once acid drainage generation is initiated, both cation exchange and acid hydrolysis may in time cause loss of strength in the containment structures and thereby establish environmental risks.

Based on the comparison of the two closure techniques a wet closure has been adopted for the Benambra Tailings Dam.

5. WET COVER CONCEPTUAL DESIGN

Under a wet closure, the long term security of the dam embankment will be critical. The embankment must continue to be a water retaining structure and must effectively contain the tailings indefinitely, certainly well beyond the usual design life of such structures. Design features to address these concerns are discussed below and a conceptual wet cover plan and section are shown on Figures 2 and 3.

5.1 Flood Control

A spillway has been designed to accommodate the Probable Maximum Precipitation (PMP) event as per ANCOLD guidelines, 1994. This spillway will provide the means for long term discharge of water to the environment and is also designed to accommodate flood flows in the event of complete blockage of the South Diversion Drain. The spillway incorporates erosion protection measures such as relatively flat slopes (less than 1V:4H), lining with interlocking, well graded boulders and hydraulic damping structures.

A minimum freeboard of 1 metre has been allowed to accommodate wave action.

5.2 Long Term Erosion

A major issue with the long term stability of the embankment is the potential for erosion, particularly through the spillway and from runoff on the flattened embankment. Erosion control measures for the spillway are discussed in Section 5.1.

Table 3. Comparison of Wet and Dry Covers for the Benambra Tailings Dam.

Issue	Wet Cover	Dry Cover
Acid Drainage generation potential - short and long term	Demonstrated effective in preventing oxidation and therefore acid drainage in the tailings dam. The method proposes no significant interference with the tailings or changes to the current environment in the short or long term.	In the short term this method requires significant exposure times of tailings to the atmosphere and disturbance of the tailings. Therefore the tailings may undergo oxidation. In the long term oxygen infiltration may be higher than the wet cover due to seepage drainage of the tailings, and erosion or other disturbances to the cover such as vegetation rooting or animal burrowing.
Constructability	No construction over the tailings. All works within the current dam area. No unusual construction problems anticipated.	The majority of the works are over the tailings requiring long drying periods and raise significant safety issues. May require thick sacrificial working platforms to be placed over the tailings surface and the use of geotextiles.
Long Term stability	Flatten embankment to minimise erosion and for seismic stability. Water cover avoids erosion or other disturbance problems.	Flatten embankment as per wet cover. Disturbance from animals or vegetation rooting may effect long term stability of cover.
Borrow requirements	Major source is for flattening of the embankment. Quantity of fill required estimated at 70,000 cu.m.	For flattening of the embankment and cover construction. Quantities estimated at a minimum of 250,000 cu.m. High uncertainty on this value as a large portion will penetrate into tailings. The range of different materials required is greater than a wet cover and no existing rock stockpiles exist. Rehabilitation of borrow areas would be difficult.
Long term surface water discharges	Will discharge indefinitely. Water quality will need monitoring and water may need treatment for an initial period. Seepages will continue to discharge.	Initially all supernatant water must be discharged and this will require treatment. Minimal seepage discharges beyond this unless cover allows excessive water infiltration.
Recommissioning if mining recommences	No significant works required.	Requires re-excavation of the dam cover which will be expensive.
Demonstrated effectiveness elsewhere	Several sub-aqueous deposition tailings dams in Tasmania and trials underway for wet closures. Examples in Canada for disposal into natural lakes. Successful decommissionings are recent and therefore no long term assessment possible.	Has proved effective on waste rock dumps. Few examples of successful decommissioning of tailings dams like Benambra. Examples of successful decommissioning are recent and therefore no long term assessment possible.
Need for Management	Will be required until monitoring statistics show effective compliance against a range of climatic events	Will be required long term to ensure effective oxygen exclusion is maintained despite drainage
Estimated cost (SAUD - 1997)	\$1.8 million	\$5-13 million
Feasibility at Benambra	Modeling shows wet cover can be maintained.	Previous sub-aqueous disposal makes placement of a dry cover difficult potentially resulting in other issues.

A series of catch drains will be constructed on the embankment to control runoff and these will direct water to drains on the margins of the embankment. These margin drains will be lined with well graded, durable rock and rock lined outlet structures will be established where the drains outlet to the natural drainage. All the drains will have a relatively low grade to reduce water velocities.

It is recognised that the drains, particularly the catch drains directly on the embankment, will block over time. In the initial years after construction there will be a monitoring period to maintain the drains. In the long term, the establishment of suitable vegetation in combination with relatively flat slopes and rock lining of high flow channels is expected to minimise the potential for erosion.

5.3 Survival of the HDPE Liner

The rate of degradation of the HDPE liner is uncertain. The majority of the liner is buried and what is exposed will be buried during the rehabilitation works. Current evidence suggests that when HDPE is buried it remains in good condition for long periods.

At some point in the future it is assumed that the liner will degrade, however, at this time it is expected that the natural processes of sedimentation will have created a relatively low permeability, oxygen consuming layer within the pond base. Consequently it is also anticipated that at this time any additional seepage through the embankment will be of relatively good quality and should not

pose any threat to the stability of the flattened embankment.

