Water in mining challenges for the Australian and international mining industry

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Abstract

Two major themes are addressed in this paper. Firstly, current and emerging concepts and issues (water banking, regional water treatment, geothermal energy, regulation) impinging on the management and beneficial use of minewaters. Secondly, the issue of cumulative impacts of mining on water resources which is of concern where ever large proportions of river catchments have become progressively more affected through time by expansion of a regional mining industry. Finally, sulfate is addressed as an emerging horizon issue in the context of cumulative impacts of mining discharges on river systems.

Keywords: mine water beneficial use, water banking, water treatment, cumulative impacts, sulfate

Introduction

Most of the challenges associated with the production, utilisation and environmental management of minewater (apart from those associated with freeze-thaw) are faced in Australia which, on average, is the driest inhabited continent on Earth. While water consumption by the mining industry in Australia accounts for around only four per cent of the total estimated water use (Fermio and Hamstead, 2012), this use has been increasing rapidly in the last decade and, in a number of regions across the country, mining has become the largest consumer of water. This is especially likely to be the case in semi-arid areas, where groundwater is used to sustain agrarian activities that may be in potential competition with mining, where artesian groundwater sustains ecological communities of national environmental significance or where there are multiple adjacent large-scale mining operations in river catchments.

Historically mines have often been net consumers of water, whilst simultaneously producing contaminated water that needs to be carefully managed to avoid environmental detriment. Indeed this issue has been the trigger for the much increased focus on optimising mine water use and balance over the past decade. The next big challenge will be shifting the paradigm to more implicitly consider and manage mine water as a resource over the life cycle (including rehabilitation and closure) of a mine.

Current and emerging concepts for minewater as a potential resource, whether it be for water supply per se or for some other beneficial use, and the challenges associated with implementation of these concepts will be the first theme that is explored in this paper. In this context it should be noted that past lack of integration of mine planning and operations with regional water planning, and differences between the mining industry sector's regulatory regime and the water sector's regulatory regime, has often strongly inhibited the most efficient use of minewater as a potential resource, irrespective of its quality, in many jurisdictions. A recent report released by the Australian National Water Commission specifically addresses this issue in the Australian context (Fermio and Hamstead 2012). A number of key recommendations were made that, if implemented, could appreciably normalise the participation in the water trading economy of producers of surplus mine-derived water of sufficient quality.

A second regulatory issue relates to the broad scale application of generic water quality guideline criteria or objectives, without the provision to be able to modify such guidelines to take into account local specific conditions. The EU Water Directive is an example of one of these types of prescriptive regimes, and there have been several papers about it at previous IMWA conferences. Bilotta et al (2012) discuss the issues in the context of turbidity, a parameter that is of direct relevance to the management of mine runoff. The ability to take into account site specific water quality conditions and to modify guideline values using local biological effects data is implicit the Australian and New Zealand Water Quality Guidelines (ANZECC and ARMCANZ, 2000).

The issue of minewater as a potential resource has recently been brought into sharp focus in Australia as a result of a combination of climate-induced and industry expansion drivers. Firstly, this country has a tremendously variable climate, having just come out of a 10 year drought cycle over the Eastern half of the continent with two years of well above average rainfall. These latter events have proved extremely challenging for minewater management of open pit mines, in the state of Queensland in particular, and have triggered both revision of the water management regulatory regimes that apply to these situations and a rethink of how minewater should be regarded as a component of regional water management and trading schemes (Department of Environment and Resource Management (DERM) 2009, Fermio and Hamstead, 2012). Secondly, in Queensland, the rapid rise over the next few years in coal seam gas production will see the need to manage large annual volumes of treated and untreated co-produced water, currently estimated to peak above 130 GL/y over a ten year period (RPS 2011).

Implicit in use of the term "minewater as a resource" is a water quality dimension. The better the quality of water that is produced in the first instance, the less further manipulation or treatment that may be required to permit reuse or discharge to the receiving environment. In this context the production, storage and use of mine water needs to be addressed as a whole of mine life issue, since attention to how water is generated on a minesite and how it is subsequently stored, discharged and/or utilised is fundamental to its ability to be successfully integrated with broader regional water planning and use frameworks. Many papers at this and former IMWA conferences and other forums address specific technical issues and challenges relating to dewatering of mines, predicting and controlling leachability of mine wastes, planning for closure, and characterisation and management of legacy sites. It is not my intention here to reprise these areas of work, but rather to highlight some of the new concepts and associated challenges for the broader future uses of minewater, with the implicit understanding that attention to those factors influencing water quality, and which can be more substantively addressed as a part of mine planning and operational management, is a key underpinning consideration.

