Closure Planning on a Large Scale – Approach to Optimising PFS Closure Designs for the Western and Central Development Areas at a site in Central Laos

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Abstract

Closure plans for an extensive mine site located in central Laos are currently being developed. The mining area includes more than 40 pits, some of which have been backfilled, and 13 waste rock dumps.

In support of the development of the closure strategy, technical studies have been completed which included development of a site-wide water and load balance, assessment of the geotechnical stability of pit walls and dumps, and geochemical characterisation to understand the distribution of ongoing sources of solute production around the site. Specific issues associated with the site include proximity of local communities and accessibility of the site, stability of the pit high walls and exposure of acid forming rock on the high walls, positive water balances for the pit lakes and the large distance across which the site is spread.

Future water quality predictions were combined with the site-wide water balance to develop an integrated closure strategy for the site, identifying optimal closure measures to mitigate water quality impacts to downstream receptors (drinking water resources) and ensure public safety. Conceptual closure designs for WRDs and pits were developed incorporating both passive and active water management infrastructure. Two companion papers describe the development of the water balance and the water quality predictions. This paper presents the practical implications of the outcomes and the overall closure strategy that was developed for the site.

Keywords: mine closure planning, integrated strategy, closure measures

Introduction

The open cut gold and copper mining operation located in central Laos comprises several gold and copper open pits, with the gold operation currently in care and maintenance. Figure 1 shows the site layout, comprising open pits, waste rock dumps, and water management structures, and the proximity of human habitation to the site.

For the purposes of closure planning, the operations have been separated into three distinct areas, based on geographical location and operational status. The current assessment primarily deals with the Western and Central Development Areas which comprise a series of open pits and waste rock dumps for both copper and gold operations that fall primarily west of the main river that passes through the site. The other two areas comprise the tailing storage facilities (TSF) and a copper open pit operation that includes the process plant and other infrastructure.

Key closure challenges at the site included human habitation and farming lands located in close proximity to the mining operations, which increase the potential risks to human health and safety post closure. Other challenges at the site include i) the large number of pits and dumps to be managed, which drain to two separate major catchments (towards the west and the east respectively), with potential for localised impacts and more distant impacts, ii) the high rainfall environment, iii) the risks of acid mine drainage (AMD), iv) steep terrain that contributes to geotechnical risks, and v) physical stability of pit high walls and other landforms. Whilst water quality is currently being managed through active treatment, groundwater quality impacts have been detected downstream of the operations.

