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A case for consequence categories to guide the closure design of landforms

P Chapman *Golder Associates Pty Ltd, Australia*

A Kemp *Golder Associates Pty Ltd, Australia*

Abstract

The legacy of many mine sites is that landforms will, in general, remain in perpetuity. Two of the key landforms are waste rock dump facilities (WRDF) and tailings storage facilities (TSFs), both of which typically require robust investigation and design as part of closure planning, followed by in depth engineering and environmental oversight during design, implementation and monitoring. However, in contrast to TSF design, few of the closure guidelines and standards provide clear direction on the level of rigour that closure practitioners, regulators and site owners should adopt during the closure planning process.

One aspect of the TSF design process that supports identification of an appropriate level of rigour during the planning process is assignment of consequence categories. This has become an integral part of the design process, providing direction on the design criteria that should be adopted. A candidate system for assigning consequence categories to landform closure planning projects is presented, along with candidate criteria/design requirements that could be considered for each category. Three examples of how the consequence category system could be applied are also provided.

Keywords: *consequences, risk, landform closure, design, tailings, TSF, WRDF, closure*

1 Introduction

For the majority of mine sites, the legacy will be a series of landforms, and possibly an open pit, that will remain in perpetuity. These landforms, which typically comprise tailings storage facilities (TSFs) and waste rock dump facilities (WRDF), can represent an ongoing liability to the mine site owner until relinquishment can be achieved. As part of the closure planning process, these landforms are often the focus due to their size, prominence on the landscape, and potential risks they pose. Indeed, the majority of long-term risks, and often more than 50% of closure costs, can be associated with these landforms. Poor understanding of waste material characteristics, landform design and construction often lead to acid and metalliferous drainage release to surface and groundwater, as well as surface erosion and exposure of elements of concern (Kemp & Olds 2017). Hence, there is a requirement for robust investigation and design as part of closure planning, followed by in depth engineering and environmental oversight during design, implementation and monitoring.

One aspect of the TSF design process that supports identification of an appropriate level of rigour during the planning process is assignment of consequence categories. This has become an integral part of the design process, providing direction on the design criteria that should be adopted. A candidate system for assigning consequence categories to landform closure planning is presented in this paper, along with candidate criteria (design loadings) that are proposed to be applied for each category during the design process.

2 Design guidelines and risk assessment methods

There are various mine closure guidelines and handbooks across the globe with the recurring theme that closure planning should start during mine planning, continuing until after closure. Many of the closure guidelines provide a framework for undertaking the closure planning process but stop short of providing direction on the extent to which the studies should be undertaken. For example, the recently updated Leading Practice Sustainable Development Program for the Mining Industry Mine Closure handbook

(Department of Industry, Innovation and Science [DIIS] 2016) is a general reference that indicates that a risk-based process should be undertaken but does not specify what rainfall event the landform should be designed for, or the design earthquake. Similar, the closure guidelines published by the Western Australia (WA) Department of Mines and Petroleum (DMP, now the Department of Industry, Resources and Safety, and the Environmental Protection Authority (EPA) indicate that *'Closure planning should be risk-based, taking into account results of materials characterisation, data on the local environmental and climatic conditions, and consideration of potential impacts through contaminant pathways (including but not limited to site activities or infrastructure) and environmental receptors'* (DMP & EPA 2015), but do not specify what events (design loading) should be considered. The guideline built on the concepts from at least five leading practice references, capturing key elements of leading practice closure planning (Kemp & Olds 2017) without including design events. The WA guidelines do, however, suggest that where modelling is used to predict long-term environmental impacts, the models should extend to 300 years or longer.

While some guidance is provided on the risk-based tools that can be used, it is not prescriptive. As such, qualitative risk tools are often adopted with low probability events 'risked away' through the assignment of low likelihood categories (rare or very rare), rather than detailed modelling to support the long-term performance of the landform. Even if an event is unlikely or rare, when high consequences can potentially occur modelling is strongly recommended to provide an improved understanding of the risk, particularly in relation to potential mitigation measures to avoid or manage the consequences.

In some cases, qualitative risk assessment (QRA) processes are undertaken but these appear to be far less commonly adopted in the authors' experience. A QRA provides a much more robust approach, drawing upon the technique of fault-event analysis to systematically combine potential faults that could result in the unwanted event (failure) occurring, and to evaluate the possible consequences of such failure. The process generally is as follows:

- Hazards (e.g. seepage, high precipitation, earthquakes) and mechanisms that could potentially result in failure of the system are identified.
- The 'causes' (failure mechanisms) are derived from the identified hazards and an understanding of the closure design, as well as from other similar examples elsewhere ('causes' include slope failure, large-scale erosion, overtopping etc.).
- The causes are logically combined through inter-linked 'AND' gates and 'OR' gates, which are used if the causes are statistically dependent or independent of each other, respectively. The causes are progressively subdivided into their contributory components through subsidiary AND gates and OR gates, until it is possible to assign a probability to an individual component cause with reasonable confidence.

This structured risk assessment approach allows for the modelling of the effects of physical events on the system (e.g. extreme rainfall, earthquakes), as well as allowing for incorporation of human interactions and environmental impacts.