The second theme to be addressed will be the issue of cumulative catchment impact, which is a major issue where-ever large proportions of river catchments have become progressively more affected through time by expansion of a regional mining industry. In Australia, addressing cumulative impact as part of the environmental approvals process has become a major contemporary issue for the rapidly expanding coal mining and coal seam gas (CSG) industries in the states of Queensland and New South Wales, where the possibility of multiple intersecting cones of depression extending over hundreds, if not thousands of square kilometres, and effective methods for utilisation or disposal of produced water is becoming a substantial issue for regulators. Landscape scale water balance, as distinct from the smaller regional scale impacts usually addressed by individual mining proponents and mine operations, is the big issue here. At a technical level, quantifying the cumulative impact presents a substantial challenge for the creation of coupled surface and groundwater models that can both adequately account for regional hydrogeological variation whilst robustly predicting extent of change.

Mine Water as a Resource

1. Water Banking

One of the key problems with fully realising the potential for mine water as a resource relates to the separation in time between when the water is produced and when it is needed. The concept of "water banking" is a term that can be applied to a range of potential water management options, involving both surface and subsurface storage. The intent of water banking is to place water of sufficient quality into storage such that it can be retrieved for beneficial use at a later date. This concept has particular appeal for those circumstances where rainfall is low or irregular, and/or for where there has been historical over-use of groundwater resources. The source of the water can be treated or untreated minewater. Minewater treatment, in particular, offers the prospect of transforming water from an initially unusable aquifer (or mine pit) into a valuable commodity in a water stressed region. However, there are typically substantial institutional and community perception barriers to such schemes where they involve supply of potable or irrigation water. The following categories of water banking are considered below: open pits, aquifer-reinjection/managed aquifer recharge and artificial aquifers.

a. Pit Lakes

Pit lakes as features of closed out mine sites continue to be of major interest in the development of closure planning strategies. In particular, for the use of such pits for recreation or for the supply of supplemental water for irrigation or stock watering in those areas which may suffer from lack of water during dry periods. Substantial technical advances in pit water quality prediction have been made possible by well monitored full scale field implementation and the evolving capacity of coupled hydrodynamic and solution geochemical models to predict trends in flooded pit water quality. The Acid Drainage Technology Initiative, Metal Mining Sector (ADTI-MMS) Pit Lake Workbook (Castendyk and Eary, 2009) represents the culmination of extensive international collaboration to address the characteristics, predictive modelling, and sustainability of pit lakes in arid and humid climates around the world, and is the first comprehensive guidebook exclusively devoted to pit lakes. Pit lakes and the factors controlling the evolution of their water quality have been a regular feature at past IMWA conferences, and this current one is no exception.

In general rapid flooding, maintenance of stratification, and the encouragement of biological productivity in the littoral (ie the photosynthetically active) zone are seen as the most critical factors for both initial and long term success of a pit lake option in the event that a high quality surface water environment is the objective. However, it may not always be possible to harvest water in sufficient quantity from a surface water catchment to ensure the pit is filled sufficiently fast to minimise the consequences of oxidation of reactive material in the pit walls. In this case the use of water produced by dewatering of other mines in the region could be considered. A good example of the effective use of this strategy is provided by the closure in eastern Germany since 1990 of the majority of lignite mines in the Lusatian and in the Central German lignite mining districts (Schultze et al 2011). Whilst diversion of river water was the main method used for fast filling of the pits, the use of water from dewatering operations of still active mines contributed substantially (21% of volume) to the filling of the pit lakes over the last 20 years.

b. “Artificial” Aquifers

The term “artificial aquifer” refers to a man-made aquifer, the storage zone of which consists of the void space in a backfilled strip mine or open pit. This concept has been demonstrated at full scale at the Elands Platinum Mine (EPM) located in the north west of South Africa (Botha and Maleka 2011). Raw water is stored in a backfilled mining void and boreholes installed in the backfill are used to extract and supply water to a water treatment plant which supplies process water for the mine. This approach reduces the risk for the mine to lose production as a result of water shortages. There is potential for this concept to be applied elsewhere where the physical and geochemical characteristics of the pit backfill are suitable.

c. Aquifer Re-injection/Managed Aquifer Recharge

Substantial national and international research has been conducted on this concept, but to date in Australia this effort has largely been focussed on the reuse of degraded and/or treated potable water (Parsons et al 2012). However, that situation is rapidly changing, in Queensland in particular, where the rapid rise in coal seam gas production will see the need to manage large annual volumes of treated and untreated co-produced water, currently estimated to peak at 130 GL/y over a ten year period.

