Assessing Water Availability for Life of Mine Operation Using Probabilistic Water Balance Model

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Abstract A dynamic probabilistic water balance model representing the water management system at Golden Grove mine located in Western Australia was developed and used to assess the availability of water for processing the minerals during the Life of Mine operation. The results showed that some risk existed of not achieving plant concentrate production due to water shortage as throughput increases and metal grades decrease during the simulation period. The model was then used to assess the effectiveness of several water management system upgrade options and estimate their costs.

Keywords water balance, probabilistic model, water shortage, system upgrade, Life of Mine

Introduction

The Golden Grove mine, operated by MMG Limited is a zinc/lead/copper metal mine located approximately 450 km northeast of Perth and 280 km east of Geraldton in Western Australia. Water is used in the process plant to produce concentrate from ore. The existing water management system of the plant (fig.1) consists of several ponds, pumps, pipes, bores, a mine water clarifier, underground mine dewatering, process plant, Cemented Hydraulic Fill (CHF) plant, Tailing Storage Facilities (TSF) and discharge to Lake Wownaminya.

Water inputs to the operation include groundwater inflow to the underground workings, groundwater abstraction from bores and direct rainfall on ponds. Tailings slurry produced during the process is discharged to TSF3 from where water is reclaimed (from decant pond and underdrain collection system) and pumped back to be reused in the process plant (GHD 2009). Water losses in the system include evaporation, water entrainment in the tailings, moisture in concentrate and water used for dust suppression and other mining activities. Excess water inputs are treated and discharged to Lake Wownaminya.

Data on water inflows and outflows of the system has been recorded since 2004. This data showed a trend of declining volume of water discharged to Lake Wownaminya, and raised questions on whether there would be sufficient water for production in future years. A study was commissioned to develop a dynamic water balance model, run the model to assess water availability for production for the existing system and to assess the cost and effectiveness of identified options to upgrade the water management system, estimating the NPV of each upgrade option and to then suggest the best solutions.

Water Balance Model

An integrated site water balance model was developed using GoldSim software (www.goldsim.com) to simulate inflows, outflows and internal transfers of water within the water management system (fig. 1). The simulation period covered 6 years and made use of the ore processing plans at the time (MMG Limited 2011). Dashboards were provided in the model as graphical interfaces to allow the user to enter and change the model input data, define settings and visualize the simulation results graphically.

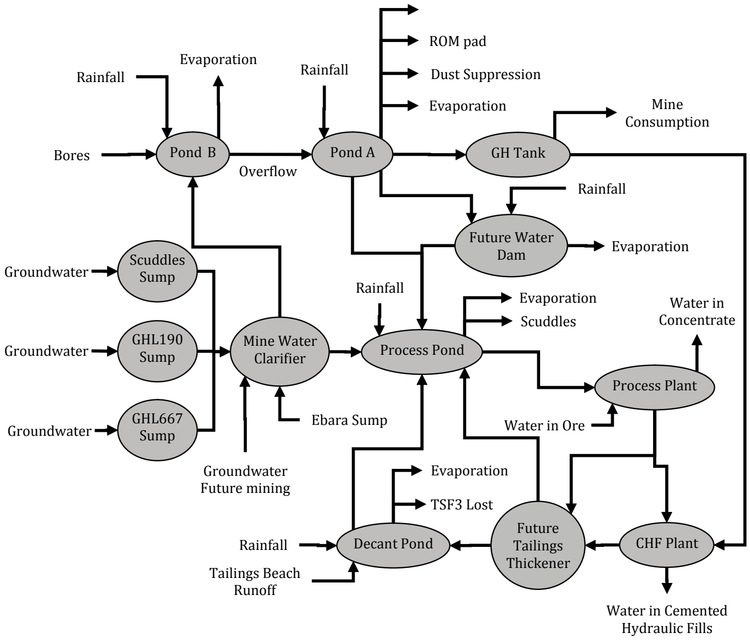

Fig. 1 *Schematic of Golden Grove water management system.*

Some of the key assumptions for setting up the model included:

- Ore processing rates and concentrate production rates were used from Golden Grove 2011 business plan;
- Evaporation pan factor was assumed to be 0.8;
- Solid content in tailings slurry was assumed to be constant 30 % w/w based on operation procedures;
- No seepage considered from ponds;
- No losses assumed in pumps, pipelines and tanks; and
- Starting and stopping of pumps were set based on water levels in sumps and ponds. Whilst in reality this is not an automatic process, it is representative of the operating philosophy.

