Dugald River Tailings Storage Facility and Process Water Dam – Robust Options Analyses

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Abstract The Dugald River Tailings Storage Facility and Process Water Dam are good examples of a robust options analysis. An initial options assessment, which considered the water management impacts of the pre-selected facility design helped produce a final facility design that has provided numerous benefits to the operation, including the reduction of reliance on external water sources by an average of 50 %. A detailed water balance model utilising a synthetic 1,000 year rainfall sequence was used to optimise the water storage requirements and achieve an outcome that would meet MMG's legislative and corporate risk requirements.

Keywords Tailings storage facility, water management, reuse

Introduction

Dugald River, one MMG Limited's (MMG) major development projects, is located in north-west Queensland, Australia, 85 km north-east of Mount Isa. The project will use conventional mechanised underground technology to mine zinc, lead and silver. The mine production will be approximately 2 Mt of ore per annum.

The Dugald River Tailings Storage Facility (TSF) and Process Water Dam (PWD) are integral components of the project from many perspectives.

Initial Studies and Assessment Criteria

Water Management Issues

The initial assessment of TSF and PWD site options was based on the following criteria:

1. Site Water Management Implications
2. Capital and Operating Costs
3. Operating and Maintenance Requirements
4. Risk of Failure
5. Site & Downstream Receiving Environment Environmental Sensitivity
6. Site Disturbance Footprint Implications
7. Expandability
8. Rehabilitation Requirements

Upon commencement of studies it became apparent that, as with other remote mine sites in northern Australia, water was likely to be the second most precious commodity after the mining resource itself. One of the main consumers of water on site will be the TSF, hence it will be desirable to recover water from the TSF and recycle it into the processing operations to the greatest extent possible (ATC Williams, March 2008).

The importance of water to the operation is also revealed as sub-criteria within each of the site options assessment criteria listed above. Key factors include:

- Climate – the tropical (wet/dry season) climate with average annual evaporation exceeding rainfall by a multiple of approximately six (500 mm rainfall and 3,000 mm evaporation).
- Rainfall seasonality and variability – around 80 % of the annual rainfall occurs between the months of December to March, and wet season rainfall variability is extreme (*e.g.* 0.01 annual exceedence probability (AEP) annual rainfall is

1,300 mm, whilst the 0.01 AEP 2-month rainfall is 1,100 mm). This means that the annual mine water balance switches between water surplus and water deficit across the year.

- Regulation of water management – these requirements preclude the off-site discharge of tailings process water, requiring adequate provision of storage for high wet season inflows in the TSF as well as PWD design. Depending on the TSF/PWD catchment characteristics, this can often require significant water storage dams, which nevertheless, due to the seasonal variability in the rainfall, cannot provide a guaranteed supply of process water throughout the life of the mine.

Options and Pre-Feasibility Studies

The TSF options analysis at Dugald River conducted by ATC Williams (2008), considered all possible options within the project area. Seven TSF sites were considered in this initial options study (Fig. 1), including locations within, to the west of, and to the east of the Knapdale Range, which runs in a north-south direction through the centre of the site. Each option varied in construction technique and operational methodology.

The Dugald River site is somewhat unique in that it contains a variety of topographic and geological conditions, ranging from gently sloping alluvial terraces to rugged ranges of hard, outcropping rock. This results in a variety of potential TSF configurations, including down-valley discharge, side-hill spigot discharge, and upstream-raised cells with perimeter spigot discharge. PWD options range from gravity-fed adjacent storages to separate pumped dams.

Each of the above configurations had unique water management benefits and drawbacks; some of which could have had significant impacts on project economics and risk management. There were, however, cases where smart engineering design could be used to convert a perceived drawback into an overall mine operation benefit.

For example, down-valley discharge TSF schemes can often involve significantly larger catchments than side-hill or cell configurations. If these catchments cannot be effectively diverted then the wet season inflows will introduce significant volumes of water into the storage system. If this water can be separated from the TSF into an adjacent PWD, the TSF at sites such as Dugald River (where external water supply is not straightforward as well as freely available), can form a valuable source of water for mine operations.