Coal seam gas water quality in Queensland varies by region but is typically brackish in quality (100-10,000 mg/L of total dissolved solids), sodic, and high in bicarbonate, making it unsuitable for many uses without treatment. Managed injection into currently over-allocated and depleted beneficial use aquifers and use for irrigation of pastures and crops are two of the potential options that are being considered for beneficial use of the high quality treated water. Santos, one of the current three approved CSG proponents in Queensland, is currently partnering with CSIRO and a major consultant (URS) for a one year trial to study the potential of injecting treated water into underground aquifer systems in the Roma area of Queensland to boost town water supplies.

Disposal options will also be needed for the brine streams produced by reverse osmosis treatment of the co-produced water. However, utilising aquifer reinjection to dispose of the brine stream is likely to be more challenging than the treated stream, given the physical (injection capacity of the much deeper potential target formations), the geochemical (for example, precipitation of secondary minerals and plugging of void space) and the community perception and regulatory issues that need to be addressed.

Comprehensive discussion and analysis of the potential issues associated with use of CSG related waters for surface irrigation, discharge to surface waters or aquifer injection are provided in recent reports (http://www.derm.qld.gov.au/environmental_management/coal-seam-gas/water-feasibility-study/) produced by the Healthy Headwaters CSG Water Feasibility program of activities funded by the Commonwealth Government and managed by the former Queensland Department of Environment and Resource Management.

2. Regional minewater treatment for beneficial use

The issue of cumulative impacts of mines on catchments is especially acute in South Africa since the limited dilution potential associated with low rainfall in much of the country exacerbates the contribution of salinity associated with minewater to the salinisation of water resources. A regional mine closure strategy developed in South Africa and being progressively implemented by the regulatory authorities is designed to ensure the orderly and responsible closing of mines which exploit the same ore body, and/or which impact on a common groundwater resource (van Tonder et al. 2009). This represents a fundamental change from the previous approach (still applicable in many other countries) in South Africa where mine closure was addressed from the perspective of individual mines and did not address cumulative effects (eg uncontrolled rebound of contaminated groundwater from multiple connected operations).

The eMalahleni mine water reclamation project, a joint initiative between Anglo Coal South Africa and BHP Billiton Energy Coal South Africa, treats (see Gunther et al. 2006; Hutton et al. 2009 for details of the process) acidic and metalliferous water from four close proximity coal mine operations. This regionally integrated minewater treatment system is a world first and is a leading practice example of what is likely to become much more widespread mechanism for regional beneficial use of minewater in the future.

The treatment plant currently produces 24 ML/d of potable grade water with 18 ML/d supplying the previously potable water deficient nearby eMalahleni municipality, and the remainder supplying process and potable water requirements for the mines. The capacity of the plant will be expanded to treat 50ML/d by the end of 2013.

Treatment of the otherwise unusable underground water will also substantially reduce the operational and post closure risk of these mines to existing surface and groundwater resources. In addition it will improve safety in still-operating underground workings that are hydraulically connect to closed workings.

There is potential for lessons learned from this project to be applied internationally where there are competing land uses and increasing pressures (especially during drought) on ground and surface water resources. This is especially likley to be the case in Australia over the next decade as the footprint of open cut coal mining and coal seam gas extraction expands dramatically in the east, and as the footprints of large open cut iron ore mines expands in the northwest.

3. Minewater as a source of geo-thermal energy

An unusual example of a beneficial use for flooded underground workings is provided from Europe where the temperature differentials between different horizons in flooded underground mine workings are providing the opportunity for the operation of large scale geothermal and heat-cold storage systems (Strebb and Weber 2011, Ferket et al 2011). One specific example is the Heerlen mine system in Belgium that extracts low–enthalpy geothermal energy from the flooded Oranje-Nassau coal mine complex (Ferket et al 2011). Approximately 300 dwellings and a number of community service facilities are serviced by the system which is based on a geothermal gradient of about 3.4°C per 100m.

Cumulative Impacts of Mining on Water

Accounting for and managing the cumulative impacts of mining on a regional or catchment scale is becoming an increasingly important issue in those parts of the world that host laterally extensive reserves of mineral or energy resources. In the case of mining, cumulative impacts can be the result of: the compounding effects of a single mining and/or processing operation; interference effects between multiple mining and processing operations; interaction between mining and non-mining (eg agriculture or urban development) domains. Cumulative impacts may occur simultaneously, sequentially, or in an interactive manner.

