Reducing capital expenditure using probabilistic simulation for water management

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Abstract

Mine water dams can represent a significant capital expenditure during site development as well as expansions. Use of probabilistic simulation to determine Design Storage Allowance, a wet season allowance, in conjunction with an ongoing water management tool can deliver optimised storage requirements. Through the use of a case study, it has been demonstrated that dam volumes can be reduced by up to 50%, delivering significant reductions in capital expenditure.

Keywords: design storage allowance, water balance, dam design

Introduction

In recent years probabilistic water balance modelling has become more common in determining operational storage requirements for both new and operating mine sites. While this is nothing new, in Queensland with industry transitioning to a new dam management guideline, there can be a double counting of wet seasons, leading to unnecessarily large dams.

Current legislation in Queensland specifies the need to nominate a Design Storage Allowance (DSA) for hazardous dams. DSA refers to the volume required to be available at the beginning of each wet season (1 November) for storage of runoff. Hydraulic design criteria (including DSA) for hazardous dams in Queensland are outlined in the Manual for Assessing Categories and Hydraulic Performance of Dams (DERM 2012).

In current applications the concepts of operational storage and DSA are often decoupled in designing water storage structures, i.e. dam volume requirements are calculated and then the DSA volume is added to this. This can result in overly conservative designs, which leads to more capital expenditure during construction than is actually required. By utilising probabilistic simulation as both a design and operational water management tool it is possible to reduce capital expenditure through the construction of smaller storages.

Methodology

The case study used for the purpose of assessing dam design volumes under a decoupled operational/DSA storage scenario in comparison to a more integrated approaches is a greenfield site in the north west region of Queensland. Rainfall runoff has been generated using the Australian Water Balance Model (AWBM) (Boughton 1993) with historic rainfall data from the Bureau of Meteorology Silo Data Drill used as input. Key dam characteristics are noted in Table 1.

Scenario 1: This is the most basic and most conservative scenario. A dam operating volume was determined through probabilistic simulation. This operating volume was taken as the volume with a 10% chance of exceedance. The DSA volume was calculated using the method of deciles as presented in the Manual for Assessing Categories and Hydraulic Performance of Dams (DERM 2012). This method of DSA calculation involves fitting annual maximum rainfall depths for the design duration to a standard statistical distribution. Design rainfall depths are then calculated for the desired recurrence interval and the DSA is calculated by multiplying this depth by the catchment area. The total volume is then given as the operating volume plus the DSA volume. This approach is intended to be representative of the general approach of determining dam volume requirements (through simulation or otherwise) and then adding a DSA volume to this.

Table 1 *Dam Water Balance Data*

Storage	Hazard Category	Wet Season DSA ARI	Total Catchment Area (ha)	Process Inputs (ML/yr)	Process Outputs (ML/yr)
Dam 1	Significant	4 Month 20 Year ARI	10	0	0
Dam 2	Significant	4 Month 20 Year ARI	18	150	73

To compare the alternative approach to sizing dams as indicated above three scenarios are described.

Scenario 2: This scenario takes an alternative approach, which is acknowledged as being less conservative to calculate the dam volume and is more likely to make use of the DSA volume for wet season storage, hence increasing site flexibility. The total volume of the dam is set at the 5% exceedance level as predicted by the operation simulation. The DSA was calculated using the Method of Operational Simulation (MOS) as detailed in the Manual for Assessing Categories and Hydraulic Performance of Dams (DERM 2012). This method uses probabilistic simulation to predict the change in storage volumes over historical wet seasons. The DSA is then calculated based on these volumes and is multiplied by a Design Storage Margin (DSM). The DSM is effectively an average of the difference between predicted and measured wet season volumes. In the absence of historical site data a DSM of 50% is specified and has been applied in this scenario. The DSA is nominated as part of the total volume rather than added to it. In this scenario dam design is supported by continued probabilistic simulation of operating conditions (i.e. a model which the site environmental officer would be the custodian of) through the life of the mine to manage the risk of non-compliance (DSA being available at 1 November) and more importantly an uncontrolled discharge.