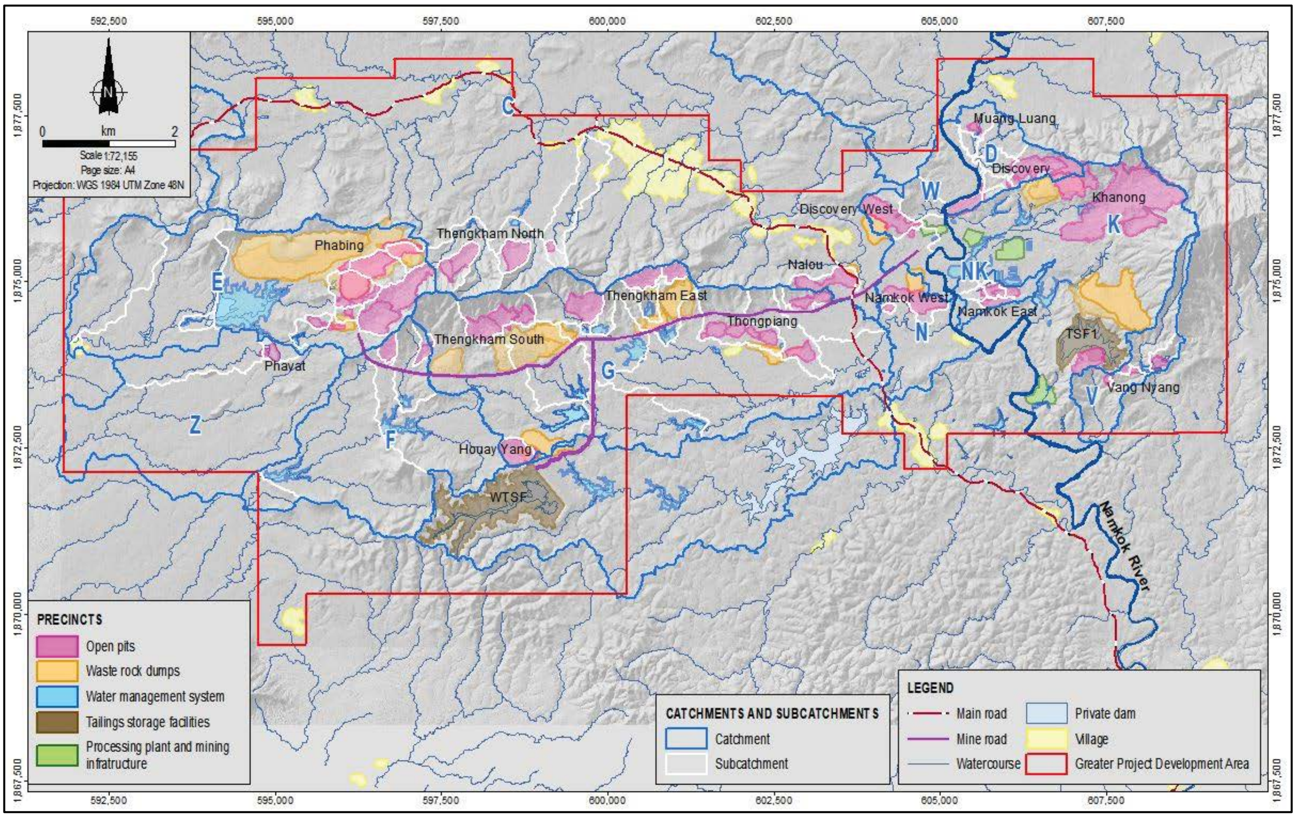

Figure 1: General layout and catchment delineation for the mine site showing primary receptors and proximity of human habitation.

Closure objectives

Closure objectives can be structured in a range of ways. Generally, high level objectives for the overall closure plan are set first, and then more detailed objectives are established for each area. The high-level objectives should address the major requirements, commitments and risks, and should be clear to designers and stakeholders. The objectives should also be cognisant of the completion criteria (i.e. can they be achieved within reason) and whether they will achieve an acceptable outcome to all stakeholders, be compliant with legal requirements and specific obligations.

More detailed closure objectives and completion criteria focus on specific closure measures that are generally more technical in nature, and, by necessity, they can only be fully defined after the closure designs have been developed. However, even at the pre-feasibility stage of closure planning, it is useful to define preliminary "completion criteria" to ensure that they can reasonably be achievable. These criteria that can be further developed as design details emerge. Two types of completion criteria are generally identified as follows: 1) Criteria related to construction (i.e. has construction been completed to specification, generally referred to as leading indicators), and 2) Criteria related to outcomes (i.e. has the closure measure met the design performance criteria, generally referred to as lagging indicators).

Both are required to measure performance and evaluate closure. Construction-related criteria generally are defined in detailed engineering design and addressed through QA/QC procedures. Outcome-based completion criteria are developed as the closure design progresses, and through consultation with local regulators or stakeholders. Table 1 summarises some relevant closure objective and preliminary closure criteria for the site.

Specific criteria (e.g. or discharge water quality) were based on local regulatory requirements, or where these do not exist or are not considered sufficiently protective, were based on international standards.

Overall approach

An initial risk assessment was undertaken that identified the major risks and key areas that would need to be addressed by the closure strategy. As noted above, water quality impacts and geotechnical stability issues were identified as major risk areas. To address the water quality impacts, an integrated model of the surface and groundwater balances for the area, combined with estimation of solute loadings from potential contaminant sources, was developed. This integrated approach allowed identification of mine precincts that represented significant contaminant sources and enabled ranking of the sources based on overall impacts. Closure designs were then prioritised toward mitigation of contaminant release from the highest ranking sources, which allowed optimisation of the overall site closure strategy. The overall process for evaluating and developing the closure strategy is illustrated in Figure 2.

