The Interaction and Impact of Water on Mining in Australia—An Overview

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ABSTRACT

The Broken Hill Proprietary Company Limited (BHP) is Australia's largest company with widespread commercial interests ranging from steel productin to minerals, oil and gas recovery. While these interests are worldwide, the Company operates or is partner in more than 30 Australian mining ventures. BHP Engineering (BHPE) is the in-house consultant to BHP but is also the largest consultancy in Australia available to general industry.

Australian Groundwater Consultants Pty Limited (AGC) is a large, independent consultancy offering specialist services in all aspects of water resources, waste management and environmental engineering, both in Australia and overseas. AGC is particularly well regarded within the industry and has a considerable record of providing solutions for mine water related issues.

By drawing on the extensive combined experience of AGC and BHP Engineering, this paper will summarize some of the unique ways in which water interacts with and impacts on mining operations in Australia, particularly in matters such as:

Slope Stability
Drainage and Dewatering
Production Cost (Transport, Drilling, Blasting, etc)
Water Supply
Water Management
Tailings and Waste Management
Environmental Issues.

The paper will also illustrate the cost benefit of providing major engineering works for reduction in total mining cost. It will be shown that, through advance planning and close interaction between outside experts (ie consultants) and on-site personnel, very significant operational cost savings can be made while at the same time achieving a safe and responsible mining environment.

INTRODUCTION

Mining in Australia is characterized by the diversity of operating conditions that apply.

This is not surprising for a continent which covers a total area of 7 686 884 km^2, comparable in size to the USA, one third of the USSR, or 32 times the size of the United Kingdom, but with less than 15 million people.

With a climate spanning temperate to tropical and large arid or semi-arid areas, recorded temperatures [1] range from a high 53^{0}C in central Queensland to a low -22^{0}C in the Snowy Mountains (New South Wales). Average annual rainfall ranges from 4.2 m to only 0.14 m, and large parts of northern Australia are subject to cyclonic rainfall and winds. Even local conditions vary greatly, and fluctuations of up to 600% in annual rainfall are not uncommon.

Of the 324 operating mines in Australia [2], a large number are located in very remote locations. With inconsistent rainfall resulting in conditions ranging from flood to drought, groundwater often of poor quality and the need to comply with stringent operational and environmental criteria, water has a major impact on mine viability and represents a significant economic, engineering and operational challenge.

