Mine water management in variable climate regimes

Sue Vink[1], Sarah Robbins[1]

[1] *Centre for Water in the Minerals Industry, Sustainable Minerals Institute, University of Queensland, St Lucia, Australia 4072, s.vink@uq.edu.au*

Abstract

Recent extreme rainfall events in Queensland have tested both strategic and operational water management practices, infrastructure and regulation of mine water discharge. Coal export losses following the 2010-11 floods have been estimated to be in the order of $2 billion and 45 of the 57 coal mines in the Bowen Basin were affected by accumulation of water on sites. This paper reviews the impacts and response of the coal industry and environmental regulators to the recent floods in the Bowen Basin and comments of the dual-challenges of sustainable mine water management in climates characterised by extended periods of drought and severe floods events.

Keywords: extreme climate variation, mine water management, Queensland.

Introduction

Water management remains a key challenge for the mining industry. Increasing competition for water resources is driving the industry to implement more efficient processing methods and improved water management systems. In addition, mines are increasingly looking to alternative water supplies, including seawater (treated or untreated) and other poorer quality water sources such as sewerage effluent, as alternate water sources to reduce competition for both surface and groundwater supplies used for agriculture or drinking water.

The climate regime can exert strong influence on mine water management strategies. Mines are located in a range of climate zones and must therefore cope with extremely high rainfall in excess of 900 mm y^{-1} in the highlands of New Guinea to extremely low rainfall less than 10 mm y^{-1} in the Atacama Desert in Northern Chile. Pressure to employ demonstrable good water management practices under all conditions is increasing as local communities, governments and shareholders scrutinise water management indicators.

While managing mine water in extreme climate conditions presents numerous challenges, the ability of a site to engineer solutions for extreme but predictable conditions is reasonably assured. A far greater challenge is presented by variable climate regimes. Balancing infrastructure capacity (including tailings and water storages, pumps and discharge opportunities), water management strategies and investment costs is difficult to rationalise unless a long term outlook is maintained. This is particularly difficult for a mining company in a climate of rapid turnover of staff and the consequent loss of corporate memory.

Queensland, Australia has some of the most variable climate in the world: long frequency cycles of extreme drought and flooding typify weather regimes throughout most of this part of eastern Australia. This paper outlines the phenomenon controlling extreme climate variation in Queensland and reviews changes to mine water management and regulation as a consequence of the recent switch from drought to flood regimes. While this paper will focus on water management in Bowen Basin coal mines in tropical North Queensland, most mines in eastern Australia are impacted by similar long term extreme variations in climate. The experience of Bowen Basin mines thus exemplifies the challenges of mine water management in variable climates.

Drivers of rainfall variation in Queensland

The single most important factor determining inter-annual rainfall variability in Queensland is the El Niño Southern Oscillation (ENSO) phenomenon, driven by cyclical changes in the equatorial Pacific Ocean circulation and attendant atmosphere interactions on a period of approximately 3-8 years. Under normal conditions the Western Equatorial Pacific Ocean is approximately 8°C warmer than the Eastern Tropical Pacific Ocean. Warm equatorial ocean waters feed moisture into the atmosphere which increases rainfall. El Niño refers to a period in which extensive warming of the central and eastern tropical Pacific Ocean leads to weaker Trade winds and drier conditions in eastern Australia. During the El Niño phase, the chance of drought in Queensland doubles while under La Niña conditions above average rainfall is prevalent (McKeon et al. 1998). The development and relative strength of ENSO events is indicated by the Southern Oscillation Index (SOI), which is calculated using the mean sea level pressure differences between Tahiti and Darwin (BOM 2012). Figure 1 shows the variation in the SOI since 1980, clearly demonstrating the cyclical nature of the phenomenon. Sustained positive values of the SOI above +8 indicate a La Niña event, while sustained negative values below -8 indicate an El Niño event. Values of between about +8 and -8 generally indicate neutral conditions. In recent years, an extended period of drought occurred in the Bowen Basin, spanning from 2001/02 until the recent extreme wet season of 2007/08, aligning closely with the prevailing El Niño/La Niña synoptic conditions.

