INVESTIGATION, MONITORING AND MANAGEMENT OF DOWNSTREAM GROUNDWATER IN THE TAILINGS STORAGE FACILITIES OF NUI PHAO MINE, VIETNAM

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ABSTRACT

With the progressive raising of the Nui Phao Mine Tailings Storage Facility (TSF) there has been a detectable increase in groundwater levels in downstream areas. The local community raised concerns in relation to the rising groundwater levels via the established grievance mechanism with Nui Phao Mine Company (NPMC). In order to understand the basis for the changes in groundwater levels and proposed mitigations NPMC undertook a comprehensive multi-phase study of the groundwater flows downstream of the TSF impoundments between 2015 and 2017. The studies included geological mapping, drilling and geophysical investigations. Once initial geological mapping was completed a line of 16 monitoring bores were installed along the property boundary with to the local community. In the dry season, only two of these bores intercepted water, and all the others remained dry. Additional geophysics and ground penetrating radar work studies undertaken failed to delineate significant water bearing structures within the boundary area. A long-term monitoring and control system has now been established to monitor both the changes in groundwater levels as well as the chemical quality of groundwater in the area. The comprehensive monitoring system will be kept in operation and maintained through operations and into the mine closure period. Analysis of the data collected prior to and during the operation of the TSF has allowed the development of a model to predict groundwater and contaminant transport flows using a finite difference code. Application of the model allowed for mitigation approaches to be considered and after reviewing a dewatering channel was proposed and constructed in the boundary area down to an elevation of 52 mRL. The drainage channel installation has successfully lowered the groundwater and surface water for the community adjacent to the property boundary. The success demonstrates the effectiveness of NPMC's grievance mechanism as well as demonstrating NPMC's willingness to work with and resolve concerns in consultation with local community members.

Keywords: tailings, groundwater, seepage, investigation, monitoring, drainage channel.

1 INTRODUCTION

The NPMC Mining Project is an open pit polymetallic tungsten mine located in Thai Nguyen Province, approximately 80 km north of Hanoi, in northern Vietnam. The open pit mine has total estimated ore reserves of 55.7 Mt and a planned mine life of 17 years. The economic mineralization consists of oxide hosted minerals of tungsten and fluorspar with sulphide hosted minerals of bismuth and copper currently also being recovered.

The Nui Phao Mine Company (NPMC) Tailings Storage Facility (TSF) (Fig. 1) consists of two contiguous cells, namely, the Sulphide Tailings Cell (STC) and the Oxide Tailings Cell (OTC) constructed as a typical valley impoundment. The STC is located upstream of the OTC impoundment which in turn is immediately upstream and adjacent of the community's land. The two cells are separated internally by an engineered embankment, named the STC embankment. Sub-aqueous tailings disposal is used for the deposition of sulphide bearing tailings into the STC. This deposition technique has the advantage of minimizing the entrainment of air/oxygen which in turn minimizes oxidation of sulphides thus reducing Acid Mine Drainage (ARD) from occurring. The OTC has conventional aerial deposition of oxide tailings due to their low sulphide content, and does not generate ARD. A typical cross-section

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Figure 1: NPMC tailings storage facilities (TSF).

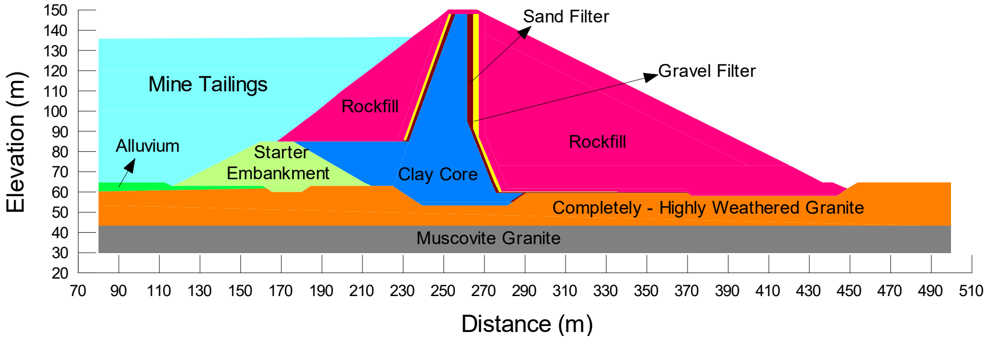

Figure 2: Typical cross-section of OTC main embankment.

