Keeping the lid on it

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Abstract

This paper describes a practical approach for understanding the water balance of mine voids that interact with large ephemeral rivers. This study used readily available information on river and floodplain hydraulics and hydrology to estimate the probability of maintaining a water seal over the sulfidic rich waste rock in a mine void.

Keywords: flood, ephemeral, river, closure, mine void, hydrology, hydraulics, water balance.

Introduction

In 1999, a 55 m deep gold mining pit was flooded as a long term solution to prevent and minimise acid generation from pit wall sulfides and in-pit placed sulfidic waste. Ten years later, during the middle of Queensland's longest drought, the water level in the main pit of the closed gold mine dropped approximately 10 m, to a level where there was a high likelihood that sulfidic rich waste material may be exposed. The original plan and execution of using a water seal therefore may not be an adequate long term solution and alternative options were assessed which could be implemented economically particularly in consideration of the site's remoteness and accessibility. Consequently any solution needed to be passive and cost effective.

This paper discusses the particular challenges of the case study, the approach to overcome the challenges, the results and the applicability of the approach at other similar sites.

Problem

To evaluate the adequacy of the closure option to use a water seal, a conventional water balance assessment needed to be completed, which would enable multiple options to be assessed. The pit only has a small catchment (10 hectares), with the main source of water to recharge the storage coming from the nearby Suttor River, when water would overtop the two weirs cut into the side of the pit. Thus the magnitude of inflows from the Suttor River (catchment area of 70,000 km^2) needed to be understood. It was estimated that 95% of water recharging the void was from flood ingress.

To quantify the flood inflows, it was necessary to determine the flood levels at the site for varying floods in particular for small floods through the weirs, both in terms of water levels and the duration of floods. The water level elevation and duration was important as ultimately this would determine the volume of water which would recharge the mine void. Further challenges were absence of stream flow gauges adjacent to or within the immediate vicinity of the mine void and limited site specific data.

Approach

To understand the mine void water balance, a conventional water balance was required. Incident rainfall and evaporative losses were estimated using patch point data available from Queensland Department Environment and Resource Management (DERM). Flood ingress from the Suttor River was via two small weirs that had approximately the same elevation yet different hydraulic conditions due to flood gradient and backwater effects.

In the absence of a stream flow gauge immediately adjacent to the site, a stream flow gauge approximately 12 km downstream was used. This gauge recorded levels at 15 minute intervals and was deemed suitable for assessing the flood level and duration. However, simply transferring the flood depth at the gauge to a point adjacent of the pit to determine the depth of the flood at the mine void did not take into account the significant overbank storage (floodplain) or the river geometry and flow characteristics.

Estimating the flood level adjacent to the pit required consideration of small to medium floods, taking into account the localised backwater affects around the mine void and the differences in the levels of rising and falling limbs of flood hydrographs. Small floods were considered to be Average Recurrence Interval (ARI) floods of one to two years with medium floods having ARIs of 10 to 20 years. Using 43 years of record at the gauge site, a flood frequency analysis (FFA) (Pilgrim 1987) was undertaken. To develop the stream gauge site flood level relationship six floods were selected. The selected floods used to define the gauge / site relationship are shown in Table 1.

Table 1 *Floods selected to determine gauge site flood level relationship*

Flood (date)	Peak Gauge Height (m AHD)	Peak Flood Depth (m)	Peak Flow (m^3/s)	Estimated ARI (year)
Feb-08	171.0	9.2	4853	17
Feb-91	170.0	8.2	3502	8
Feb-07	166.7	4.9	809	2
Feb-87	165.7	3.9	525	1.6
Dec-97	164.1	2.3	160	1.2
Jul-08	163.7	1.9	92	~1

AHD - Australian Height Datum

For each selected flood, using MIKEFLOOD a combined one dimensional and two dimensional hydrodynamic model, the rising and fall limb of the flood hydrographs were calculated by modelling the 12 km reach between the mine site and the gauge. This produced a relationship between the recorded level and the flood level at the site. This relationship could then be used to determine the hydraulic conditions at each weir and therefore represent the volume of water entering the mine void with greater accuracy. This approach was adopted rather than simply applying the bed gradient as the friction slope.