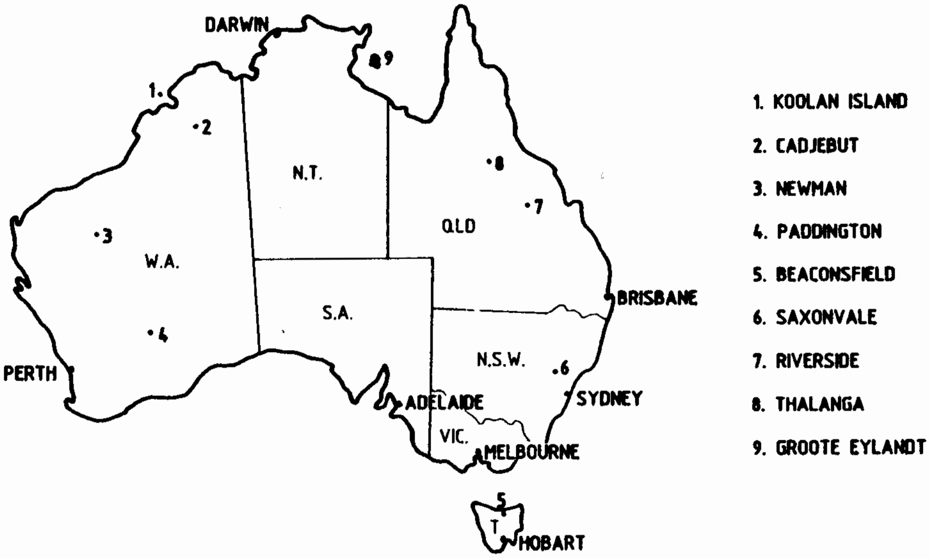

Figure 1 - Project Locations

WATER AND MINING IN AUSTRALIA

Most of the effects that water has on mining in Australia do not differ in principle from those elsewhere in the world, but because the climate, the distance to general infrastructure and the geology is unique, and particularly because the water resources are largely underdeveloped and unexplored, investigative techniques and solutions can be very different from those traditionally adopted elsewhere. It is also worth remembering that European settlement of Australia is relatively recent, and information on such things as evaporation and rainfall is often limited with fairly short periods of record. In many remote mining locations in Australia, no local data on rainfall, evaporation and runoff are available prior to mine feasibility studies. Under these adverse conditions, investigations and solutions are particularly difficult and vulnerable in a world of ever changing commodity prices.

The water supply investigations undertaken for the proposed Thalanga lead, copper and zinc mine in Northern Queensland is a good example of this. Located in an extremely dry area of Australia, a reliable water supply for the mine was essential. The very limited amount of existing information on possible local water sources was discouraging. Water was available from a dam some 135 km away, but the cost of pipelines, pumps, etc exceeded A$12 million, a detrimental price to the project. A decision tree for the investigations was set up containing possible cost of supply, level of confidence in supply adequacy and cost of investigations to increase this confidence. With high evaporation rates, inconsistent and inadequate surface water availability, it was decided to investigate the possibility of a local groundwater supply initially. However, because this part of Australia had experienced almost seven years of drought, traditional geophysical methods were not readily applicable. Extensive exploration drilling was out of the question because of the large area to be covered. After three months of frustrating work, some local storms provided enough ground moisture for a resistivity survey to be completed successfully and two small yield sources were identified and drilled. While the supply found was adequate for initial production estimates, changing commodity prices forced the mine to evaluate higher production rates for which the supply was considered inadequate. This was followed by changes in world lead, copper and zinc prices which compared unfavourably to further mine development at the time. In this case, the economics of water supply played a major part in determining the viability of commencing mining operations.

A similar experience at the Paddington gold project of Pancontinental Mining Ltd in Western Australia reached a favourable result. When the feasibility of mining was being evaluated, two options for water supply were available - connection to the Goldfields and Agricultural Water Supply Scheme (a public water supply pipeline carrying water 600 km from Mundaring Weir near Perth) 25 km away, or local groundwater. For the project's water requirement of 3 500 kL/d, the capital cost of connection to the Goldfields pipeline would have been prohibitive, at more than A$30 million. However, the groundwater resources of the project area were not at that time considered capable of supporting a sustainable abstraction rate of this size.

An extensive groundwater exploration programme was completed involving geophysical surveys, test drilling and test pumping, resulting in the location and development of a previously unknown major aquifer system just 5 km from the mine site [3]. This water supply is hypersaline, at up to 120 000 mg/L total dissolved solids (TDS), with pH of around 5. Nevertheless, it proved suitable metallurgically, with the small, high quality water supply for gold elution obtained by desalination of part of the raw water supply using vacuum distillation. With an acceptable capital cost of less than A$5 million for water supply, the project has proceeded to development and has been producing for several years. The high salinity of the water demands a slightly higher cost for reagents, mainly for pH adjustment, but the overall cost saving of the groundwater scheme proved to be overwhelming in the project economics.

Few mine water-related problems in Australia are insurmountable and, with a high level of technical awareness, combined with the availability of expertise and perseverance, much can be achieved to minimize the cost and impact of water on mining.

WATER AND STABILITY

It is well known that the combination of high water pressures and steep slopes can be destabilizing, and the impact of water on open pit stability is probably one of the best recognized mine water issues. This is a result of the safety consequences and very high cost involved in mining to gentler slope angles or recovery from slope failures. The current cost to remove 100 000 m^3 of material following a failure is approximately A$0.25 million for a truck and shovel operation. However, a much more significant loss is the cost associated with lost production and, in the worst case, irretrievably lost ore reserves.