of the embankments is presented in Fig. 2. Construction of the combined TSF commenced in September 2011 i.e. 18 months before the commissioning of the process plant and continues to be constructed in a staged fashion to ensure that there is typically 12–36 months of tailings storage capacity, in both the STC and the OTC. The commissioning of both cells in the TSF started in the first quarter of 2013 with the commissioning of the NPMC process plant.

2 SEEPAGE HISTORY

Community concerns were first raised in relation to rising groundwater levels at the end of the wet season (April–October) in the north-east boundary area of the TSF in October 2015. The concerns reported were about surface seepage and flows not seen previously. During 2015, the water level within the OTC operating pond was at approximately 83 mRL. The elevation of the community paddy fields adjacent to the TSF boundary area range from 60–54 mRL. At this time some areas within the community lands witnessed water "boils" in natural ground, and other surface expressions. As a temporary measure an open channel drain system was installed in the garden of the households at the lowest elevation (Fig. 3).

The flow rates observed in these drains ranged from 2–3 L/s. The drains were excavated to approximately 1 m in depth. However, there was still community concerns regarding the impact on their wells and concern that the well water might not be suitable for general use.

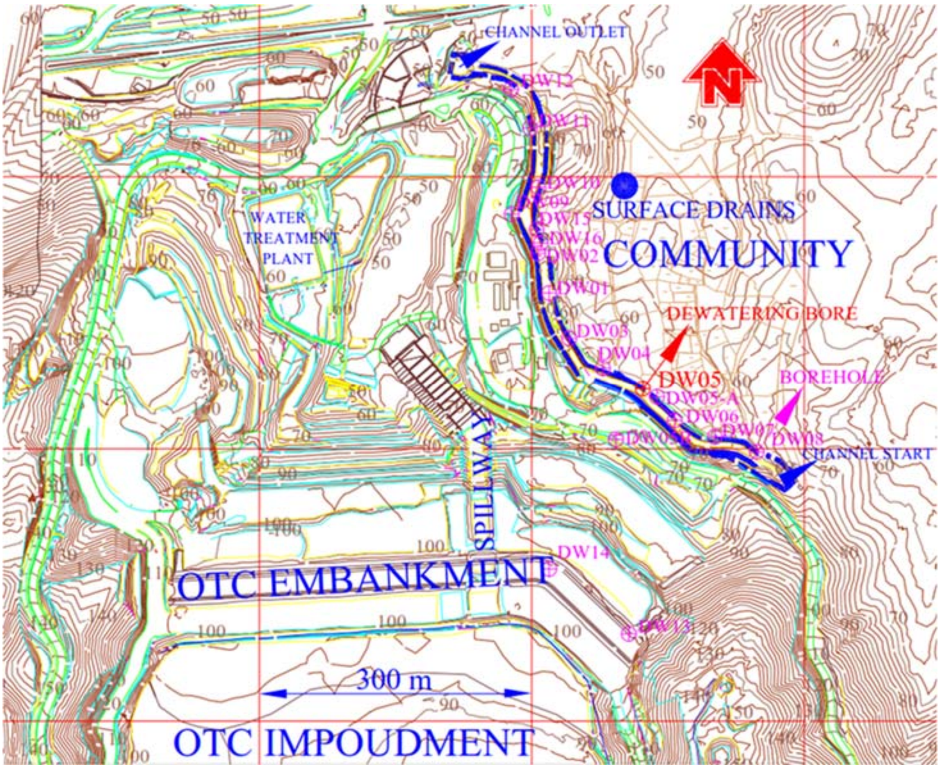

Figure 3: Location map of boreholes and drainage cut of trench.

As a precautionary measure NPMC responded by supplying drinking water to the villagers. From a risk review conducted NPMC determined there was potential for this near surface seepage to negatively affect the community's general forage and cropping vegetation and would need to be further studied to determine the actual cause of the seepage. NPMC considered this issue as a risk to the mine's on-going social license to operate, and that works should be undertaken to remedy the symptoms whilst the root cause of the problem was studied.