It was found that simply adopting a set level based on the difference in bed elevation under-estimates the flood level at the site (particularly for smaller events) and hence would under-estimate the volume of water flowing into the mine void. This is particularly important as the recharge of the pit relies on the overtopping of the weirs. The difference of applying this approach is shown in Figure 1 which shows the pit lake elevation over the period since the pit was originally flooded.

Figure 1 shows the difference in taking into account the Suttor River flood hydraulics. That is multiple filling events over the period from 2000 to 2008 which individually and collectively changed the water level in the pit. This representation of the pit lake level was determined using historical rainfall and evaporation values obtained using patch point data (as noted above), the stage storage curve of the pit (surveyed prior to the pit being flooded) and the relevant gauge relationship. The pit's catchment area was only its surface area.

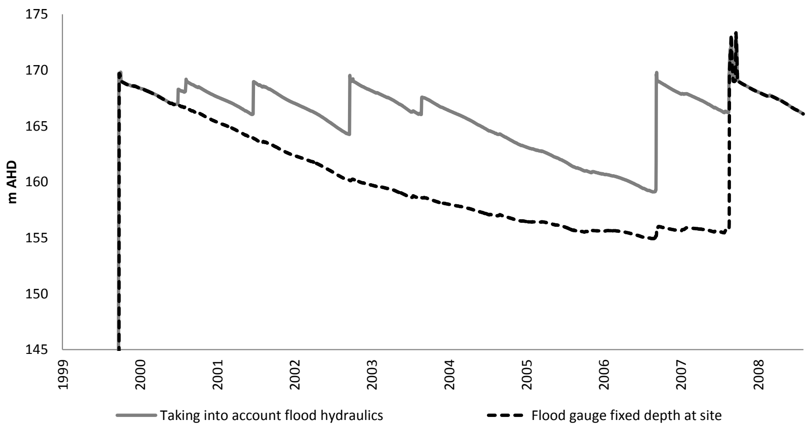

Figure 1 *Mine Void Water level simulated since pit flooded*

These results of the pit level taking into account the flood hydraulics agreed with anecdotal evidence given by the site caretaker (Hawker and Hardy 2010) which noted a series of filling events since the pit was originally flooded post 1999 and also that the level of the water towards the end of the drought was estimated to be not less than 160 m AHD. In the absence of any recorded void water levels, the calculated void water level as shown in Figure 1 was accepted as being the best representation of the actual water level.

By taking into account flood hydraulics, the water balance of the pit appeared to better represent smaller floods and accordingly the adopted approach would substantially influence whether or not the water seal and current weirs, combined were a sustainable solution. This is a result of the trade-off between increasing the frequency which the Suttor River flows into the pit and the maximum volume that can be stored (limited by the weir level) and hence the volume available to be evaporated. The larger the volume of stored water (void surface area largely unchanged dependent upon level), the longer the period of time until the water level recedes exposing dumped rock and pit wall sulfides.

Results

With the relationship between the Suttor River and the two weirs established, options could then be developed to improve the likelihood of maintaining the water seal over the dumped waste rock, or if the current arrangement was sufficient in the near to immediate future. Records show dumped sulfidic material is at levels of up to 155 m AHD (sulfides in pit walls potentially up to 160 m AHD) (Scott 2007).

Given the remoteness of the site, the solution needed to be passive, that is, a solution not relying on active management, pumps, pipelines, power, dosing systems (to neutralise pH) etc. As such, the options available to determine an acceptable solution were limited to changing the elevation and/or widths of either or both of the weirs.

To demonstrate the importance of better understanding the Suttor River flood levels, the results of both weirs level set at 169 m AHD (current crest levels) are presented in Figure 2 and Figure 3, showing both the results when using the "fixed depth" (Figure 2) and also the results determined based on the site-gauge level relationship taking into account the "flood hydraulics" (Figure 3). In both cases the results are of a simulation forecasting 10 years into the future with weir levels set at 169 m AHD (weir widths unchanged) using historical data randomly applied. This shows, as expected, that the range of results is less spread and the mean level is higher for the simulation taking into account the "flood hydraulics".