It is typically found that while the variability in material properties may change the Factor of Safety of a slope by 20%, even relatively small changes in groundwater pressures may change it by up to 200%.

As a result, concentrated efforts to depressurize pit slopes are common. However, as the majority of open pits in Australia are in a fractured rock environment which rely on secondary drainage paths through interconnected fractures, traditional depressurization techniques can be a hit and miss exercise. In addition, pit slopes are often found to have an overall permeability in the 10^{-5} to 10^{-7} cm/sec range where depressurization is notoriously difficult to achieve. In this regard, there is a particular interest in how permeability changes with strain relaxation of the rockmass and whether this change is sufficient to allow adequate depressurization.

Major geotechnical and hydrogeological studies completed at BHP's Mt Newman Iron Ore Mine in Western Australia in 1987 have led to the implementation of an ongoing programme of slope depressurization using horizontal drainage holes to enable pit development to more than 300 m below water table level, with stable slopes designed to minimize waste stripping requirements. The footwall and hangingwall rocks have low to very low permeabilities (10^{-7} to 10^{-6} cm/sec) compared with the high permeability of the orebody itself (in the range 10^{-5} to 10^{-4} cm/sec) [4].

DRAINAGE AND DEWATERING

Water entering a mine causes a wide range of problems to mining in general. Weak or slaking materials in the pit will, in the presence of even minimal amounts of water, quickly disintegrate into a semi-liquid mudpaste. This causes problems not only to trafficability in the pit, but also on ramps and haulroads. Mud from the pit floor carried onto the haulroads may clog up the road gravel surface and subsequent rain can result in substantial production losses.

Larger amounts of water entering an open pit will hinder production or even stop it for considerable periods of time. The cost of cleanup and lost production can be very high and may even result in the mine closing. The impact on underground mining can be even more severe, with mine closure a frequent result of sudden ucnontrolled inflows.

In the highly variable climate of Australia, proper drainage and dewatering is paramount to most mines.

To prevent surface water entering the pit, diversion drains and bunds are normally constructed around the pit. The size of these drains depends on the perceived loss associated with flooding of the mine, a loss which traditionally is very hard to quantify. With the rainfall pattern dominated by short duration, high-intensity rainfalls in many of Australia's mining areas, frequently the drainage works constitute major engineering works.

The Saxonvale coal mine in New South Wales is a single pit operation and the diversion drains are designed to carry the peak flow rate resulting from the Probable Maximum Precipitation (PMP) storm. Although the total average annual rainfall is only 650 mm, the PMP storm intensity is 240 mm in one hour. The drains are up to 20 m wide and 5 m deep. At the multiple pit coal mine of Riverside in Queensland, the drains are only designed to carry the one in 50 year flood. Located within range of cyclonic rain depressions, the drains are so large that they were dug by dragline.

In underground mining, the sudden inrush of water is, at best, a major operational problem, at worst a matter of life or death.

Cadjebut is a newly opened BHP lead-zinc mine in north-western Australia. The ore is a stratiform deposit in a karst limestone sequence. A major aquifer overlies the orebody in a notably cavernous zone, known as the "Vughy Dolomite", separated from the main ore horizons by a 6 m non-vughy zone. There is no evidence yet of any direct connection between the roof aquifer and the workings, and dewatering has, to date, been achieved by conventional pumping from surface boreholes to achieve adequate depressurization for roof stability. Future dewatering as the decline proceeds to greater depth below the present 100 m below surface will be achieved largely by in-mine drainage from roof drainholes included ahead of the mine advance.

As the drift goes deeper, very large heads will be present and the intersection of a continuous fracture (or an old exploration hole) is of major concern. Investigation and scientific research [5] have been undertaken to estimate the likely inrush of water under the three pressure domains of:

- Initial sudden inrush under full head (of short duration)
- Dewatering of the stored water within the fracture system
- Long-term drainage of the general area through the fracture.