3 HISTORICAL ARTISNAL MINING

The small-scale tin mineralization veining present in the area has been subject to extensive artisanal underground working. Anecdotally this has been occurring for approximately the last four decades. NPMC commencing site clearing activities in 2011 at the TSF area, the works also exposed a number of historical artisanal tin mining shafts and vents within the footprint of the planned TSF embankments, and in the downstream area adjacent to the community. The actual extent of the mining activities and the degree to which they are interlinked within the hillside were not known. Historic mining was suspected to direct the groundwater flows to the east (i.e. towards the community) rather than on both sides of the ridge, which in turn has caused the water table to rise in some of the community areas. As part of the initial study NPMC determined that the mine workings; locations and directions, should be further evaluated to assess their effects on the seepage occurring, and to help provide reliable data to allow long-term resolution of the issues.

4 SITE INVESTIGATION

In response to the community's concerns, NPMC also carried out a comprehensive seepage investigation for the TSF between 2015 and 2017. The assessment comprised of a detailed geological mapping, geophysical investigation and a drilling program.

The geological mapping demonstrated that the groundwater flow systems exist in fractured granite rocks, along micro-granite dikes and their contacts which are mainly represented by muscovite-biotite and biotite granites, granodiorites and their frequent microgranular enclaves (Frequent microgranular enclaves have a few bigger feldspar and quartz phenocryst than the host). Additionally, the historic mine workings could create preferential groundwater flow paths towards the community settlement area.

Electrical resistivity imaging (ERI), ground penetrating radar (GPR) and seismic refraction (SRF) profiles were repeated over three lines at locations in the boundary ate downstream of the OTC. Initially is was expected that jointly interpreting the three data sets would give a more reliable and less ambiguous interpretation than analyzing any single data set. However, it was not technically capable to delineate significant structures of water bearing jointly or separately.

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A line of 16 bores were then installed along the downstream of the property boundary adjacent to community area (Fig. 3). The bore holes were drilled down until the drill intersected intact bedrock. As a result, hole depths range from 30–60 m. During this first drilling campaign there were only two bores, namely DW05 and DW05B that intercepted water. Pumping tests were carried out on these two bores and indicated flows of about 2 L/s in DW05B and 5 L/s in DW05. The flows and groundwater levels measured during pumping proved the two bores are hydraulically connected and share the same source. The DW05 hole was developed as a dewatering bore with well screen through the fractured granite zone located at depths from 9–24 m. The bore is currently being pumped at 5 L/s for supplying domestic water, after chemical analysis determined suitability, for use in the contractor's campsite. The other bores were retained for groundwater level and water quality monitoring. The thickness of the unconfined aquifer was inferred to vary from 1–8 m and a hydraulic conductivity of 3 x 10-4 m/s was estimated.

5 GROUNDWATER MONITORING

The NPMC operating license requires that monitoring bores be sampled monthly or higher frequency with the water being subject to a full range of chemical analysis and the standing water level recorded. License limits to date demonstrate that all monitoring bores are in accordance with Vietnamese Standards [1]. Comparison of the results with the baseline values provides an early indication of seepage which may occur and allows implementation of further investigation and assessment of any potential impact on the environment. If necessary, appropriate actions can then be undertaken to recover the seepage to the extent that is practicable or necessary to limit any negative environmental impact. Where no negative impact is recorded then the waters can be discharged as part of the overall licensing and water management plan.

From the data collected to date the water table generally fluctuates seasonally and annually in response to changes in the groundwater recharge from both precipitation and percolation from surface-water bodies. Seasonal variations of some 3.5 m occurred in 2015 due to significant rainfall events during the wet season. The depth from ground surface to the water table also varied with time and location. At the downstream of OTC, it was observed to be near the land surface with depth ranging from 1.0–5.0 m. Monitoring bores typically exhibited more pronounced responses to rainfall when the preceding 3-day precipitation amount is greater than 50 mm. The true static (non-disturbed) groundwater levels can be deduced by removing the upper fluctuations of the water levels due to rainfall recharge during wet seasons. The monitoring showed an increase in ground water levels from March 2015 to March 2016 (i.e. dry seasons) by about 2.0 m to RL 57.8 m.