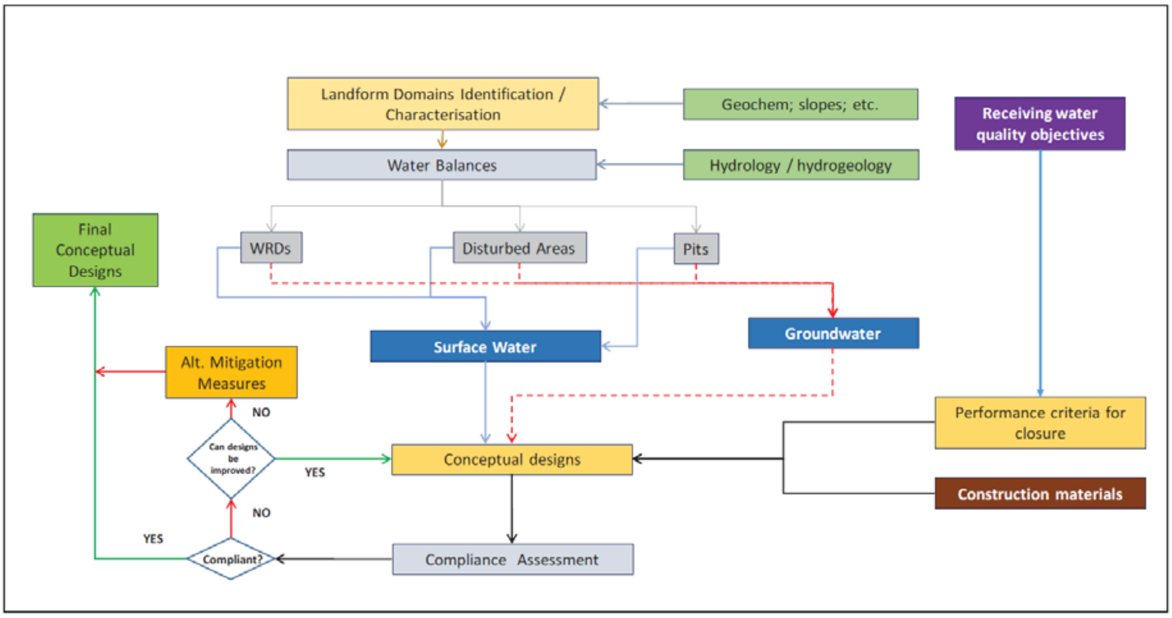

Figure 2: Overall approach for developing closure plan.

Table 1: Closure objectives and preliminary completion criteria.

No	Closure Objective	Draft Completion Criteria
1	The site must be rendered safe to humans, domestic livestock and wildlife.	Final landforms constructed to design specifications. Identify hazards and Install appropriate signage on site access routes and pit locations. Community education.
2	The residual landforms are to be physically stable.	Stability analysis and inspection. Landforms are non-eroding.
3	The site must be rendered geochemically stable (i.e. non-polluting).	Surface water diversion drainage control measures are installed and meet design criteria. Surface water quality achieves the appropriate water quality criteria as determined at closure. Groundwater water quality achieves the appropriate water quality criteria as determined at closure. Water treatment meets discharge limits.
4	The closed site must be able to sustain an agreed post-mining land use.	Rehabilitated areas meet the agreed end land use, and these areas can be managed without significant external inputs and ongoing management. Species used for revegetation are capable of setting viable seed and recolonising disturbed areas. Vegetation is resilient and self-sustaining without additional inputs.
5	Project benefits contribute to sustainable economic and social development beyond mine life.	Meet the agreed end land use, which provide opportunities for local communities to maintain their sustainable livelihood.