In contrast to the closure guidelines, the guidelines for designing TSFs, for example Australian National Committee on Large Dams (ANCOLD) (2012) and Canadian Dam Association (CDA) (2013), provide much more specific direction on the design criteria to be adopted, which are linked to consequence categories. The fundamental principle of the consequence-based approach is that the design rigour is driven by the potential consequences of catastrophic failure, particularly in relation to loss of life and environmental damage. While this is similar to a risk-based approach, the requirement to consider specific criteria result in a reduction of the likelihood component of risk, through application of higher criteria for higher risk facilities. It should also be noted that guidelines such as ANCOLD (2012) and CDA (2013) still support a risk-based approach, but also strongly recommend that the specific criteria are applied.

By way of example, in the ANCOLD (2012) guidelines, the designer must consider the 'Severity Level', which is based on the potential consequences of a flow failure, including damage to infrastructure, business importance (to the owner), impact on public health, social dislocation, impact area, impact duration and impact on natural environment. Guidance is provided to the designer to enable them to select a level between 'Minor' and 'Catastrophic'. Once this is selected, the population at risk is considered, with the five categories ranging from <1 to >1,000. A combination of these values provides a 'consequence category', ranging from Very Low to Extreme (see Table 2 in ANCOLD (2012)).

Once a consequence category has been established, the design loads that must be considered can be identified. The main two design loads are the design storm (Tables 4 to 6 in ANCOLD (2012)) and the design earthquake (Table 7 in ANCOLD (2012)). For an 'extreme' consequence category, the 1 in 10,000, 72-hour design storm is indicated for retention, the probable maximum flood (PMF) for TSFs with a spillway and for the design earthquake, a 1 in 10,000 return period event is indicated.

3 Possible framework for assigning consequence categories for waste rock dump facilities

In order to develop the basis of a consequence category approach for closure design of waste landforms, the typical sources of high consequence need to be identified. It should also be recognised that 'failure' in the context of closed landforms is more likely to be chronic, rather than the acute failures that are more likely in the operational phase. With that in mind, the following areas are proposed as the 'key' drivers of potential adverse impacts:

- Geochemistry of the materials and the influence of this on the quality of runoff water and seepage.
- Exposed materials in landform, in terms of erosional stability (and as an input to geotechnical stability).
- Potential for wind erosion.

However, recent failures have highlighted the requirement to also assess geotechnical stability post-operations against operational stability. The same criteria will apply and are therefore not included here as it should be addressed as part of the facility geotechnical assessment, but for the closure situation.

Following the source-pathway-receptor model, the potential to impact surface water and groundwater is also a key component of closure planning.

A framework has been developed by blending these two areas (sources and receptors) to provide a basis for identifying a 'Closure Consequence Category' that would guide the level of rigour that should be applied, and the detail associated with the risk assessment. These are presented in Table 1. The outcome of the assessment will guide whether (and where) further work needs to be undertaken to assess/identify potential pathways and quantify the impacts.

Table 1 Closure consequence category aspects

Aspect	**Low potential (1 point)**	**Medium potential (2 points)**	**High potential (3 points)**
Geochemical classification	NAF	<10% of material is PAF	>10% of material is PAF
Presence of elements of concern (metals/metalloids)	Benign	Limited elements; Minor concern	Multiple elements; Major concern
Erosional stability of exposed materials	Durable	Moderate	Erodible/dispersive
Potential for wind erosion	Durable	Moderate	High
Potential impacts on surface water (via water erosion)	No downstream impact expected and no current users	Receptors exist and potential impacts expected but no current users	Impacts on existing receptors expected and downstream users present
Potential impacts on groundwater (via seepage)	No downstream impact expected and no current users	Receptors exist and potential impacts expected but no current users	Impacts on existing receptors expected and downstream users present

NAF – non-acid forming; PAF – potentially acid forming (site specific assessment recommended, including acid neutralising potential, where any PAF is present).

The proposed process is that a landform is assessed, before any mitigation measures are put in place, and scores assigned by aspect. For example, a landform with significant amounts of PAF materials and hazardous components (metals or metalloids) would receive three points for each of these aspects. The minimum score is six and the maximum score is 18. Depending on the score that results, the level of rigour proposed for the closure planning process would vary, with the following ranges proposed:

- 6 to <10 – LOW Closure Consequence Category.
- 10 to <14 – MEDIUM Closure Consequence Category.
- >14 – HIGH Closure Consequence Category.

Table 2 provides a proposed framework for the level of rigour, including the design loadings, type of risk assessment and suggested time frames for numerical modelling. Design life is not included and should be determined on a case by case risk basis and commensurate with modelling time frames.

Table 2 Closure design requirements by category

Category	Design earthquake	Design storm event#	Design wind speed	Risk assessment method	Modelling time frame
Low	OBE	1 in 1,000	1:100	Qualitative	>300 years
Medium	84th Percentile MCE	1 in 10,000	1:500	Qualitative or QRA	>500 years
High	MCE	PMF	1:1,000	QRA	>1,000 years

OBE – operating basis earthquake; MCE – maximum credible earthquake; #Critical duration event for conveyance, 72-hour event for retention; consider climate change; PMF – probable maximum flood; QRA – qualitative risk assessment.

