The Impact of Climate Change on a Mine Water Source

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Abstract

Boddington Gold Mine (BGM) in Western Australia relies on a stable supply of water from the nearby Hotham River. The mine's operators recently commissioned Golder Associates Pty Ltd (Golder) to estimate future flow rates in the river over a 30-year period (2012-2042).

Golder's methodology comprised the calibration of a catchment runoff model, the generation of stochastic rainfall data and the application of suitable climate change projections. Groundwater interaction and land management practices were not considered.

The approach outlined above resulted in the estimation of 30-year flow series that reflect prevailing rainfall trends and either consider or ignore the predicted impact of climate change. The most conservative of these flow series suggests the mean annual flow in the Hotham River will fall by approximately 20% over the next 30 years.

Introduction

Mineral processing works at BGM are dependent on the abstraction of water from the Hotham River. Since the existing abstraction arrangement is to a large extent governed by the actual flow rate in the river, declining levels of rainfall in the catchment have the potential to affect future operations at BGM. In light of these issues, the mine's operators commissioned Golder to estimate likely flow rates in the river over a 30-year period (2012-2042), taking into account the possible influence of climate change. The results of this study have been incorporated into BGM's operational site water balance model.

Catchment Analysis

The surface area of the study catchment is approximately 3964 km^2. A long-term flow gauge station is located at on the Hotham River at Marradong Road Bridge (MRB). This is located a short distance downstream of the point at which water is currently being abstracted for use at BGM.

Rainfall patterns vary significantly within the catchment. For example, the long-term average annual rainfall decreases by 50% between Boddington (740 mm) near the offtake point and Cuballing (375 mm) at the eastern extremity of the catchment.

River Flow

Daily flow data recorded at MRB were obtained from the Department of Water (DoW) and cover the period 16 June 1966 to 15 May 2010.

Rainfall

There are long-term rainfall stations located in Boddington and Bannister, both of which lie within the study catchment. A third station, in Marradong, is located roughly 5 km outside the catchment boundary. All three stations have been observing rainfall for over 95 years.

The areal rainfall over the entire study catchment was estimated using the Thiessen Method (Shaw, 2004). This approach involves the weighting of individual data based on the fraction of the catchment represented by the recording station. The weighted readings are then summed.

Evaporation

Evaporation has been recorded at BGM for approximately 10 years. These data were “looped” in order to provide an estimate of evaporation for the period 16 June 1966 to 15 May 2010.

Catchment Runoff Model

The Australian Water Balance Model (AWBM) is a freely-available water balance model that relates areal rainfall to catchment runoff in the form of either daily or hourly data.

The model uses three moisture storage containers (related to partial catchment areas) to simulate runoff. The moisture balance of each container is measured at hourly or daily intervals depending on the adopted model timestep. At every time step, rainfall is added to each of the three moisture stores while evaporation is subtracted. Excess moisture is directed to either surface runoff or base flow, depending on the value of user-defined model parameters. It is also possible to simulate the delay in runoff reaching the outlet of the catchment

Model Calibration

The objective of the calibration process is to establish a relationship between historic rainfall and observed runoff based on a set of calibrated model parameters. These parameters can then be applied with confidence to simulate catchment runoffs based on an alternative, in this case stochastic, rainfall series.

To compare the observed and simulated flow data, the Nash–Sutcliffe efficiency coefficient was used to assess the predictive power of the catchment runoff module developed in Goldsim Software (www.goldsim.com). Using a GoldSim optimisation tool, random AWBM parameters were generated to produce alternative simulated flow series. This process was continued iteratively until the Nash-Sutcliffe coefficient was maximized.

Flow Duration Curve

Comparison of observed and simulated flow duration curves, shown in Figure 1, was one of the approaches used to assess the accuracy of the AWBM calibration process. For the range of flow rates at which water is abstracted by BGM, a strong degree of correlation was achieved between observed and simulated daily flows noting that in general, simulated data is unlikely to be entirely accurate regardless of methodology (Cole et al. 2003).

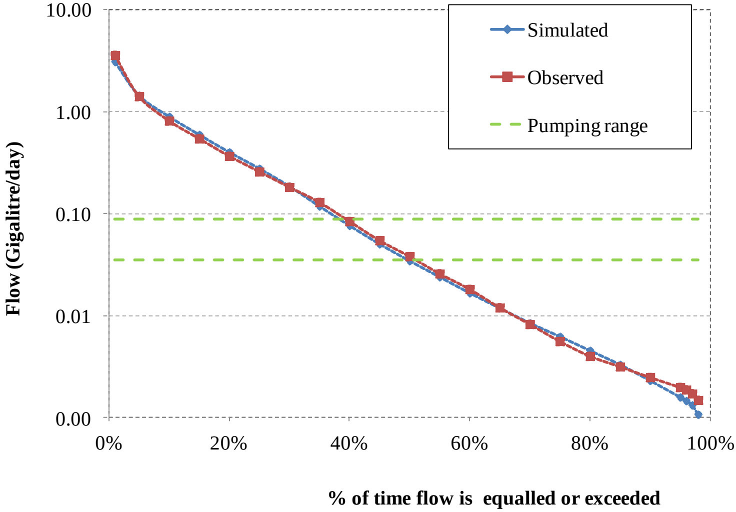

***Figure 1** Flow Duration Curve*

Model Parameters

The adopted values of the AWBM model parameters are provided in Table 1 below.