For all weir levels considered for differing levels of sulfidic material (in pit walls) the results are shown in Table 2. For example over the 10 year forecast period for a weir level of 166 m AHD, it was calculated that there was a 23% likelihood of the water level receding to 159 m AHD using a "fixed depth" to represent the flood condition between the gauge and the level adjacent to site. By comparison taking into account the "flood hydraulics" modelling showed that the water level would not recede to 159 m AHD. As there was some uncertainty at the level which sulfides in the pit walls (potentially up to 160 m AHD) (Scott 2007) the probabilities of reaching a range of levels where sulfides were suspected were reported.

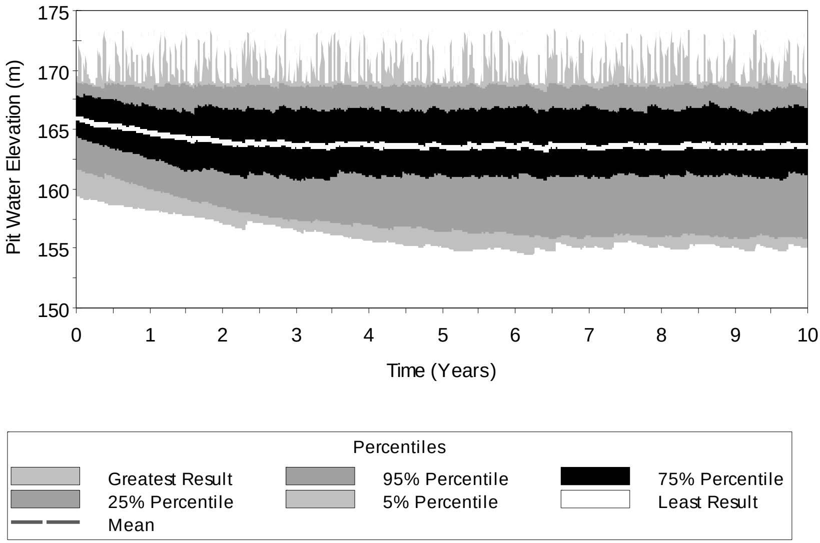

Figure 2 *Mine Void Water level simulated over 10 years using a fixed depth between gauge and level at the site (weir levels 169 m AHD)*

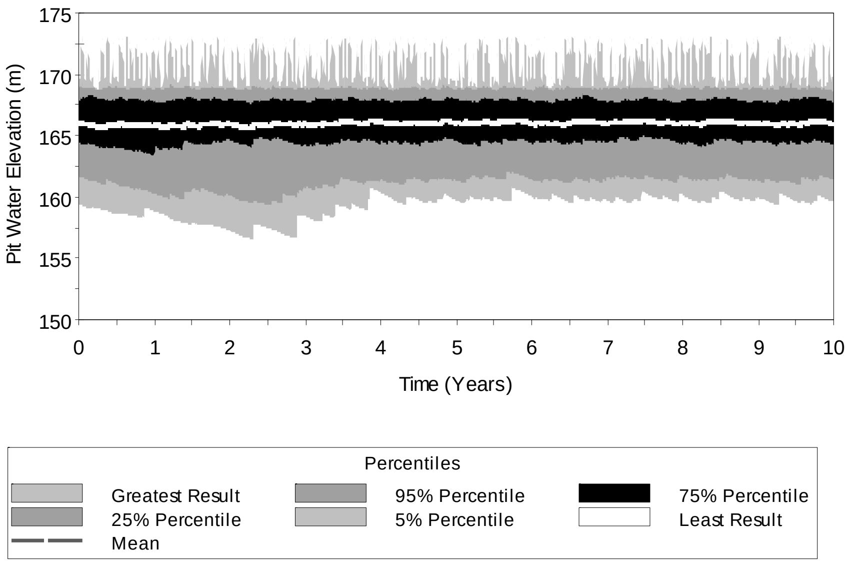

Figure 3 *Mine Void Water level simulated over 10 years taking into account floodplain storage and river hydraulics between gauge and level at the site (weir levels 169 m AHD)*

Taking into account the flood hydraulics to better understand the pit/river interaction, it was found that it is highly unlikely that the water level would recede to a level where oxidation would occur and correspondingly exposing sulfides contained in the dumped waste rock below 155 m AHD. By contract Table 2 shows that using a “fixed depth” relationship between the level at the site and the recorded river gauge level, it was calculated that there would be 20 % likelihood of exposing the dumped rock.