5.4 Seismic Stability

There are a number of faults within the vicinity of the dam raising the possibility of significant earthquakes affecting the dam. There are several factors decreasing the susceptibility of the dam to earthquake damage, these are:

- the relatively flat rehabilitated slope;
- the rockfill construction of the dam; and
- bedrock within one metre of the embankment foundation.

The tailings are predominantly silt sized and saturated and may therefore be susceptible to liquefaction in the event of an earthquake. The embankment has been designed as a standalone structure and does not rely on the strength of the tailings for stability.

5.5 Quality of Long Term Water Releases

In recent sampling, the water quality in the tailings dam was within the stipulated discharge limits in the draft Works Approval and the Waters of Victoria SEPP emission limits for discharge directly to the Tambo River.

In the long term, it is anticipated that the water quality will continue to improve to a point where treatment of the water before release is no longer required. The primary reasons for this is the development of a natural sediment layer over the tailings effectively isolating the tailings as molecular diffusion will largely control geochemical reactions in the top five to ten centimetres (RAAS, 1992). The sediment would result from natural runoff to the dam.

An option that may be considered is the use of a peat/sand mixture or some other organic rich material as a cover over the tailings. This is to create a substrate which may provide a reactive surface for chemical exchange and attachment sites for microbes. It will in addition provide an oxidation barrier against oxygenated waters contacting the peat after thermal overturn. It will need to survive long enough until the natural accumulation of organic materials from the catchment takes its place. The substrate can act to

accelerate the establishment of the wetland system and assist in its longer term viability.

The long term discharge will be via the spillway directly to the nearby Straight Creek.

There are some minor seepages (totally <1 L/sec) emerging from the toe of the embankment. These seepages are acidic and show elevated heavy metal concentrations. The seepage will be collected via a series of gravel drains constructed in the rehabilitated embankment and passed through a passive system of anoxic limestone drains and/or an underflow Reed Bed wetland to treat the discharges prior to their entry into Straight Creek. These drains, and wetlands, have been shown to raise the pH and to produce a reduction in metal and sulphate concentrations in waters passing through them (Jones and Chapman, 1993).

5.6 Long Term Stability of Tailings

The long term geochemical stability of the tailings is reliant on maintaining a water cover over the tailings. To allow water release in the years immediately after closure, a temporary pipe siphon system has been designed that will maintain a minimum water cover of two metres over the tailings.

At closure a small area of tailings will be relocated to deeper water to ensure that the water depth is maintained. The siphon will direct discharge to the licensed discharge point on the Tambo River (some five kilometres from the dam) until the water quality in the dam improves to a point where long term releases will be directly to the nearby Straight Creek.

The physical stability of tailings would potentially be compromised by wave action agitating the tailings. Given the greatest fetch on the dam is 300 metres, this water depth is considered sufficient to avoid disturbance by wave action.

Consolidation of the tailings could be expected to continue into the future however, as the level of the tailings drops the water level will not alter. The release of pore water to the pond will have some water quality issues however the quantities will be relatively small compared to natural inflows to the dam.