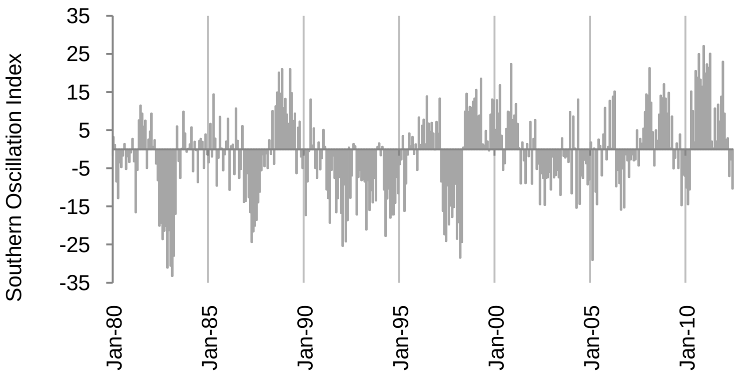

Figure 1 *Variation in Southern Oscillation Index since 1980 (data: BOM 2012)*

ENSO events are also reinforced or dampened by the Interdecadal Pacific Oscillation (IPO) operating on a much longer time scale of 20-30 years (Mantua et al. 1997). This compounds variability and unpredictability of long term climate variations in Eastern Australia. The developing La Nina in mid-2010 was reinforced by the IPO leading to the highest recorded sea surface temperatures off Australia's northeast coast and consequent highest rainfall totals throughout Queensland on record.

Although the ENSO phenomenon has been well described since the 1960’s and the IPO for over a decade, only relatively recent advances in global ocean circulation models has allowed reasonable prediction of ENSO events, including the timing of switches between El Niño/ La Niña periods and the relative strength of each period. The Australian Bureau of Meteorology (BOM) has developed a coupled ocean-atmosphere model “Predictive Ocean Atmosphere Model for Australia” (POAMA) to predict changes in sea surface temperature and rainfall on timescales of weeks to seasons. The development of this model over the last decade has facilitated improvements in seasonal and intra-seasonal forecasts for applications in agriculture, energy, water management, financial markets and insurance (Hudson et al. 2011). The model can now predict significant anomaly correlations in sea surface temperatures at lead times of 9 months (Wang et al. 2008) and rainfall at lead times of two weeks to months (Hudson et al. 2011). These predictions are not currently being used to forecast mine water inventories or to guide management strategies.

Bowen Basin mine water management

Coal production in the Bowen Basin has been increasing dramatically since the 1970’s and now occurs in high densities in localised regions throughout the basin. This growth, fuelled by ongoing high demand for coking coal from development in China and India, has sometimes been constrained by water availability. Mines in the Fitzroy region typically use surface water supplies as groundwater supplies are generally limited and/or of poor quality in the region, with the exception of a few localised bore fields. Given that surface streams are often ephemeral in the region, the predictability of water supply availability is lessened. For example, the Isaac River in the heavily mined Isaac-Connors region experiences flows of greater than 100 ML d^{-1} on approximately 10% of days (Figure 2).

In response to the increased competition and scarcity of water supplies, significant investments have been made by water supply providers and by mining companies in regional and mine site water infrastructure in the Bowen Basin to alleviate these pressures, including works to transport water between catchments to supply high density mining regions. The most recent additions, the Burdekin Falls to Moranbah pipeline and the Eungella pipeline opened in 2007 (after the extended drought period), costing an approximate $271M in capital expense and providing an additional 25 GL y^{-1} of water to the Isaac-Connors mining region. The planned Connors River dam will add further capacity to the region, supplying mines and other water users in the Bowen and Galilee Basins.

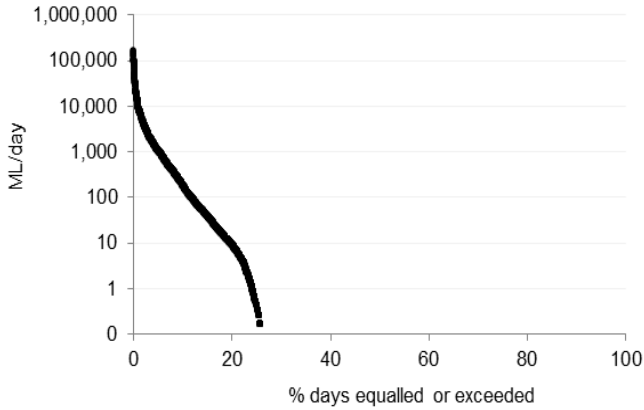

Figure 2 *Exceedance curve of stream flow in the Isaac River at Deverill (data: DNRM 2012).*

Despite the expansion of water infrastructure in the Bowen Basin, dramatically lower annual rainfall in the order of 30% during the last El Niño drought phase, significantly affected mine water supplies. Record low water levels in major supplies resulted in cuts to high security water allocations to the mines. This increased cost and reduced supply security, prompting considerable efforts to improve operational water management. In order to meet corporate targets for reduced freshwater use and improved water-use efficiency, most sites increased the amount of worked water being used for tasks such as coal washing and road dust suppression.