Conversely, with side hill or cell TSF designs, the aim is to minimize the contributing catchment so that the focus of the structure can be to maximize the evaporative beach dry-

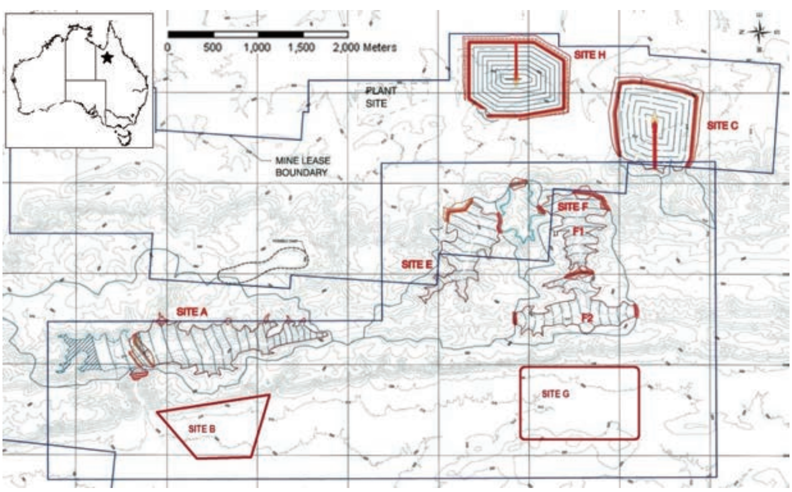

***Fig. 1** Dugald River TSF Site Options – Initial Assessment*

ing of the deposited tailings. Process water, bleed water and rainfall/runoff must be removed from the tailings to an adjacent or separate PWD for storage or evaporation.

For the seven TSF/PWD options a qualitative ranking system was developed for each of the criterion listed above, to allow a transparent overview of the relative benefits and drawbacks.

Common practice sees the initial options assessment focusing on the tailings storage issues (for example tailings thickening and delivery, embankments requirements and storage filling rates/densities). There is often insufficient attention given to the associated water management implications, which in reality can completely change the relative ranking of a particular scheme.

After this initial screening of the seven options, two very different sites and associated construction/operation methodologies were selected to proceed to the feasibility design stage. The two selected options included:

1. Down-valley discharge TSF/downstream PWD, located in a valley within the hard quartzite rocks of the Knapdale Range (known as Site A);
2. Upstream-raised cell, perimeter spigot discharge/separate PWD, located on the gently sloping alluvial grounds to the east of the Knapdale Range (known as Site H).

Site A was ranked the highest due to its tailings storage efficiency and potential for expansion, with water balance modeling required to investigate the issues involved in the sizing and operation of the PWD. Site Hwas also considered deserving of further study, given its proximity to the proposed process plant site (ATC Williams, March 2008).

Selected Option

Feasibility Study Outcomes

The feasibility studies examined the logistics of both sites, exposing some of the key benefits of the down-valley discharge option (Site A). These included the reduced capital cost through utilising the natural containment properties of the Knapdale Valley, expandability and the potential to delineate a large PWD for the mine. Site H was more restrictive from a sizing perspective (due to tight lease boundaries), and it did not contain the relatively impermeable natural formation that could be used as a natural barrier to seepage. Site A was therefore selected to proceed to detailed design.

Knapdale Valley Site (Site A) Overview

Dugald River tailings will be pumped to the Knapdale Valley TSF approximately four kilometers north-west of the processing plant. The TSF will be located within a long, narrow bifurcated valley running north-south on the western side of the Knapdale Ranges. The TSF concept will involve down-valley discharge of tailings to the TSF Embankment, with all decant and runoff water conveyed via a gravity decant structure to the PWD directly downstream.

The PWD will contain all water released from the deposited tailings, as well as storm water runoff from the 338 ha catchment. The PWD will potentially also need to provide storage for underground mine dewatering and additional mine site water inputs during wet season high rainfall periods, when other water storages on site approach their capacities.

The structural geology of the Knapdale Valley has indicated that there is no evidence of significant defects that could extend from the TSF – minimizing the risks of significant seepage occurring from the structure (ATC Williams 2011). Natural geology is mainly comprised of quartzite rock with a permeability of $k = 10^{-7}$ m/s over the upper five meters and reducing one to two orders of magnitude at greater depths. Any further benefits of reducing permeability by lining the structure were quickly ruled out due to the substantial capital costs.

The TSF embankment will be constructed of local rockfill. It has been designed to retain tailings but to allow some decant seepage through to the PWD. The PWD Embankment will be a water retaining structure constructed of rockfill with a thin, impermeable PVC geocomposite fitted to the upstream face. The adopted down-valley discharge and associated water management practices will facilitate timely rehabilitation, with the TSF capped with a low water flux, naturally self-shedding cover.