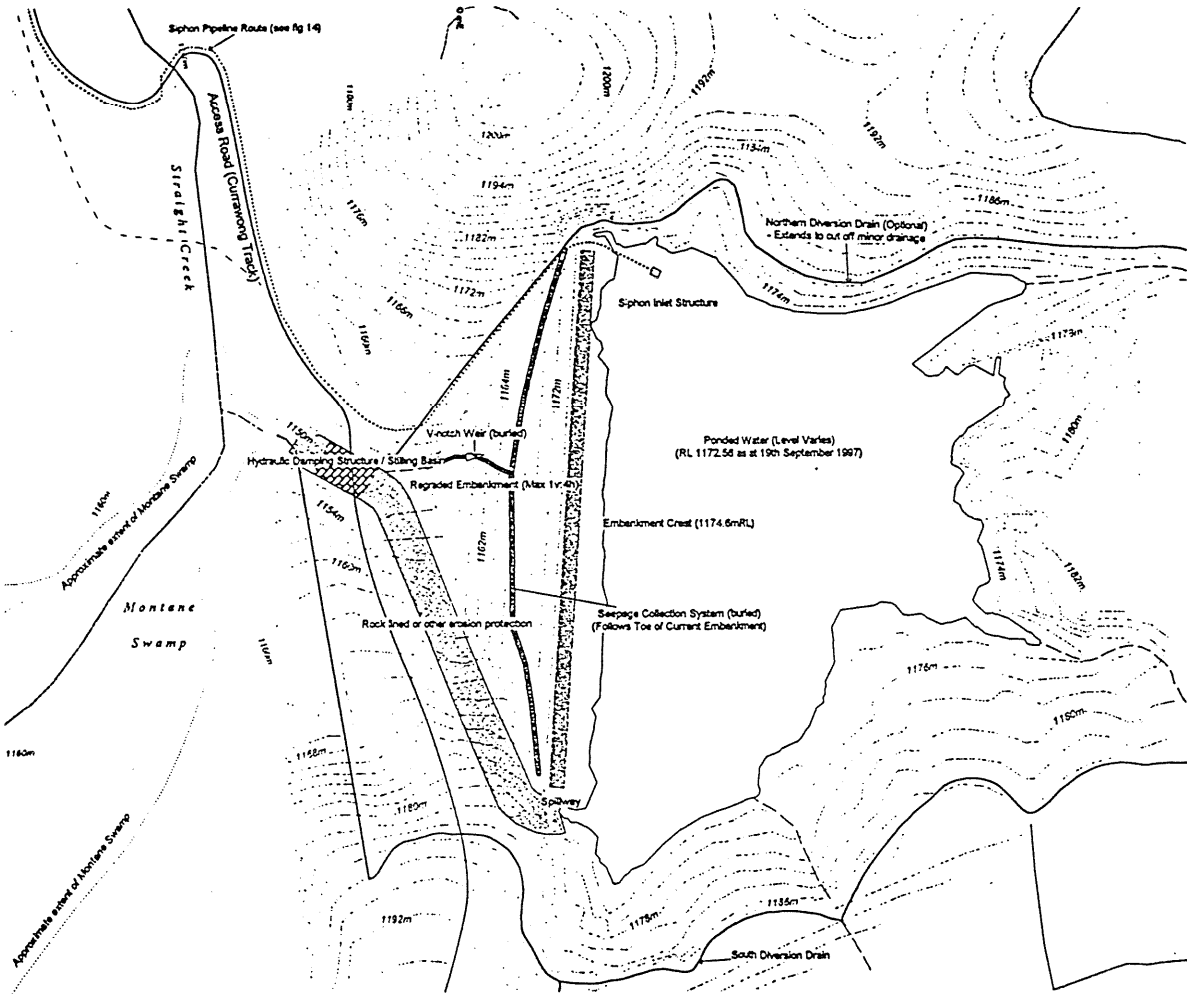


Figure 2. Conceptual wet cover plan

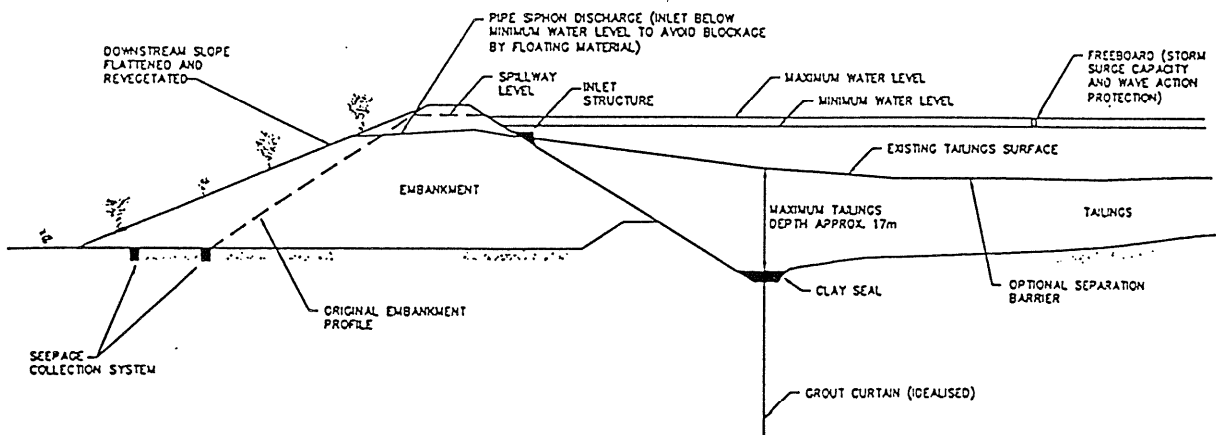


Figure 3. Conceptual wet cover section.

6. CONCLUSIONS

Monitoring results from the Benambra Tailings Dam indicate that sub-aqueous disposal of pyrite rich tailings with a high net acid producing potential has prevented significant oxidation from occurring within the tailings.

Based on the successful performance of a wet cover during the operational life of the dam, and concerns regarding the constructability and the long term stability of a dry cover, a wet closure has been adopted as the closure and rehabilitation strategy for the dam.

The major issue with a wet closure at the Benambra Tailings Dam is the long term quality of water discharged to the environment and the stabilisation of the embankment.

In the long term the environment within the ponded water on the dam is expected to approach natural conditions with a layer of sediment from catchment runoff covering the tailings and the establishment of appropriate flora and fauna.

Flood control and long term erosion were seen as the major issues affecting the long term stability of the embankment. Conceptual designs have been provided to address these issues.

Monitoring of the dam will be necessary in the years immediately after closure to gauge the evolution of the dam to a near natural system. It is expected that after some appropriate time period defined by the monitoring results the dam will require only minimal to no surveillance.

At the time of writing this paper, the dam is on care and maintenance awaiting a final decision on whether mining at Benambra will be reactivated or if the wet closure strategy will be implemented.

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