A benchmarking study of water use in several coal mines in the basin suggested that if all mines adopted leading practices for maximising water re-use, savings could be made in the order of 70% of freshwater use and 40% of total water savings (Moran et al. 2006). Interestingly, modelling of mine water systems on a number of mine sites using the infrastructure configuration present during the drought, but driven by a 100 year rainfall record, showed that the water status of mine sites in the region varied considerably. ***Figure*** **4** Figure 3 shows the water status of several mine sites ranging from water replete to water scarce (Moran et al. 2006).

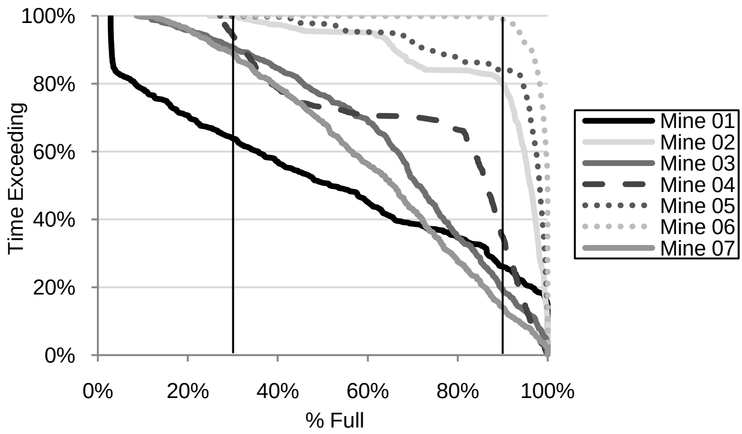

Figure 3 *Water status of seven mine sites in the Bowen Basin. Wet and dry indicators are shown by the vertical solid lines. One site has a high risk of running dry (black solid line) while two other sites have a significant risk of requiring to discharge being >90% full at least 80% of the time (Moran et al. 2006).*

Water quality implications of mine water management

One of the consequences of increasing water re-use on sites during the drought was that water quality was compromised. In general, salinity in the stores could be expected to increase on the order of 3,000–4,000 mg/L (Moran et al. 2006). There were, however, some unexpected benefits; for example, enhanced flotation efficiency using saltier water outweighed the increased equipment maintenance costs due to corrosion and degradation of gland seals (Moran et al. 2006). The increased risk of accumulating water that might not meet water quality release criteria was not considered to be an unacceptable risk owing to the fact that no mines had discharged water for the most of the previous decade. Indeed, some mines had instead redesigned infrastructure to maximise the capture of as much rainfall/runoff as possible (QRC 2011).

Although direct input of rainfall and runoff generally diluted the water stored in pits and dams (Vink et al. 2009), water quality deteriorates during storage. Figure 4 shows the increase in salinity of approximately 3,000–4,000 µS/cm over only 6 months for one pit following flooding in 2007/2008. This increasing salinity further compounded each site's opportunity to release water.

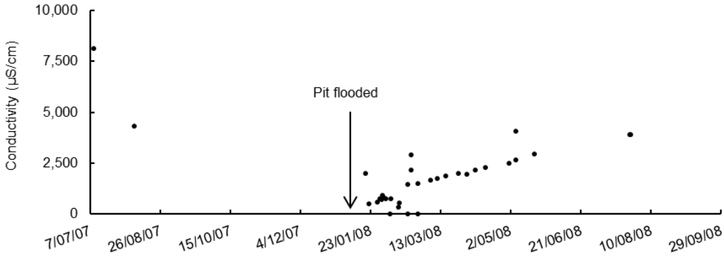

Figure 4 *Electrical conductivity of water stored in a flooded mine pit in the Bowen Basin during the 2007-08 wet season.*

The floods of 2007/08 & 2010/11

In 2007 El Niño conditions weakened and the ensuing wet season rainfall, influenced by La Niña conditions, resulted in flooding of mining pits on several mine sites in the basin. Around 400 mm of rain fell from December 2007 – February 2008. The largest event saw 129 mm rainfall in just three days in January 2008, followed by another 103 mm in a 24 h period on 5 February 2008. Several mine sites flooded over the course of the wet season and many mines were unable to comply with their discharge regulations. Flooded sites were granted Transitional Environmental Programs (TEP), allowing discharge at higher volumes and salinity above those stated in site's Environmental Authority (i.e. a mines environmental licence conditions), to avoid infrastructure damage and potential hazards, and to allow for production to resume. The most severely affected mine released 138 GL of water stored in its pits during the subsequent dry season.