Advance warning of intersecting a fracture is, of course, of major importance. Traditionally, this is achieved through probe drilling of the advancing face. However, this technique interferes with production and may still miss the water-bearing fracture. BHP has therefore over the last two years made a determined effort in the development and application of ground probing radar to be used for the detection of underground fracture systems.

PRODUCTION COST

Where abundant groundwater is present in the orebody or associated stata, it can have a significant impact on mining cost. Substantial delays can be experienced when opening up new mining areas or during the construction of ramps, and handling of wet ore can cause problems in unloading, at conveyor transfer stations and bins, and even at point of sale.

Advance dewatering may therefore be desirable and, while presplitting and the construction of dewatering trenches may be useful, the low permeability materials often found in Australian mines can limit the effectiveness of these measures.

In many Australian mines, the groundwater is either highly saline or acidic. This results in increased corrosion of machinery, particularly when the water is mixed with weak floor materials forming an aggressive, abrasive mud-slurry. Apart from the increased maintenance cost, the availability of machinery may decrease, affecting production schedules and cost.

However, one of the most significant cost impacts results from the need to use water tolerant explosive slurries or waterproof packaged ANFO (Ammonium Nitrate Fuel Oil) instead of conventional bulk ANFO which can only be used in completely dry holes. The cost of bulk ANFO is currently around A$500/tonne, whereas the cost of using water tolerant explosives may be up to three times greater.

Some success has been achieved in dewatering of blastholes through the use of mobile, truck-mounted pumping equipment. Holes are individually dewatered prior to the loading of explosives but this method will only work where permeabilities are so low as to prevent water reoccurring within the following 48 to 72 hours, the time required to prepare and fire the blast pattern.

At the manganese mine on Groote Eylandt off the coast of northern Australia, this method of blasthole dewatering is successfully used, with annual savings in blasting cost in excess of A$1 million.

WATER SUPPLY

Extensive drought periods are common to Australia and the identification and development of a reliable water supply can be difficult, particularly given the often remote location of mines where a whole new town may have to be supported. In addition, construction machinery and other supplies have to be transported long distances, site accommodation is often non-existent and power and other requirements have to be provided independently.

The common trend for water demand to increase beyond the initial estimate can also be a problem when available resources are limited. This has, in some instances, proved a major obstacle to production expansion.

In 1979, ten years after commencement of operations, the Mt Newman Mining Company realized that annual water demand would increase to 12 000 ML within the next ten years. Located in the middle of the very dry Pilbara Region of North Western Australia, this would result in an annual deficit of the local groundwater supply of 7 000 ML. Extensive studies showed the most feasible solution to be aquifer recharge and the A$10 million Ophthalmia Dam was built [6].

The supply source can be either surface water, groundwater or a combination of both. Environmentally and operationally, groundwater is often the preferred source in Australia because it is not subject to evaporation, is less susceptible to climate fluctuations and less obtrusive than a surface water supply. However, groundwater supplies of adequate quality and quantity can be very difficult and expensive to find in a country where groundwater salinities of up to ten times seawater (300 000 mg/L) are common. Surface water supplies can also have unacceptable environmental side effects such as increases in local wild animal and mosquito population leading to increased risk of severe diseases as encephalitis, amoebic menengitis, etc.

The relatively short life of modern Australia combined with the still large and unpopulated areal space can make evaluation of water resource potential extremely difficult because records of streamflow, rainfall and geology are often scarce or non-existent. As a result, analysis of baseflow rates, likelihood of flood, and aquifer yield becomes very complex, costly and often subject to error.

Despite extensive and ongoing analysis, the rate of flow into the Ophthalmia Recharge Dam at Newman is still the subject of intense debate. The unreliability of early estimates is best illustrated by the fact that the three times the dam has filled to date have been during dry season rainstorms and not during the cyclone season on which design was based.