In support of this approach, a number of supporting studies were completed. The key studies were as follows:

- Geotechnical assessment of pit slope and landform stability
- Geochemical assessment to examine the distribution of reactive materials and ongoing sources of solute production around the site, the subject of a companion paper (Linklater et al. 2018).
- Hydrological assessment with detailed delineation of water catchments within the project area, and the development of a closure water balance model, and the subject of another companion paper (Luinstra et al. 2018).

The outcomes of these studies were then used to identify and evaluate various closure and mitigation options, and to support the selection of specific closure measures for the development of the integrated closure strategy, as discussed below.

Evaluation and selection of closure options

Mine plans and designs included operational controls to both manage waste rock (with the intent to encapsulate acid generating waste rock) and water at the site, with the objective of meeting closure designs. These designs were implemented with varying degrees of success. Similarly, whilst the control measures for the placement of acid waste rock were identified, these were not always successfully implemented, as identified during site visits. Another complicating factor that became apparent was that due to variations to the mine plan, not all the pits were mined to completion which meant that some of the waste rock dumps were not constructed as per final designs. Furthermore, whilst low lying pits in some instances were backfilled, the sidehill pits generally resulted in the exposure of acid generating wall rocks, which, considering the steep terrain, were expected to be ongoing sources of contaminants in the longer term.

To develop the closure strategy, the mining areas were divided into key precincts based on the catchments and downstream receptors. Then, based on the constraints and observations identified above, key risks and concerns were identified. Based on these risks, potential closure options were identified and evaluated against the closure objectives and completion criteria. A spreadsheet-based collation of all these aspects was produced to allow comparison of different locations across the site, and filtering according to selected attributes.

Open pits

The options analysis for the final pits (based on Life of Mine plans) were completed based on the site water and load balance (Linklater et al. 2018; Luinstra et al. 2018) and the geotechnical evaluation linked to the understanding of the following criteria (where available):

- AMD runoff from pit walls, including poor quality pit lake discharges (to ground water and surface water);
- Stability and access, unstable walls;
- Unstable waste dumps within pit footprint, including AMD drainage from waste dumps or backfill;
- Backfill slumping; and,
- Proximity to sensitive sites / receptors.

For most precincts, do nothing was eliminated as an option since stability (highwalls) and water quality issues (AMD) were identified for most pits, with the exception of some of the low lying gold deposit pits and pits that have been backfilled.

As identified in the risk assessment and supported by the water quality predictions, AMD from the pit walls is a long term risk with significant consequences. Based on flow volumes and water quality observed and predicted), passive treatment options were eliminated as they would not be expected to be effective nor meet discharge water quality criteria. Active water treatment was therefore identified as a prerequisite to meet post closure objectives.

In all cases some measure is required to limit or prevent public access to pit high walls, where a risk of instability has been identified.

Waste rock dumps

The waste rock dumps, based on life of mine landforms shapes and construction to design specification (except for waste rock dumps already completed that are not to design specification) were evaluated based on an understanding of the following criteria:

- AMD potential based on NAF/PAF material distribution
- Physical stability of Slopes / Profiling
- Surrounding land use
- Drainage / upstream catchment
- Rehabilitation to date
- Erosion
- Constraint to Earthworks
- Proposed end Land Use

Stability analyses indicated that measures to address slope stability were not required for most landforms. Whilst the design criteria indicated that acid mine drainage would be limited for many of the waste rock dumps, some landforms that have not been constructed to specification would however require mitigation. For these dumps, a conceptual hybrid type barrier type cover was selected to reduce infiltration and control solute releases.

The high rainfall environment at the site indicated that erosion of the waste rock dumps is likely to be a significant risk to the long term stability of the landforms. In some cases, re-sloping would further reduce the risk of erosion and should be adopted where feasible. In some instances, cutting and filling (for re-sloping) of the NAF outer layer may compromise the thickness of the NAF layer (as per design) and so should only be considered where this was not a significant risk. Revegetation was selected for all locations where vegetation had been poorly established on the waste rock dumps.

Clean water diversions were also identified for most waste rock dumps to reduce run-on and overall risk of erosion by crest overtopping.