The water chemical tests indicated the sulphate levels have gradually increased since May 2015 and exceedance of the standard limit was apparent at DW05.

6 SEEPAGE AND SOLOUTE TRANSPORT MODELLING

NPMC decided to develop a transient seepage and contaminant transport model to assist the understanding the groundwater flows and the migration of sulphate species. The water levels in the OTC impoundment were assumed for February 2017, i.e. when the modelling using a finite difference code VS2DTI was undertaken, and modelled through to ultimate embankment height at the end of the mine. Three sections were selected for the modelling work as shown in Fig. 4.

The results of the analysis modelled indicated that the groundwater could be lowered to historic levels by simply constructing a cut off channel at 52 m RL. The drainage channel solute transport model also predicted the sulphate concentration on the community ground surface would be reduced and would meet the statutory limit of 0.4 g/L.

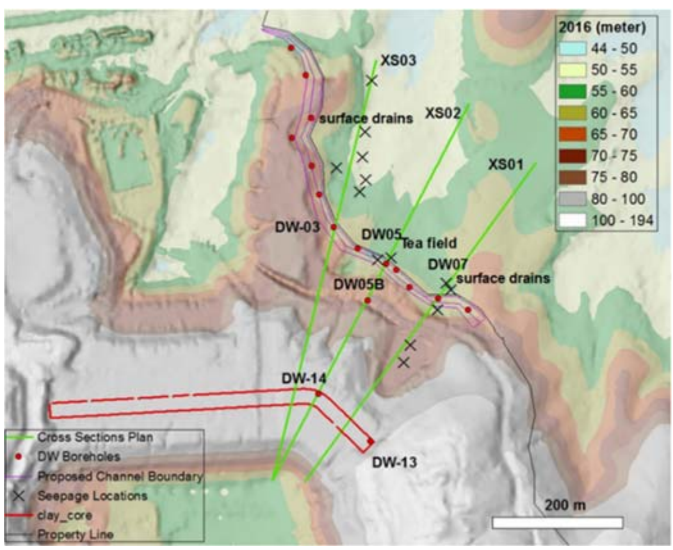

Figure 4: Observed seepage and modelling sections.

7 DESIGN AND CONSTRUCTION OF DRAINAGE

As a temporary measure dewatering bore DW05 was utilized in conjunction with two surface water collection sumps with pumps that were located at a low point adjacent the TSF access road for 2 years (i.e. 2015–2017). These facilities appeared to successfully dewater 80% of the seepage areas in the community. However, there were still water “boils” at two locations – at the community house at the lowest elevation. As the constant operation of the dewatering pumps required substantial labour attention and maintenance, additional options and studies were undertaken to determine a permanent long-term resolution of the issue. The studies undertook physical and economic evaluations including the following concepts:

- Resettlement of directly affected households;
- Resettlement of households who lodged claims (3 times the number of households who were directly affected);
- A dewatering bore field (even though only 2 bores had previously contacted water and were not successful in lowering of groundwater levels);
- A collection sump with pump located at the old tin mine, northwest of the community. The probability of success for this option was ranked low as NPMC had concerns about this site given it is heavily contaminated due to large mineralized waste dumps from the historic artisanal workings; and
- A drainage cut-off trench (COT).

The COT was determined to be the most preferred option considering a range of metrics; on-going cost, achieving community satisfaction, meeting environmental requirements, degree of difficulty in execution, and most importantly the overall likelihood of successfully mitigating the issue. The risks associated with the development of the channel were foreseen as follows:

- The potential slope instability of the COT channel which in some steep sections would require local stabilizations;
- The potential for excessively lowered water levels in the community area. This might require a flow control gate downstream of the COT channel; and
- The quality of the water before being discharged off-site. This could require water to be pumped back to the OTC impoundment or treatment through the NPMC waste water treatment plant (WWTP) prior to final discharge.