Because of the often unreliable nature of both groundwater and surface water supplies, it is considered good practice to pursue both as possible sources. It is then possible to change direction if the cost or inadequancy of one source becomes prohibitive, or to adopt a conjunctive use approach where both options are found to be somewhat limited.

This was done at the Riverside Coal Mine (Queensland) where original intentions included the supply of water from a dam on the local Eureka Creek. However, investigations showed that this dam would have a less than even chance of adequate supply and emphasis was changed to proceed with the A$19 million Braeside borefield supply scheme.

WATER MANAGEMENT AND ENVIRONMENTAL ISSUES

Proper water management is essential in protecting the sensitive natural balance of the Australian environment.

Frequently, it is necessary to implement water management procedures which deal separately with "clean water" (which originates either externally or from within the mine area but remains uncontaminated by it) and "dirty water" (process wastewater and other water which may have become contaminated by the mining operation).

Environmental criteria in Australia are normally such that while Clean Water can be released from the mine site, Dirty Water is not allowed off site without treatment to an acceptable standard. In uranium mines, a "no release" or "restricted release" policy applies. Alternatively, such water can sometimes be reused in the mining process. This generally requires all water from mine and plant areas to be collected and retained in properly designed structures with spillage containment structures. As a result, it is common practice to minimize the amount of Dirty Water generated on a mine site. While this may be necessary in the high rainfall areas of tropical northern Australia or the south-eastern corner, where annual precipitation exceeds the evaporation potential to deal with the net surplus of potentially contaminated water generated in the mining operation, it also occurs in the arid regions, where water is scarce, and re-use of mine wastewater becomes a vital part of overall water management. In this regard, the operational constraints can often be more severe than the statutory requirements as a result of the significant impact water has on mining.

The gold tailings retreatment operation of Golconda Ltd at Beaconsfield in Tasmania, despite the most careful water management practice, produced a water surplus, necessitating the development of a process to recover cyanide from the wastewater circuit to enable its release to the estuary adjacent to the site. This has proved to be of secondary benefit to the Company, as the value of recovered cyanide and small additional amounts of gold turned the cyanide regeneration process into a profitable venture.

To assist in formulating water management policies and designing the engineering works required for control of Dirty Water, computer models of the entire mine water circuit are extremely useful. The highly variable climate, combined with numerous combinations of operational conditions, makes such models invaluable in Australia.

It may not be possible to predict what the actual combination of events may be but, based on sensitivity analyses, engineering works such as retention dams and pipelines can be designed and an optimum management strategy formulated. This enables precautionary measures to be taken and appropriate action can be effected once a certain condition is recognized. Thus, environmental and operational impacts are minimized.

Where water may be suitable for subsequent release, water balance models, together with flood warning and predictive models, form the bases for release policies. This is of particular importance in the dry part of Australia where floods are rare, large but of very short duration, thus limiting the release potential when dilution criteria have to be observed.

The use of water balance models has led to some interesting findings and has often changed the original operating conditions.

Recent studies at Saxonvale Coal Mine showed that the mine can operate independently of an external water supply even under extended drought conditions. The A$3.3 million pipeline originally intended to supply the mine is now only used for potable water supply. In fact, Saxonvale is likely to have an excess water problem and the water balance model has been used to assess the impact of controlled release to the nearby Hunter River.

At Riverside Coal Mine, water balance models showed major loss of water from the tailings due to evaporation. Since water there is a very precious commodity, the operation of the tailings dam was significantly changed to preserve water.

A much overlooked, but very important benefit of water balance models, results from the need to collect and evaluate data on site. This creates a much higher awareness of water matters among operating personnel, which of course is essential to the success of any water management policy.

COST BENEFIT OF ENGINEERING WORKS

The significant reductions in mining cost that can be achieved through engineering in a mining environment is best illustrated by an example.