Several key inflows and outflows of the water management system depend on rainfall and evaporation. Site specific long-term meteorological data used in the model has been obtained from the SILO (www.longpaddock.qld.gov.au/silo) data drill set for the geographical coordinates of 28°45′ S 116°57′ E. The data set covers the period of 1889–2010 for rainfall and evaporation.

Monthly rainfall and evaporation data for Golden Grove site was obtained for the period of 1987-2009 and 1999-2007 respectively from the Annual Aquifer Review report (URS 2010). Monthly average of rainfall and evaporation are calculated for SILO data and the results are compared with the Golden Grove site data (fig. 2 and fig. 3).

Based on the results there is a good agreement between SILO and Golden Grove monthly rainfall. But SILO evaporation is on average 25 % higher than that recorded onsite (but generally with a smaller percentage difference on the months with high evaporation). As rainfall and evaporation data were available for 121 years and the modelling period covered 6 years, the model was run for 117 rainfall and evaporation sequences using Monte Carlo simulation (Ang and Tang 1984). The results were presented based on average and 95 % of the 117 sequences.

The model results for the base case (no change to the existing water management system), showed water shortage leading to lower production especially in years with high evap-

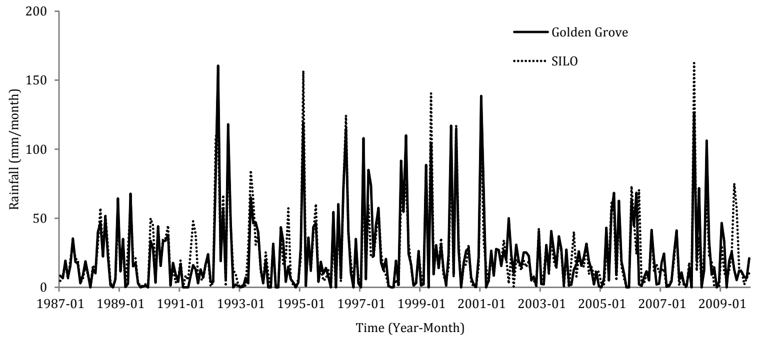

Fig. 2 *Comparison of SILO and Golden Grove rainfalls.*

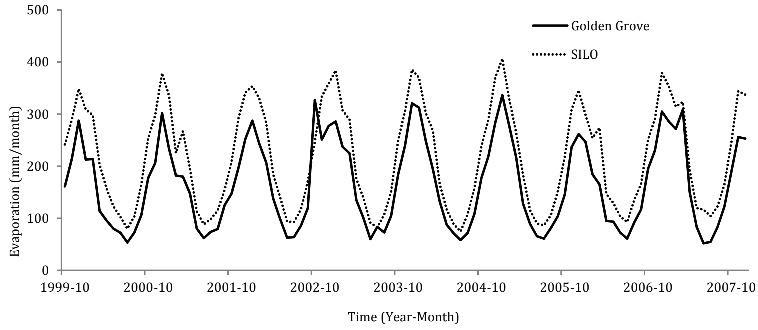

Fig. 3 *Comparison of SILO and Golden Grove evaporations.*

oration rate. Results of modeling are presented for average and 95 percentile of the 117 rainfall/evaporation sequences (fig. 4). As shown in the Fig. the concentrate production shortfall against plan would be higher in years 3 to 5 because of:

- Higher ore processing rate as the open pit becomes active; and
- Lower copper grade in the ore leading to production of greater volume of tailings.