NPMC established an integrated project team comprising geotechnical, hydrology, environmental and hydro-geology disciplines to design the COT. Physically the COT starts from south east of the OTC embankment and discharges water at the outlet in the north west, next to the lease boundary (Figs 3 and 4). The location of the COT extends over gently undulating terrain and within the confined space of the boundary area between the TSF and the community, posing significant construction challenges. The COT floor was proposed to be excavated down to RL 53-52 (Figs 5 and 6), i.e. with the minimum depth as indicated in the groundwater modelling. This elevation is about 1 m below the lowest water level encountered in the community. The COT maximum depth is approximately 20 m, bench height of 10 m, inter-bench slope 60 degrees, overall slope of about 53 degrees and design base 3 m wide. Some parts of the drainage channel have been stabilized by backfilling with bulk rock waste rock that does not exhibit and ARD potential (non-acid generating (NAG)). A pump station is currently being constructed at the COT outlet. The pump station will allow water to be transferred first to the sump in the pit for a preliminary treatment then will be processed via the site water treatment plant before being discharged to the environment.

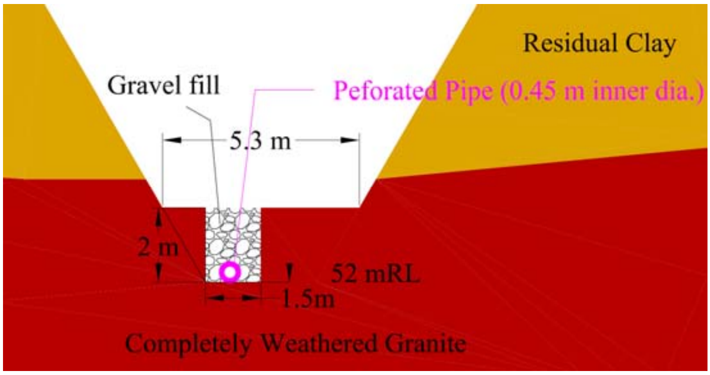

Figure 5: Bottom drainage in the channel.

Figure 6: COT construction in progress (March 2018).

Due to deteriorating condition of COT walls greater than 8 meters in height and space limitations (property boundary, agriculture, and surface infrastructure) when excavated down to the bottom of the COT, the COT design was modified to include a buried drainage system in the base of the COT. This modification to include a buried drainage system allowed the equipment to work at higher elevations with wider working widths and reduced the ground disturbance at the toe of the cut slope. The buried drain collects seepage water into a corrugated-perforated HDPE pipe and transports water to the pump station. (Fig. 5). The corrugated-perforated HDPE pipe was supplied with "easy-fix" male and female ends. This offered quick, easy and safe constructability which provided time and cost advantages over conventional over rolled steel corrugated pipe, or concrete culverts. Since the corrugated-perforated HDPE pipe is flexible, it can accommodate the contours of the ground, direction changes and adapt to underground obstacles more easily than rigid pipe. The pipe is available in 6 m lengths and 450 mm inner diameter. Final trench cutting (1.5 m wide and 2 m deep) followed by pipe laying and then post filling with cobbles was performed progressively in 6 m sections to minimize the linear extent of the potential slope slumping during the final and deepest cut of the trench to the design base.

8 INITIAL OBSERVATIONS

The construction started from 15 December 2017 and by the time of writing this article (i.e. April 2018) 477 m of drainage pipes have been installed. While the project has not been completed (Fig. 6) to the total design target of 500 m pipe, the surface and community ground water issues have been successfully resolved (Figs 8, 9). The drainage trench has certainly helped the situation and it is expected to achieve full functional goal when the drainage system is scheduled to be accomplished by the end of June 2018.

As predicted from the modelling, the seepage was observed running along microgranite dikes and their contacts distributed throughout the both sides of the excavation (i.e. the community side and the mine site). Some mine workings were encountered at higher elevations and dry; however, one exception was encountered near the middle of the channel at 52 mRL (Fig. 7). The flow in this artisanal working was estimated to be steady over 24 hours and in order of 3 L/s. This historic tunnel was later backfilled with gravel and rockfill (i.e. free draining).

Figure 7: Water coming from old mine working during COT construction (February 2018).