Mine water releases were restricted in the following years in response to public concern over the potential impacts of the release of saline water into water ways in the Fitzroy, resulting in many mines storing large quantities of excess water into the following wet season. Above-average rainfall in 2008/2009 and 2009/2010 did not relieve the excess water inventory held on sites. Opportunities for water release were limited by new regulations introduced to address the cumulative impacts of mine water discharge (discussed below) and a lack of appropriate infrastructure at some sites.

Preparedness of the industry for another extreme wet season varied. Following the 2007–2008 wet season most companies rationalised water storage capacity and many invested in additional storage, upgraded pump capacity and discharge point infrastructure. In addition, a number of mines continued to use pits as water storages.

The 2010/11 wet season saw record rainfalls throughout Queensland and within the Bowen Basin (~660 mm), leading to further significant flooding of mine operations. By the end of February 2011 over 80% of the 57 coal mines in the Bowen Basin were operating under restriction due to excess water. To compound the issue, a further 281 mm of rain fell in March/April 2011. Coal production was reduced by over 30% in 2011 with revenue losses estimated to be in the order AUD$5 billion and royalties to the state government reduced by AUD$400 million

(QRC 2011). In May 2011 about 500 GL of water remained on sites and as of late July 2011, 69 Transitional Environmental Programs (TEP) were in place to allow releases in order to manage the excess water. TEP's were also granted to a coal seam gas company to manage excess water. Some mines required 12 months to return to production after the floods and many mine sites continue to transfer water between pits to allow mining.

In order to continue production, mines are currently pumping water between pits as well as constructing new storages and water treatment facilities. These measures however cannot represent a long term sustainable solution as the repercussions of increased energy consumption and lack of brine disposal options remain problematic.

Mine discharge regulation: The Fitzroy model conditions

Since 2001, coal mine water discharge has been regulated by conditions listed in each mine's Environmental Authority, a regulatory instrument issued under the *Environmental Protection Act 1994*. After the 2007/08 floods, the Queensland government released two reports on the impact of mine water releases and the cumulative impacts of mining on water quality in the Fitzroy (Hart 2009; DERM 2009). These studies found that mine discharge requirements were inconsistent amongst mines, and that discharge water quality limits for some coal mines were insufficient to adequately protect downstream environmental values (DERM 2009). The end-of-pipe discharge EC limits varied widely and in some cases, discharge timing was not linked to stream flow of the receiving waterways.

In response, the Queensland government introduced the draft Fitzroy model conditions in June 2009. The draft model conditions introduced standardised conditions for determining the minimum stream flow for receiving waters for a discharge event to occur, and for determining the EC limits and rates of release of mine water discharge. Allowable discharge opportunities became more tightly coupled with the streamflow of receiving waters, on the assumption of a higher assimilative capacity for salt load from mine water discharge under higher stream flows. Many of the streams in the region are ephemeral and as such, potential discharge days of mine sites are limited. Streamflow tends to recede rapidly after rainfall events in these rivers which means that the window of opportunity to discharge mine water is brief, often only a matter of days after rainfall events. The draft model conditions tightened mine water discharge regulation and, in some cases, decreased mine water discharge opportunities (QFCI 2012). Consequently, during the 2010/11 wet season floods, the Queensland government received over 100 applications for TEP's to allow for additional mine water release opportunities to avoid infrastructure damage, avoid hazards and to resume operations (QFCI 2012).

The model conditions were reviewed and updated in mid-2011. The new model conditions were intended to provide greater flexibility to sites to a reduce reliance on TEPs whilst maintaining water quality objectives set to maintain environmental values. Concessions to mine operators in the new model conditions include a greater flexibility to obtain site specific amendments to the conditions and allowing for higher volumes of discharge release under high streamflow conditions (QFCI 2012).