Sensitivity Analysis

Sensitivity analysis was conducted to assess the effects of changes in the groundwater inflows to the system and reduced evaporation as these parameters had the biggest effect on inflows and outflows of the system. The model was run with modified groundwater inflows (-10 %, -20 %, +10 %; fig. 5). The results showed that 20 % decrease in groundwater inflow to the mines would reduce concentrate production by on average 7600 t/a. An increase in groundwater inflow rate however would not have any effect on concentrate production as the pumping capacity from pond A to the process pond constrained the availability of water for production and therefore any extra water would be discharged to Lake Wownaminya rather than being used in the process plant. An expansion of the pumping capacity however would have a beneficial impact on reducing production shortfall against plan.

As Golden Grove evaporation is about 25 % lower than SILO evaporation, the model

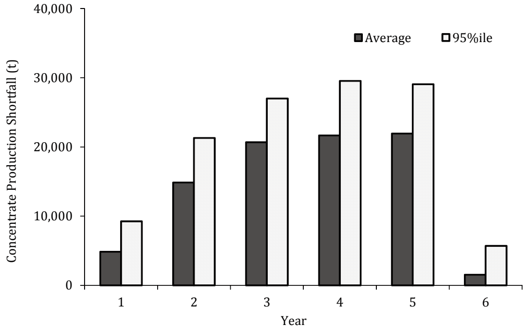

Fig. 4 *Concentrate production shortfall for Life of Mine period predicted by model for the base case.*

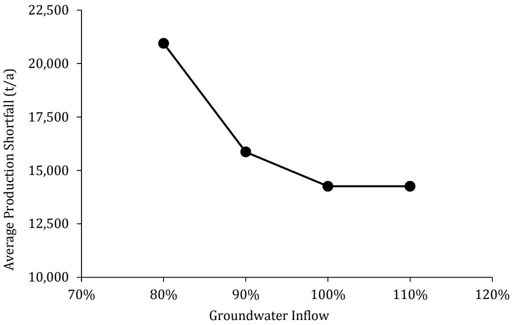

Fig. 5 *Effect of groundwater inflow changes on concentrate production shortfall.*

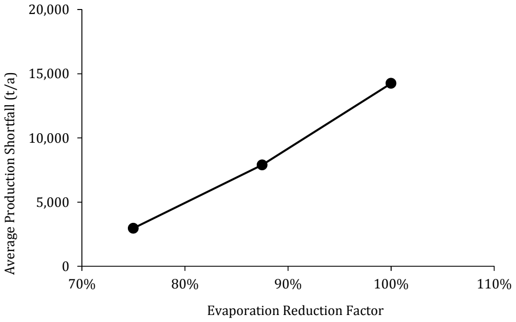

Fig. 6 *Effect of evaporation reduction on concentrate production loss.*

was run for the SILO evaporation reduced by 25 and 12.5 % (fig. 6). The results showed that if actual evaporation was 25 % lower than SILO sourced evaporation data the shortfall would drop from about 14,200 to 3,000 t/a. The sensitivity of production to evaporation highlighted importance of restarting measurement of evaporation on site.

Scenario Analysis

As objectives of this modelling study were finding solutions for potential water deficit in the future, it was decided to run the model for several water management system upgrade scenarios. After discussion with the mine site team 9 scenarios were defined (Table 1). Generally the scenarios are based on the following options:

- Storing the extra water in a water storage dam during the wet seasons rather than discharging the water to Lake Wownaminya and using the stored water later during the dry seasons. As evaporation depends on the area of the storage, three different storage areas and volumes are defined;
- Recycling some water from the tailings by using tailings thickeners before discharging tailings in TSF3. Two different outflow solid contents are defined and used;
- Supplying water from additional bores during the dry seasons;
- Upgrading pumping system from pond A to process pond to be able to transfer additional water supplied from bores; and
- Combination of two or more of above mentioned options.