Water Balance Modeling

Objectives

Given the site configuration and water management benefits outlined above, a comprehensive water balance model was developed by ATC Williams for the Knapdale Valley TSF/PWD scheme. The model has been run on a daily, two-stage (TSF and separate PWD) mass balance approach over the life of mine, using actual daily climatic records. Inputs into the TSF system include tailings bleed and catchment runoff, with outputs being decant delivery to PWD and evaporation. PWD inputs include TSF decant and catchment runoff, with outputs comprising process water return and evaporation. The objectives of the water balance were to examine:

- The ability of the TSF decant to maintain the decant pond in a minimum condition;
- The water level fluctuation in the PWD due to the seasonal climatic impacts;
- The expected return water rates from the PWD to the Process Plant and continuity of supply due to the seasonal impacts; and
- The required capacity of the PWD to adequately provide for the regulatory Design Storage Allowance (DSA), which equates to the 100 year ARI, 2-month inflow. The prime management objective of the PWD is that it has sufficient capacity to store the DSA for the combined facility at the beginning of each wet season (taken to be 1st November).

Rainfall Analyses

A database of 123 years of daily rainfall and evaporation has been compiled for hydrological modeling of the Dugald River TSF/PWD site (ATC Williams 2011). The data was obtained from an Australian Bureau of Meteorology archive of interpolated rainfall and climate data (DSTITIA 2010). The interpolated data is synthetic, with no original meteorological station data left in the calculated grid fields. The prime advantage of the archive is that representative datasets can be interpolated for any set of coordinates in Australia.

From the rainfall data analyses it is apparent that the Dugald River climate is cyclic in nature. The 5-year moving average indicates pronounced cycles of "wet-wet" and "dry-wet" seasons, with the most recent 5 years being the highest 5-year sequence on record.

In order to provide a statistical check of the water balance results from the actual rainfall data, it was decided to synthesise further data. This provides a means of analyzing the potential for further such "wet-wet" sequences, and also allows such sequences to be placed at the beginning and middle of the 22 year Life Of Mine (LOM) simulation, rather than just at the end. This was achieved using specialized software to develop 1,000 years of daily rainfall data with the same statistical characteristics as the existing record.

Key Factors

Model inputs and outputs having a significant impact on the four defined objectives include inputs and outputs as follows:

Model Inputs – Catchment Runoff

Catchment runoff is the dominant source of water in the TSF/PWD system. TSF runoff collects in the Decant Pond, from where it is conveyed to the PWD via the decant system. The PWD has its own external catchment, contributing runoff directly to the storage.

Watershed modelling of the external catchments was conducted using the Boughton SFB model, which has been specifically developed for ungauged catchments by correlating real rainfall records and yields for catchments in Australia. It takes into account antecedent catchment conditions by separately assessing the residual moisture stored in the soil, migration of water down the soil strata to base flow, and migration of water up the soil strata to evaporation in order to calculate the total water available for runoff.

Given that no quantitative runoff data exists for the Knapdale Valley, a range of Boughton parameters were trialled to examine the sensitivity of the PWD volume response. This involved equivalent catchment yield factors ranging from 0.28 to 0.5, with 0.35 adopted for design.

Model Outputs – Process Return Water& Closure Implications

Preliminary water balance modelling indicted that without recycling, the PWD would run at a net water gain throughout the LOM, resulting in final storage volumes in excess of 10 GL. This is an unacceptable situation given the environmental issues with respect to facility closure and the discharge of potentially contaminated water, and would represent a significant economic legacy issue for MMG at the completion of mining.

It hence became clear that PWD water would need to be utilised to the maximum practicable extent in processing and related mine activities (*e.g.* dust sprays, mine service water streams), in order for the Knapdale Valley TSF/PWD scheme to be considered viable. Additional water for the operation, including for potable water supply, would be sourced from Lake Julius due to a lack of significant local groundwater resources in the area.

The proposed mining plan utilises campaign-based paste thickening, which would lead to a variable make-up water demand, ranging from 40 to 134 m^3/h (with an annual average of 68 m^3/h). The addition of a water treatment plant half way through the operation, which could supply cleaner water to other site uses (and bring the average annual reuse rate to 100 m^3/h), was found to reduce the modelled final PWD storage volume from an average of 1,200 ML (with no treatment plant) to 400 ML (with treatment after year 10).