Figure 8: Community land area (wet) before COT construction (March 2017).

Figure 9: Community land area (dry) after drainage construction (March 2018).

9 LONG-TERM MONITORING

Ongoing testing and monitoring of supernatant pond and seepage water samples from TSF during operation is needed to verify control methods and TSF geochemical stability. The 2-year data was gathered and utilized to assess the effectiveness of the drainage channel.

The groundwater levels started showing the achievement of the dewatering when the construction was about to be completed (Fig. 10). The acidity (pH) generally varied within the limits set in the Vietnamese Standard (i.e. in the range from 5.5–8.5) [1]. The total dissolved solids (TDS) were high in OTC (3–4 g/L) but within the specifications for groundwater with 1 g/L in community area and 1.5 g/L in the dewatering bore DW05 over the 2-year period. The bi-weekly to weekly chemical test results have indicated a minor

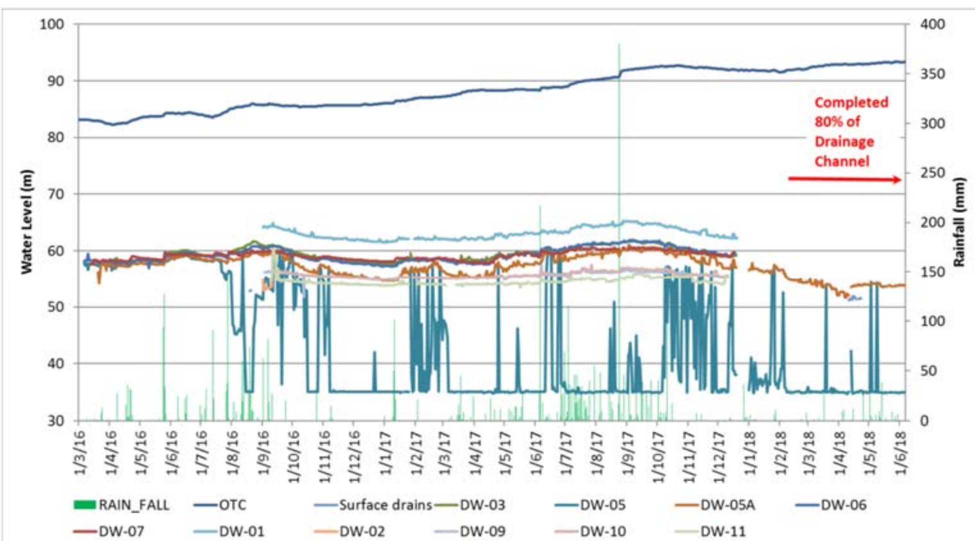

Figure 10: Groundwater level monitoring.

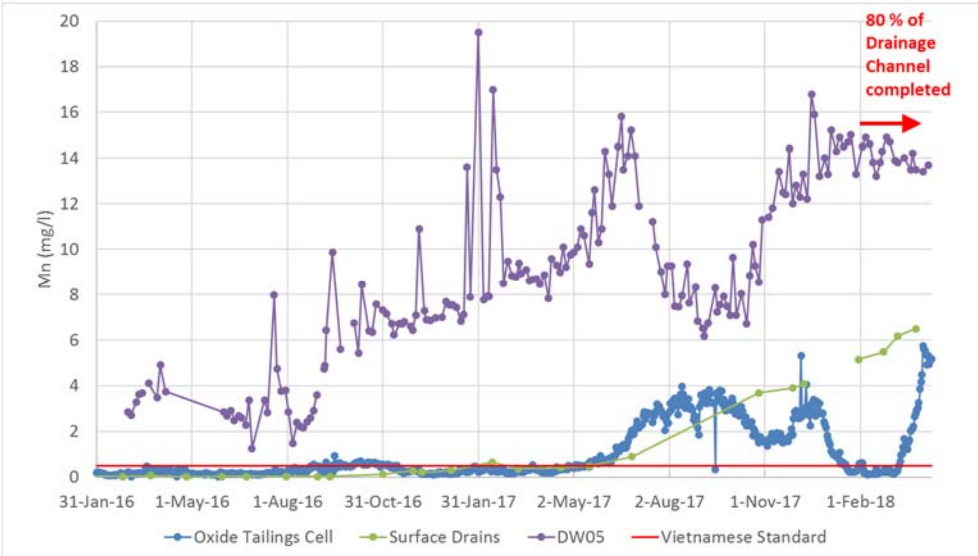

Figure 11: Manganese monitoring.