***Table 1** AWBM Parameters*

Partial Areas	Surface Storage Capacities (mm)	Constants
A1 = 0.076	C1 = 15	Base Flow Index = 0.18
A2 = 0.094	C1 = 189	Base Flow Recession = 0.98
A3 =0.830	C3 = 316	Surface Flow Recession =0.90

Climate Change Analysis

Predictions provided by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), outlined in "Climate Change in Australia" (CSIRO 2007), have been used to estimate the impact of climate change in future years. The CSIRO projections are the most conservative of those presented by 15 leading organisations and institutions from around the world.

CSIRO has assessed the impact on the Australian climate of six future scenarios developed by the International Panel on Climate Change (IPCC). No probabilities of occurrence have been applied to these scenarios, each of which is defined by a unique pattern of economic, social and environmental trends.

All six scenarios (A1F1, A1T, A1B, A2, B1 and B2) were considered in this study. However, scenarios A2, A1B and A1F1 are projected to have a similar effect on

Australian rainfall levels until 2050. Overall, A1F1 is the most conservative of the six scenarios and is referred to below as the "worst-case" scenario.

Generation of a 30-year Stochastic Rainfall Series

Stochastic rainfall data were generated using a GoldSim variation of a multi-state Markov chain model (Srikanthan and McMahon 1985).

The model considers rainfall on any given day as being in a particular "state" of intensity, the upper and lower boundaries being user-defined. The model then generates a synthetic sequence of daily precipitation based the probability of rainfall in one state being succeeded (on the following day) by rainfall in either the same or a different state. These probabilities are collated in what is known as a transition probability matrix (TPM). Seasonality is represented by using 12 separate TPMs, one for each calendar month.

Calibration of the model is concerned with preserving the daily, monthly and annual statistics of the observed data (which is the primary input). This was achieved by iteratively varying the limits of each state as well as the number of states to be considered in each month. Calibration and simulation are effectively the same process, since once calibration is achieved, the resulting output data are considered valid. Historic rainfall data recorded prior to 1990 were not considered given the shift in climatic conditions which has occurred in the south-west of Western Australia since the 1970s (Department of Climate Change and Energy Efficiency 2011).

Adjustment of Stochastic Rainfall

The CSIRO's climate projections relate to the years 2030 and 2050. Linear interpolation was used between these years to derive estimates of the annual and seasonal changes in rainfall by 2042. The likely monthly changes in rainfall (by 2042) were estimated using the interpolated seasonal projections. 2042 estimates to the stochastic rainfall series on a linear basis were applied using Goldsim modelling.

Generation of 30-year Flow Series

The relationship between observed rainfall and runoff as defined using the AWBM model was used to generate long-term flow data based on the stochastically-generated rainfall series taking into account climate change. By developing a GoldSim version of the calibrated AWBM, it was possible to produce 30-year flow series based on either adjusted or unadjusted stochastic rainfall data. These were repeated for 100 realisations in order to present the statistical likelihood of river discharges based on a larger sample base.

Results and Conclusions

Figure 2 compares 30-year annual mean flow series for both unadjusted and adjusted (worst-case scenario) stochastic rainfall data. Figure 3 shows box and whisker plots of the monthly results for the stochastically-generated flow data. The boxes show the monthly 25th percentile, mean and 75th percentile flows while the whiskers show the least and greatest monthly flows.

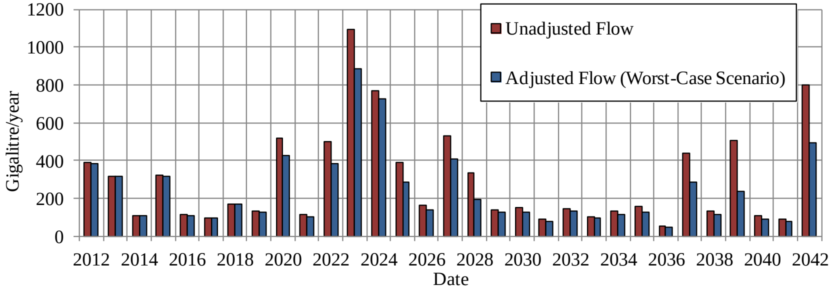

***Figure 2** Annual Mean Flow Series (2012-2042) – Unadjusted and Adjusted for Climate Change*

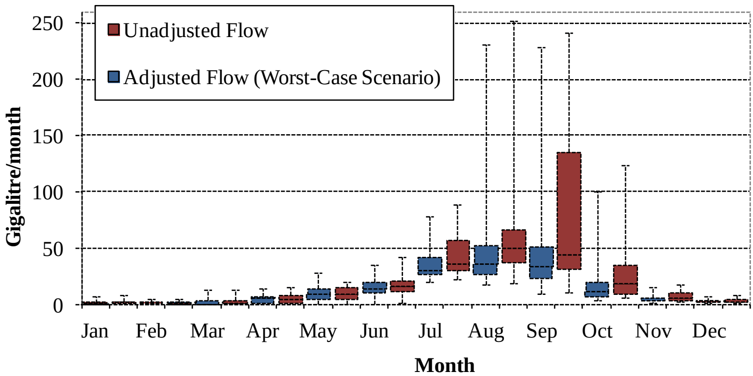

***Figure 3** Monthly Statistical Results (2012-2042) – Unadjusted and Adjusted for Climate Change*

The methodology and results of this study suggest the following:

- Mean annual flow in the Hotham River is likely to fall by around 20% between 2012 and 2042.
- Climate change will not affect the availability of mine water during wet years.
- The adjustment of the stochastic rainfall data (to account for climate change) does not significantly alter the projected frequency of dry years within the future flow series.
- The impact of climate change on flow rates in the Hotham River is likely to be greater in wetter years.

Acknowlegdements

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