In addition to the design requirements outlined in Table 2, it is also proposed that any aspect that receives a score of three should be understood in detail, either through investigation or modelling, to more confidently predict the performance of the proposed closure measure, regardless of the overall consequence category.

4 Worked examples

Three examples are provided to outline the proposed process.

The first example is a TSF that is raised upstream using tailings borrowed from the nearby beach. Laboratory testing indicates that the tailings are fine (in the order of 80% fines content; percent passing the 75 micron sieve), NAF, but with minor metals. There is a surface water receptor nearby, but the groundwater is hypersaline and hence is not considered a receptor. Based on this, the landform would be assigned 13 points, as follows:

- Geochemical classification – NAF = 1 point.
- Presence of elements of concern – Limited elements; Minor concern = 2 points.
- Erosional stability of exposed materials – Erodible tailings on outer slopes = 3 points.
- Potential for wind erosion – High by virtue of fine materials = 3 points.
- Potential impacts on surface water – Local receptors and users = 3 points.
- Potential impacts on groundwater – No receptor or users = 1 point.

This results in the landform being assigned a MEDIUM Closure Consequence Category, with the design requirements for this category as per Table 2. Moreover, each of the aspects that received three points – erosional stability, wind erosion and surface water – would need numerical modelling to inform the mitigation measures required to manage the risks.

The second example is a WRDF that contains more than 10% PAF materials, but with only minor elements of concern. However, the rock is durable and there are no surface water or groundwater receptors or users nearby. Based on this, the landform would be assigned nine points, as follows:

- Geochemical classification – PAF >10% = 3 points.
- Presence of elements of concern – Limited elements; Minor concern = 2 points.
- Erosional stability of exposed materials – Durable rock = 1 point.
- Potential for wind erosion – Low = 1 point.
- Potential impacts on surface water – No receptor or users = 1 point.
- Potential impacts on groundwater – No receptor or users = 1 point.

This results in the landform being assigned a LOW Closure Consequence Category, although it is noted that there should be a focus on geochemistry in the design. While there is a potential source (the PAF rock), there are no receptors and the durable waste rock will prevent erosion (transport) of the materials. A detailed understanding of the location and extent of the PAF would, however, be required.

The third example is a TSF that contains some PAF materials (<10%), with multiple elements of concern that could be released. As with example 1, the tailings are fine (in the order of 80% fines content), there is a surface water receptor nearby with users, but the groundwater is hypersaline and hence is not a usable receptor. This landform would be assigned 15 points, as follows:

- Geochemical classification – PAF <10% = 2 points.
- Presence of elements of concern – Multiple elements; major concern = 3 points.
- Erosional stability of exposed materials – Erodible tailings on outer slopes = 3 points.
- Potential for wind erosion – High by virtue of fine materials = 3 points.
- Potential impacts on surface water – Local receptors with users = 3 points.
- Potential impacts on groundwater – No receptor or users = 1 point.

This results in the landform being assigned a HIGH Closure Consequence Category. In this case, a detailed understanding of the potential release of multiple elements of concern would be required, with the surface water pathway investigated and modelled to define the mitigation measures required. As for example one, the erosional stability and wind erosion would need numerical modelling to inform the mitigation measures required to manage the risks. Due to the HIGH classification, the design life for this landform would be higher and the design requirements would be elevated, as outlined in Table 2. This is commensurate with the risk the landform poses, both chronic (wind erosion, water erosion and seepage) and acute (geotechnical stability and surface water contamination).

5 Conclusion

In contrast to closure guidelines, the guidelines for designing TSFs provide much more specific direction on the design criteria to be adopted, which are linked to consequence categories. This paper presents a candidate system for assigning a Closure Consequence Category using a blend of consequences (receptors) and material characterisation (sources). Three categories are proposed, with design requirements that the design life, design loadings, type of risk assessment and suggested time frames for numerical modelling. For higher categories, the design requirements increase. It is also proposed that any aspect that is of significant concern and is assigned the highest potential (three points), should be considered in significant detail and, where required, modelled to provide a defensible basis to define the mitigation measures required.

In regard to risk assessment, the use of the QRA process is proposed for HIGH consequence categories, to provide a greater level of rigour in the closure planning process.

References

Australian National Committee on Large Dams 2012, *Guidelines on Tailings Dams, Planning, Design, Construction, Operation and Closure*, Tasmania.

Canadian Dam Association 2013, *Dam Safety Guidelines 2007*, 2013 edn, Toronto.

Department of Industry, Innovation and Science 2016, *Leading Practice Sustainable Development Program for the Mining Industry Mine Closure Handbook*, Canberra.

Department of Mines and Petroleum & Environmental Protection Authority 2015, *Guidelines for preparing mine closure plans*, prepared by the DMP and the EPA, Perth.

Kemp, A & Olds, W 2017, 'Reducing mine closure risk and financial liability through improved up front planning', *2017 AusIMM NZ Conference Proceedings*, Christchurch, pp. 86–95.