Scenario 3: Scenario 3 is similar to Scenario 2, except that Dam 2 volume is staged over the life of the mine. The dam is initially designed for the first 5 years of mine life, hence representing capital deferment. As mine life approaches this point (5 years after production) a more informed decision can be made on water storage requirements for the remaining life or next stage of the mine. Similar to Scenario 2 this scenario would also be supported by probabilistic simulation to manage dam volumes.

Results and Discussion

The results of Scenario 1 are summarised in Table 2. Figures 1 and 2 shows modelled dam levels over the mine life for Dams 1 and 2 respectively. Under the methodology used wet season rainfall inflows have been double counted, i.e. wet season rainfall inflows have been accounted for both in the 'operating' volume and in the DSA volume. Although this may not always be the case it is typical of the kind of conservative assumptions used. After addition of DSA, for both dams the total volume is greater than the greatest results predicted through operational simulation which is considered to be over-designed.

Table 2 *Dam Volume Results for Scenario 1(90% exceedance values reported)*

Storage	Operating Volume (ML)	DSA Volume (ML)	Total Volume (ML)
Dam 1	27	68	95
Dam 2	430	180	610

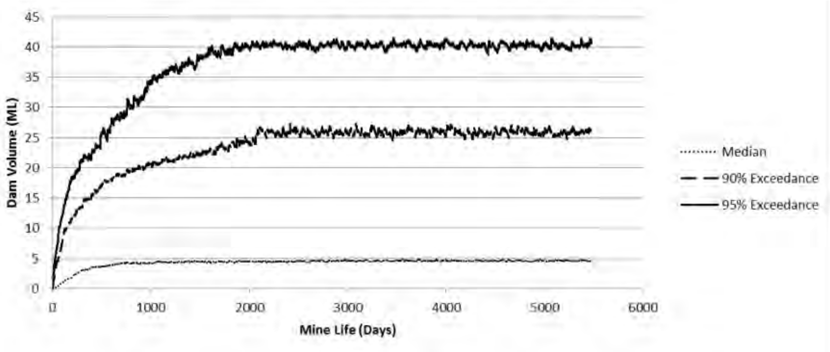


Figure 1 *Results of probabilistic simulation for Dam 1*

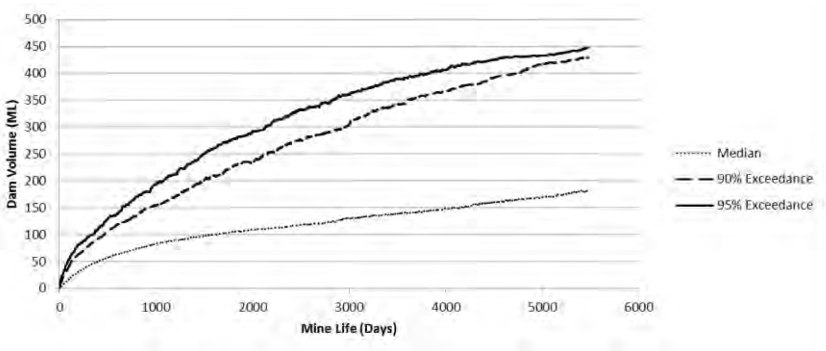


Figure 2 *Results of probabilistic simulation for Dam 2*

Table 3 summarises the storage volumes determined under Scenario 2. Dam volumes predicted under this scenario are significantly lower than that of Scenario 1 as DSA is effectively incorporated into the operating volume. Although this is the case the risk of uncontrolled discharge over the life of the mine is 5% as per the method used. DSA volumes predicted with the MOS were also lower than that predicted in Scenario 1, although it is noted that level of effort and documentation required for DSA prediction through MOS is much greater than that required for the method of deciles. It is expected that the DSA will decrease as wet season data is available and model uncertainty becomes more quantifiable. Although this method could have been used in Scenario 1 for DSA calculation, the method of deciles can be used in the absence of operational simulation and Scenario 1 is typically used when operational simulation is not used in dam design.