In Australia the matter of cumulative impacts is a rapidly developing issue with the simultaneous expansion of large open cut coal mines and coal seam gas extraction in the eastern half of Australia, and the large open cut iron ore mines in the northwest of Western Australia. In particular, the rapidly developing issue of large coal mines and CSG was recognised by the Australian Government funding in November 2011 a $150m five year program of assessment and research specifically addressing the (cumulative) impacts of large coal mines and coal seam gas extraction on water resources and associated environmental values (http://www.environment.gov.au/coal-seam-gas-mining/about.html).

The program of works to be undertaken by this Government initiative will address the full range of technical issues ranging from the fundamental science of groundwater modelling of laterally extensive heterogeneous and interleaving geological formations, through to developing strategic assessment methods that can be used to define the maximum extent of mining development that can occur in a given region before there may be an unacceptable impact on water resources. The objectives are firstly to improve confidence in prediction of cumulative impacts and secondly to be able to specify the (regionally specific) extent of development that can occur without unacceptable detrimental impact.

Whilst there is a reasonably extensive literature on the concept of cumulative impact assessment, with several recent projects having been undertaken in Australia to develop frameworks to account for the cumulative impact on surface and groundwater from mining (Franks et al 2010 a,b; Howe et al 2010; SKM 2011), there has been relatively limited application of these suggested approaches to test their particular limitations or efficacy for the broader mining industry. Rigorous comparative evaluation of cumulative impact assessment methodologies will be a very fertile current research field with the outcomes of major interest and import to the future of mine regulation.

Sulfate, in particular, is an emerging issue for considerations of cumulative impact from minewater as sulfate is typically one of the major solutes present in most minewaters, irrespective of pH. There are two reasons for this. Firstly, it's direct contribution to salinity in water discharged to catchments, and secondly its indirect effect as a result of microbial reduction of sulfate to hydrogen sulfide in the porewater of downstream sediments containing sufficient organic carbon. Whilst sulfate *per se* is of low toxicity (ANZECC and ARMCANZ, 2000), hydrogen sulfide is more toxic than hydrogen cyanide. If sufficient reactive iron is present in the sediment, then the produced sulfide will be converted to diagenetic iron mono and disulfides (eg mackinawite and pyrite), so under these circumstances toxicity from hydrogen sulfide will not be such an issue.

Provided that the sulfide-containing sediment remains wet then this material will be relatively innocuous. However, if the waterbody dries out and the sediment becomes exposed to oxygen, then the familiar condition of acidic and metal rich drainage can occur. This scenario has particular implications for those environments subjected to seasonally wet and dry cycles, and to periodic drought. Anthrogenic acid sulfate conditions were a cause for major concern in the lower reaches of Australia's Murray-Darling River system during the years prior to the end of the recent drought period (Baldwin and Capon 2011). Whilst general land management practices, rather than mining, were the primary source of the sulfate in this instance, the lesson from this situation is that cumulative inputs of sulfate-containing minewater into potentially suspectible river catchments will likely be much more rigorously assessed in the future. Indeed, this issue will be a topic for consideration in the revision that is currently underway of the Australian Water Quality Guidelines.

Conclusions

This paper has identified and discussed emerging concepts and associated challenges for the beneficial use of minewater, including water banking (pit lakes, aquifer reinjection, and artificial aquifers), regional water treatment and geothermal energy. In many cases the regulatory framework can be the single largest issue that needs to be addressed, whether it be via the application of generic rather than locally derived water quality criteria, or the application of a separate regulatory regime to minewater that prevents or inhibits the integration of mine water management systems into a regional water management and utilisation plan.

The ability to account for the regionally cumulative impacts of mining on water resources is emerging as a major issue that needs to be implicitly addressed as part of the environmental impacts assessment and approvals process. In Australia this is being triggered by the resources boom involving coal mines and coal seam gas in the eastern half of the continent, and the large scale expansion of iron ore mining in the northwest. The need to address cumulative impact is especially likely to emerge for laterally extensive resources where incremental development has the potential to ultimately substantially impact the regional water balance.

Finally sulfate has been identified as an emerging horizon issue for the management of minewaters. Whilst sulfate itself is relatively non-toxic and has historically been regulated on the basis of human drinking or stock watering criteria, this may soon change given the potential for bacterial reduction of sulfate to sulfide in the sediments of water bodies, and the formation of sulfide minerals (anthropogenic acid sulfate soils). Whilst the formation of these sulfide minerals may not be of substantive concern if the sediments remain wet, they can result in a significant environmental management issue if the water body dries out as a result of either drought or abstraction of water for other uses (including mine process supply).

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