Fencing, as noted for the open pits, is not considered a feasible method to limit public access as fences are likely to be removed by the local population.

Sediment dams

The options considered for sediment structures included refurbishment or enhancement to support aquaculture and/or sources of freshwater supply. However, most of the sediment ponds rely on decant structures or spillways that are seated on the embankments or adjacent to the embankments, and as such will require active long term care and maintenance. In the event of failure most of the sediment ponds would represent a significant public safety risk and for this reason all structures not required for active water treatment and management would be breached and decommissioned.

Roads and infrastructure

Haul roads represent one of the largest sources of suspended solids release from the site; these roads also provide ready public access to the site, and since it is in the interest of public safety to discourage such access, all haul roads would be decommissioned and revegetated. Only service roads required to support active closure measures would remain.

Contingency strategies

As indicated by the water and load balance calculations, some areas may result in local water quality impacts. The following supplemental strategies would be considered:

- Alternate cover systems: Percolate and toe seepage from the waste rock dumps that may not have been constructed to design may be an ongoing source of solute that could cause exceedances of receiving water quality objectives. Should this prove to be the case, the effectiveness of the NAF cover will be assessed to determine net infiltration and oxygen ingress. The need for a revised cover system will be assessed, and if it is shown that an improved cover will mitigate these impacts, the revised cover will be constructed as a first contingency.
- Seepage interception: If the cover is shown to be unlikely to mitigate observed impacts, toe seepage and groundwater interception will be implemented as an alternate contingency. Interception wells will be established along the toe of the waste rock dump and contaminated water will be pumped and treated at the local water treatment facility.

Ongoing monitoring and assessment may also identify a requirement for additional contingency strategies, including strategies to mitigate groundwater sources. Mitigation measures that may apply could include the installation of interception wells for collection and treatment of flows, or, where groundwater is used for drinking water supply, sourcing drinking water from elsewhere.

Conclusions

Key to development of the mine closure strategy was the development of an integrated water and load balance to assess the potential impacts on the receiving environment, identify suitable closure measures and to assess their individual and combined effectiveness and ensure a cost-effective outcome acceptable for the site as a whole. As illustrated in Figure 2, development of the integrated closure strategy requires a number of key steps to be followed:

- Assess the ‘do nothing’ case to determine if objectives will be met
- Where objectives were not met, identify mitigation options
- Assess options to select the preferred approach in the context of the broader site strategy.

These steps require a number of site specific studies to first identify and quantify the potential risks that need to be addressed post closure, and then to evaluate and support the selection of the mitigation measures to reduce potential impacts to acceptable levels.

Another important step to facilitate the overall closure process is the development of measures that can be implemented during operations to integrate the closure strategy into the remaining operational life.

As indicated in the current assessment, the assessment of water quality impacts from the waste rock dumps and pit walls clearly identified the key sources that may lead to downstream impacts. This focussed the development of the closure strategy on identifying measures to reduce the most significant sources at site. Specifically, closure measures should seek to limit the volume of water contacting waste or pit walls, and allow contact water to be collected efficiently.

Potential mitigation methods include:

- Improving covers on dumps that have not been constructed to design
- Installing diversions to minimise the contact of water with waste dumps or pit walls
- Constructing centralised active water treatment with sludge disposal in adjacent pit lakes.

The geotechnical conditions indicated potential instability in some pit walls and waste dumps. However, full stabilisation will be costly and, in some cases, create significant additional disturbance and safety risk. Therefore, it will be necessary to stabilise pit walls and waste dumps only where the instability represents a risk to people, and where the stabilisation can be accomplished without additional safety risk. Specifics vary from area to area, but in general this means:

- Stabilizing pit walls where failure could cause release of large volumes of contaminated water or directly impact areas used or traversed by people
- Stabilise waste dumps as part of closure re-sloping.

Safety is likely to be an issue in stabilisation of high pit walls, and will need to be assessed in a later stage of design. For this PFS-level planning, it has been assumed that safety concerns will not limit pit wall or waste dump stabilisation.

References

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