Scenario	Description
A1	Do Nothing - No changes in the existing water management system
A2	1400 ML storage with 10 ha area
A3	1100 ML storage with 15 ha area
A4	1000 ML storage with 20 ha area
A5	Tailing thickeners with 40% w/w outflow solid content
A6	Tailing thickeners with 50% w/w outflow solid content
A9	Additional bores(4ML/d)
A10	Additional bores(4ML/d), Increasing pond A to process pond capacity to 6480 m^3/d
A12	Additional bores (2ML/d), Increasing Pond A to process pond (6,480 m^3/d), 50 ML Storage with 2.5 ha area

Table 1 *Description of defined scenarios.*

The developed water balance model was used to run all of the 9 scenarios for the 6 year period. For each scenario the model was run for 117 rainfall and evaporation sequences and the results were statistically analysed to predict the potential concentration production shortfall (fig. 7). The results show that if the water management system is not upgraded the annual mean and 95 percentile concentration production lost is estimated to be about 14,000 and 20,000 t. Storing water in the storage dam will not eliminate the production lost. With using the 15 and 20 ha dams which have a reasonable height, the lost production is still high (4,500 and 6,500 t). The 95 percentile lost is significantly higher than the mean lost (roughly about two times).

The results also show that tailings thickeners are very effective in reducing the risk of water shortage. Using tailings thickeners with 40 % w/w outflow solid content there would only be on average a 1,000 t annual production shortfall against plan, using tailings thickeners with 50 % w/w outflow solid contents there would be no production shortfall against plan.

Supplying water from additional bores with total yield of 4 ML/d would also be a very effective solution in reducing the risk of production shortfall against plan. In this case the capacity of the pumping system from Pond A to the process pond would need to be increased from 4320 to 6480 m³/d. A better option would be to supply 2 ML/d from additional bores and storing the water in a relatively small storage (50 ML capacity).

The lost revenue from the production shortfall estimated based on production shortfall mass calculated in the previous section, the corporate economic assumptions for metal prices and the CAPEX and OPEX estimated for each system upgrade option were used to calculate the net present value for each option using a discount rate of 8 %. For each option the NPV was calculated for every one of the 117 rainfall and evaporation sequences and then the mean and 95 percentile of the results were determined (fig. 8).

Based on the results, the NPV for options which considered the water storage dams were positive but relatively low comparing to the scenarios which considered the use of tailings thickeners or additional bores. The reasons for this were:

- CAPEX of dam construction is very high; and
- These scenarios do not eliminate the production shortfall.

NPV of the scenario A9 is negative because it does not have a significant effect in reducing the production shortfall against plan as the water pumped from additional bores is not

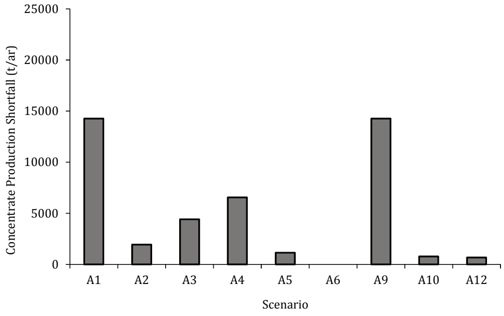

Fig. 7 *Mean concentrate production shortfalls for scenarios.*

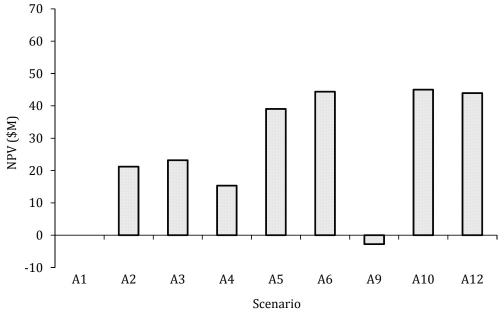

Fig. 8 *NPV for system upgrade options.*

transferred to the process pond because of limited capacity of the pumping system. NPV of options using tailings thickeners or additional bores are very close because both eliminate the water shortage and have relatively low CAPEX.

Conclusions

Assessing the water balance for Golden Grove has shown that a probabilistic dynamic water balance model can be successfully used to simulate the availability of water for the Life of Mine operations. It has also shown that the model has the capability to assess the effectiveness of solution scenarios when the production shortfall risk is present. Modeling can also be used to understand the information gaps and improve the water management and monitoring program.

Acknowledgements

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References

Ang AH-S, Tang WH (1984) Probability concepts in engineering planning and design, Volume II: Design, risk and reliability, John Wiley & Sons, New York

MMG limited (2011) Golden Grove business plan

GHD (2009) Report for Golden Grove Tailings Storage Facility 3 Detailed Design

URS (2010) Golden Grove 2010 annual aquifer review