Concluding remarks

Mine water management is complicated in the Bowen Basin by high intra- and inter-annual variability in rainfall; this variability is governed, in part, by synoptic scale climate patterns including the ENSO cycle and the IPO. In the last decade, mines in the Bowen Basin have experienced extended periods of droughts and water scarcity, and more recently periods of extreme flooding. Security of operations and mine productivity is affected under both of these extremes.

At the site scale, these conditions present significant challenges in developing effective mine water management strategies, including planning and operating protocols and infrastructure investment decisions. These challenges are furthered by the role of people and memory within the corporate structures; high staff turnover means that lessons learnt long ago may have been more recently forgotten (or at least deprioritised) in the corporate conscious.

The recent extreme wet seasons of 2007/08 and 2010/11 resulted in widespread mine water accumulation across the Bowen Basin, reducing productivity and closing mine operations in some examples. The cumulative pressure of increased saline water discharge to river systems in the region from the 2007/08 floods initiated a significant reform of mine water regulations. Striking the balance between effective yet flexible regulations to accommodate the extreme climate variability in the region is an ongoing challenge for regulators and operators.

The mining sector and government regulators have learnt significant and, at times difficult, lessons over the extreme wet seasons of recent years; the foremost of which has been a heighted understanding of the objectives and constraints operating on both parties. From a regulatory perspective, water quality objectives have been set for the region's waterways that clarify expectations for water quality management. Although, significant reforms have also been made to mine water discharge regulations, providing a greater degree of flexibility to mine operators and to better addressing the cumulative impacts of saline mine water discharge on river systems in the region, significant quantities of water continues to accumulate on sites. The mining industry has invested significantly in infrastructure to provide greater flexibility and contingency options in the case of extreme weather conditions in the Bowen Basin; both for the provision of water in droughts and for discharge and storage during wet seasons. Many sites have also implemented improved water inventory systems, to enhance operator and corporate understanding the quantity and quality of mine-affected water stored on site

There is an urgent need to develop better long term solutions to managing water on mine sites in the Bowen Basin in the face of high rainfall events. These solutions should improve the ability to anticipate high inflows based on weekly to monthly meteorological forecasts, to account for and mitigate risks associated with the likelihood of above or below average seasonal rainfall, and develop improved water management strategies on mine sites in the face of large climate variability. Incorporating predictive capability based on synoptic seasonal climate outlooks into water planning is recommended to improve mine site water management in the Bowen Basin and other mining regions operating under extremely variable climates.

References

BOM (2012) Bureau of Meteorology, accessed from www.bom.gov.au, 2012

DERM (2009) A Study of the Cumulative Impacts on Water Quality of Mining Activities in the Fitzroy River Basin, The State of Queensland (Department of Environment and Resource Management).

DNRM (2012) Water Data Monitoring Portal, accessed from http://watermonitoring.derm.qld.gov.au/host.htm, 2012. The State of Queensland (Department of Natural Resources and Mines).

Hart B, Greenfield P, Pascoe M (2008) Review of the Fitzroy River Water Quality Issues – Report to Queensland Premier, http://www.fitzroyriver.qld.gov.au/hartreport.html

Hudson D, Alves O, Hendon HH, Marshall AG (2011) Bridging the gap between weather and seasonal forecasting: intraseasonal forecasting for Australia. Q. J. R. Meteorological Soc. 137: 673 – 689.

Mantua NJ, Hare SR, Zhang Y, Wallace J, Francis RC (1997) A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society, 78(6): 1069 – 1080.

McKeon GM, Hall WB, Crimp SJ, Howden SM, Stone RC, Jones DA (1998) Climate change in Queensland's grazing lands. I. Approaches and climatic trends. Rangeland Journal 20: 151 – 176.

Moran CJ, Cote CM, McIntosh J (2006) Northern Bowen Basin water and salt management practices. ACARP report C15001, http://www.acarp.com.au/search.aspx?&qS=C15001, p 357.

QRC (2011) After the Deluge, AusIMM Technical Meeting, Queensland Resources Council, 17 February 2011.

Vink S, Moran CJ, Golding SG, Baublys K, Nanjappa V (2009) Understanding Mine site water and salt dynamics to support integrated water quality and quantity management. Water in Mining. Perth WA.

Wang G, Alves O, Hudson D, Hendon H (2008) SST skill assessment from the new POAMA-1.5 system, BMRC Research Letters 8: p 2.

QFCI (2012) Queensland Floods Commission of Inquiry – Final Report, Queensland Floods Commission of Inquiry, March 2012.