Koolan Island is a BHP iron ore mine located in the remote King Sound off the North West Australian coast. The very high grade ore forms part of a heavily folded and overturned geological sequence, and mining is influenced by the steeply dipping orebody, the proximity of the ocean and the need to mine both below the fresh water table and below sea level. The island has a small community of 800 people and water is supplied from two small borefields on the island. The major borefield supplies water from an aquifer system located immediately behind the high wall of the pit [7].

In 1985, mining progressed for the first time below the water table causing much inconvenience to mining. As this was still well above the sea level, concern was expressed as to the long-term impact of groundwater on mining and stability. This concern was heightened by the knowledge of significant friable sand and silt material in the footwall.

With an orebody dipping steeply towards the ocean, there was also a great desire to minimize the amount of bench development on the footwall in order to maximize pit depth and minimize waste stripping.

Accordingly, a team of relevant expertise was assembled to investigate the various issues, including mine planning, pit stability, artificial support, water supply, dewatering, planning and marketing. The experts included both external consultants and representatives of the operating company.

Depressurization to achieve stability was a particularly sensitive issue as the main water supply adjacent to the pit had to be protected, being the only viable water supply source available on the island.

As work progressed, it became apparent that the need for both stability measures and dewatering was dependent on the detailed mine plan, and several alternatives were studied in detail.

In the end, a combination of artificial support, depressurization and dewatering was agreed upon. The combined total cost of these was in the order of A$5-7 million, or only around 5% of the total extraction cost. However, the net returns in added mineable ore reserves through being able to steepen the pit walls were in excess of A$50 million.

CONCLUDING COMMENTS

It has not been possible, nor was it intended, in this brief summary to cover all of the areas where water interacts or impacts on mining in Australia. However, the experiences related above do illustrate some of the unique ways in which water affects the Australian mining industry. As a mining company or as a consultant new to these conditions, the specific problems can prove to be major pitfalls.

In a world of increasingly uncertain commodity prices, mining has become a very dynamic undertaking. Flexibility is important and, as a result, mineplan and production changes place a vital responsibility with the engineers involved. This, combined with the often adverse Australian mining conditions, makes it even more important not to force "permanent solutions" too early, but to approach problems in a well organized and flexible manner, allowing solutions to change as more and more is learned. To achieve this, people involved in the day-to-day running of the mine must have access to, and constantly interact with, the best possible expertise.

Historically, there is a tendency for mine operators to regard water management as a separate and non-productive entity, "something the engineers fiddle with". However, the impact of any kind of water on mining is often of major operational concern and unwanted water or inadequate water supply can make or break an entire mining operation. The integration of mine planning, production planning and operations personnel with hydrogeologists, engineers and water quality specialists is therefore extremely important for a mine facing any kind of water problem.

Consultants must also remember that the operator's input to any solution is essential. Not only does he have the necessary practical information and experience, but he also ultimately controls the outcome of any engineering solution. If the operator does not understand or agree with the objective or the solution, then even the best technical solution is doomed.

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REFERENCES

1. Austrlaian Bureau of Meteorology (unpublished data).

2. Australian Mining Industry Council (unpublished data).

3. Dundon, P J, Boyes, B A, and Haydon, D J, 1988. "Water Supply Development for the Paddington Gold Project", Second Int Conf on Prospecting in Arid Terrain, AusIMM, Perth, WA.

4. Christensen, L J, and Nidigal, V, 1986. "Mt Whaleback Mine Dewatering", Large Open Pit Mining Conference, AusIMM, Newman, WA.

5. Helm, D, 1988. "Prediction of Groundwater Flow at the Blendevale Prospect, Western Australia", Third Int Mine Water Congress, Melbourne, Australia.

6. Clark, G B, and Kneeshaw, M, 1983. "Artificial Recharge in the Pilbara, Western Australia", IE Aust Hydrology and Water Resources Symposium, Hobart.

7. Dundon, P J, 1986. "Dewatering Investigations at Koolan Island", Large Open Pit Mining Conference, AusIMM, Newman, WA.