Table 3 *Dam Volume Results for Scenario 2(95% exceedance values reported)*

Storage	DSA Volume (ML)	Total Volume (ML)
Dam 1	33	45
Dam 2	135	448

Under Scenario 2 the chance of non-compliance over the life of the mine of both dams is increased as the proportion of the total dam volume assigned as DSA has increased. This likelihood would then be actively managed through use of probabilistic simulation of operating conditions. Probabilistic simulation has previously been documented to be a powerful tool in active mine water management bridging the gap from design to operation (Gimber & Robertson 2010). Forward predictions are made using current conditions to inform water management strategies to ensure compliance. Likelihood of non-compliance or in extreme cases uncontrolled discharge can be quantified through this forward prediction and actions can be taken to reduce this risk if necessary. Depending on the particular site and licensing conditions this may include controlled release, transfer between storages or temporary storage.

Table 4 summarises the storage volumes determined under scenario 3. Under this scenario, Dam 2 consists of a structure of approximately 60% of the volume of that predicted under Scenario 2 and 50% of that under scenario 1. Probabilistic simulation of operating conditions would be used to manage Dam 2 volume over the initial years of operation. Actual operational water usage statistics can then be used to inform water storage requirements for the remainder of the mine life. It can be difficult to accurately predict actual site water usage pre-construction. As such, conservative estimates of usage are often applied in initial design. Staging of construction of water storage infrastructure is then considered the optimal approach to reducing mine-enabling infrastructure development costs as true water usage statistics can be utilised. This holds true as long as construction remobilisation costs are not inhibitory.

Table 4 *Dam Volume Results for Scenario 3(95% exceedance values reported)*

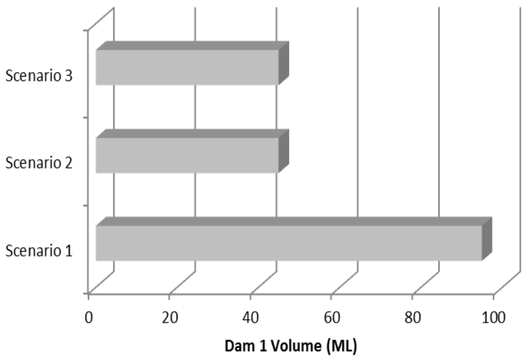
Storage	DSA Volume (ML)	Total Volume (ML)
Dam 1	33	45
Dam 2	135	280

A summary of the calculated dam volumes is shown in Figure 3. This highlights the significant savings that can be made through the proper use of probabilistic simulation in dam design and operation.

Conclusions

It has been shown that through the correct application of probabilistic simulation volumes of constructed storages can be reduced by up to 50%, which represents significant savings on capital expenditure. As a part of this exercise the following key point are made:

For dams with upstream catchments the DSA can be a significant volume. If the DSA is added to the calculated operating volume of a dam, this can lead to over design of the structure. Nominating the DSA within the operating volume can lead to more acceptable dam volumes, although this can also increase the risk of non-compliance. This increased risk can be mitigated through the use of active mine water management facilitated by probabilistic simulation.



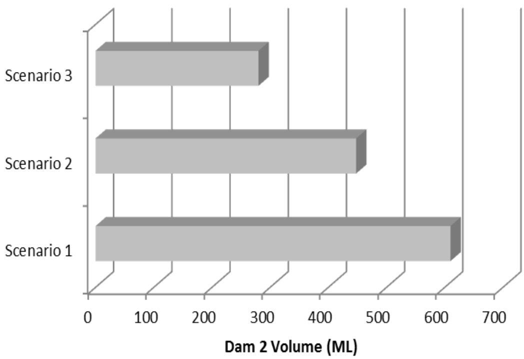


***Figure 3** (LEFT) Summary of Dam 1 volumes (RIGHT) Summary of Dam 2 volumes*

Probabilistic simulation can also be used as a tool for staging dam volumes. Dams can be initially designed with a reduced design life. Risk of volume exceedance can then be managed using probabilistic simulation. Once mine operation has commenced and water usage figures have been established more informed decisions can be made regarding storage volumes over the remaining mine life.

References

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