Should pit wall sulfides be present above 156m AHD then modelling showed that there was a 2% likelihood that water level would recede and expose this material with current weir level (169 m AHD) and contribute to acid mine drainage. This increased to 53% likelihood with the current weir level (169 m AHD) if sulphides in the pit wall at elevations up to 160 m AHD as suspected (Scott 2007). Quarterly water quality results taken at numerous locations in the pit showed minimal variation in the pH hence concluding that maintaining a water seal of the dumped rock (below 155m AHD) would limit acid generation.

The outcome of this approach clearly shows that the current hydrology of the mine void is sufficient to maintain a water seal over the dumped waste rock. It was recommended that the weir levels remained unchanged based on these findings yet the forecasts should be reassessed periodically until final closure plans are implemented to take into account the latest climate and gauge data. The recommendation to maintain the current arrangement (weir levels at 169 m AHD) into the foreseeable future would have not been the same if the flood hydraulics of the Suttor River had not been investigated.

Applicability of this approach

As many current, abandoned and future mine sites are and will be located adjacent to or even within existing water courses, the approach followed in this case study is applicable to many sites. This is particularly relevant for metalliferous mines, abandoned or in care and maintenance, or mines that have acid mine drainage where preventing oxidation using a water seal can be a solution. Furthermore this approach can also be considered as part of the closure of a site rather than having levees sized for the probable maximum flood (PMF) as levees are prone to differential settlement and therefore overtopping and the general uncertainty of flood estimation.

This case study was completed with limited data using for the most part publically available data, and where some data had to be purchased it was inexpensive, which is particularly important as the case site is in care and maintenance and hence not generating a return. Current environmental compliance conditions of existing operating mines require the collection and monitoring of stream gauges where a site is adjacent to a water course as well as the collection and monitoring of climate data (particularly rainfall, evaporation). The purpose of this monitoring is often used for emergency management (preparedness and response) and for regulated releases of mine process water. However monitoring is often located upstream of the site and immediately downstream of the site (or at release points) rather than at locations to enable an accurate estimation of how a mine void may

Table 2 *Probability of Exposing Sulfidic Material (over forecast period of 10 years)*

Level of Sulfidic Material in mine void	**Flood Condition**	**Weir Level (m AHD)**			
		169 m (Current level)	**168 m**	**167 m**	166 m
160 m	Flood Hydraulics	53%	29%	21%	NIL calculated
	Fixed Depth	*82%*	*52%*	*29%*	*27%*
159 m	Flood Hydraulics	10%	7%	1%	NIL calculated
	Fixed Depth	*59%*	*29%*	*28%*	*23%*
158 m	Flood Hydraulics	4%	1%	NIL calculated	NIL calculated
	Fixed Depth	*49%*	*6%*	*2%*	*NIL* calculated
157 m	Flood Hydraulics	2%	NIL calculated	NIL calculated	NIL calculated
	Fixed Depth	*30%*	*2%*	*NIL calculated*	*NIL calculated*
156 m	Flood Hydraulics	NIL calculated	NIL calculated	NIL calculated	NIL calculated
	Fixed Depth	*20%*	*NIL calculated*	*NIL calculated*	*NIL calculated*

NIL calculated – water level was not calculated to recede to this level, so theoretically zero % likelihood.

interact with a water course at closure if determined suitable. As some sites footprint is over a substantial distance this approach remains applicable to sites even with monitoring. Furthermore this approach could limit the need for additional monitoring to understand the water level and interaction of pits with floods. To do this however the importance of high resolution survey data of the water course remains essential to take advantage of this approach together with nearby monitoring (stream gauges) taken at frequent time intervals.

The approach aligns with commonly adopted water management and engineering methods in flood estimation and mine water management. Accordingly, given the numerous abandoned mines with the liability now resting with the government, this approach can be used to better leverage the federal government network of flood monitoring sites, existing aerial captured photographic and topographic information to more accurately determine the reliability of water seals on mine voids and ultimately quantify its liability and rehabilitation costs.

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