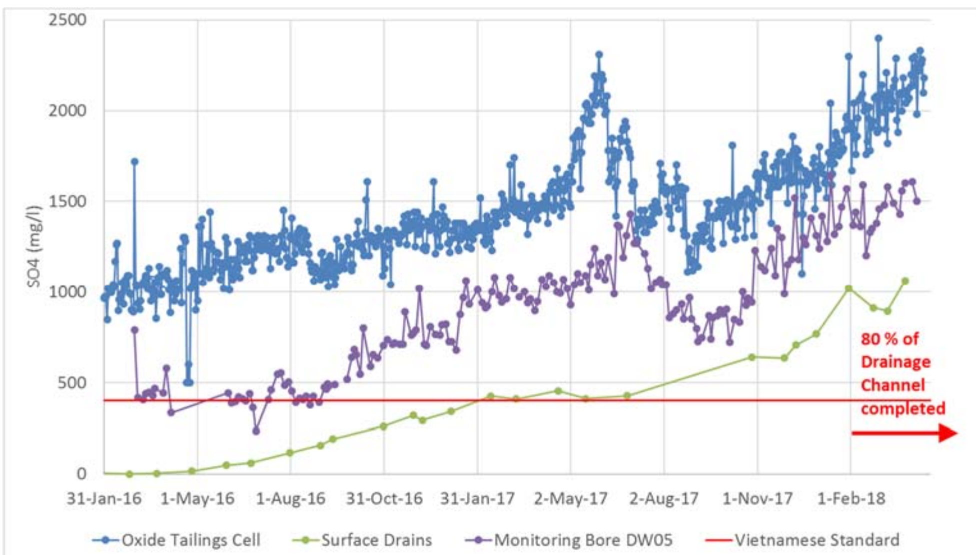

Figure 12: Sulphate monitoring.

change in manganese and sulphate (Figs 11, 12) since the construction of the drainage trench. It is expected these elements will be diluted by rainfall recharge to the groundwater and show some improvement after 2018 wet season. The improvement is expected to result from the high rainfall during the coming wet season to gradually dilute the groundwater through recharging and bringing the chemistry back to levels similar to prior to the commissioning of

NPMC TSFs. The site is characterized with mean annual rainfall of approximately 2000 mm and wet season (i.e. April–October) accounting for 80% of yearly rain. The long-term monitoring will continue and will be operative to assist the updates to the closure planning of the mine.

10 CONCLUSIONS

The studies, design and construction of the NPMC TSF drainage has been well prepared and planned with considerable technical effort across multiple Departments at NPMC. The investigation and design analysis assisted effectively the design to propose appropriate methodology and proper channel elevation. The outcome of this project has successfully resolved the water issues being encountered by the community and is concrete example of the way in which NPMC demonstrates its responsiveness to resolve the concerns validly raised by community members. The extensive TSF investigation and on-going monitoring is to guarantee mitigation of unexpected minor impacts from the operation and ensure cost-effective models are developed to assist with future closure planning activities.

This paper presents a successful solution to seepage water management of the NPMC TSF with focus on long-term physical and geo-hydrological stability. The COT is expected to not only resolve the current community's water issue but also to allow NPMC to achieve "walk-away" conditions that assure physical, hydrological and chemical stability of the site without the need of long-term monitoring and maintenance post mine closure. This approach is consistent with the core values of NPMC as well as showcasing the motivation and ability of NPMC's management and engineers to quickly deal with operational impacts and come up with resolutions that avoid passing the burden of today's resource extraction to future generations.

One of the key learnings form this issue is that civil works and control systems for TSFs should be designed in the pilot stages of mining projects with conservative criteria and robust structures, with consideration of post closure (in-perpetuity) requirements.

ACKNOWLEDGEMENTS

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