Associated studies indicate that there is negligible impact on closure if the final PWD volume is less than 600 ML, but that closure may be delayed up to 5 years if the final volume is greater than 2,000 ML (ATC Williams 2011).

Design Storage Allowance & Required PWD Capacity

Design Storage Allowance and Adopted PWD Design

Queensland regulatory guidelines require operations to provide the DSA volume on 1st November each year, and one of the key objectives of the water balance modeling is to predict compliance of the proposed design. The guidelines discuss two methods of estimating the DSA, and hence the required storage capacity of the PWD. Both methods have been assessed using the synthetic 1,000 year rainfall database, for which 978 separate LOM simulations were conducted. The higher resultant 2-month wet season inflow (3,835 ML) was adopted as the DSA.

In order to then select an appropriate design PWD capacity, the DSA was added to the 1st November water balance volume with a chance of exceedence equivalent to once in the operational life (approximately 1 in 20), resulting in a design capacity of 8,360 ML.

Modelling Results

Various stochastic and simulated water balance outcomes are presented in Fig. 2. The stochastic data indicates a maximum simulated PWD volume of just under 6,000 ML, however the significantly lower 95th percentile outcomes show the sensitivity of the system to extreme wet season rainfall. The conservative nature of the DSA design approach is also apparent, with the design capacity almost 40 % higher than the maximum simulated PWD volume.

Fig. 2 also shows available water storage and DSA provision assessments. In reality

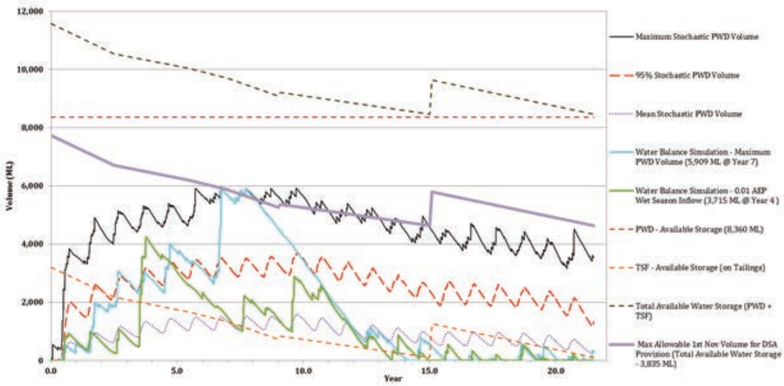

***Fig. 2** Dugald River Process Water Dam Stochastic and Simulated Volume Outcomes, Available Water Storage & DSA Provision over Life of Mine*

there is significant additional flood water storage within the TSF. Whilst long-term storage on the tailings is not encouraged, it nevertheless needs to be included when assessing the risk aspects associated with the selection of the required PWD capacity. It is apparent from Fig. 2 that the maximum allowable 1st November PWD volume is always well in excess of the 95th percentile outcomes. However, given that the severity of recent wet seasons has increased; it is considered that this additional capacity represents appropriate defensive design for a 22 year mine life.

The performance of the proposed TSF and PWD combination will be continuously assessed against its design assumptions. A rigorous monitoring program, including meteorological data, key inflows and outflows, and regional groundwater levels will be implemented, as will annual audits of the facility and calibration of the water and tailings balance model against actual processing tonnages, tailings volumes and densities.

Conclusions

The Dugald River Project TSF has provided MMG with an opportunity to utilize process water as a resource capable of providing approximately 50 % of the mine’s annual water requirements. A multi-faceted approach to selecting and sizing the PWD for the facility has been utilized to produce a combination that satisfies the site’s legal obligations and reduces the mine’s reliance on external water sources.

A robust water balance model was developed for the TSF and PWD that utilized both historical and synthetic climate data to predict and verify required storage volumes. The model accounted for sensitivities in catchment runoff and process water reuse rates, and conformed with the regulatory need to be able to store a specified DSA at 1st November in each year of operation.

This approach has led to a design that is “best-for-project”, providing optimal solutions across multiple assessment criteria. It has shown that, by including site water management impacts as a priority in initial options analysis and feasibility studies, TSF/PWD combinations may provide substantial benefits to project economics if properly managed.

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Additional information can be found at http://bitly.com/IMWA2013_380