Hydrological Prediction and Problems in Mine Planning GENERAL REPORT

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The nine papers received for this technical session cover a very wide range of hydrological problems in various parts of the world. Three of these papers deal with hydrological predictions for new mines, while three are concerned with the prediction of water chemistry. The three remaining papers deal with gas injection as a dewatering tool, discharge formulae verification and the use of a physical model to predict subsurface strata movement and fracture development due to longwall mining.

Hydrological problems in mine planning represent a major risk in many mining operations, booth as a potential life or equipment hazard and a major financial risk. The initial paper selected to review was therefore one by the president of a gold mining company, rather than by one of the specialist scientists, to remind us all that the main reason problems are faced and overcome in the mining industry is usually a commercial one. In one commercial undertaking, the ability to accurately assess future risk is a highly desirable planning tool and hence in mining, the ability to predict the nature and magnitude of hydrological problems is often very important.

E M Caringal presents a paper on the gold deposit located at Barrio Longos, Philippines, in which he outlines the hydrological problems facing that operation and the manner in which the developing Company has sought to overcome their problems. The mine site is subject to three sources of unwanted water in-flow, namely, the sea, normal surface run-off and groundwater. Each of these has had to be studied to assess the physical controls on the in-flow and so enable the development of engineering solutions to the problems. The Company has used an Australian consulting engineering firm who in turn utilised the resources of two consulting engineering firms specialising respectively in coastal engineering and groundwater.

The problem of sea water in-flow was addressed using a coffer dam while the problem of groundwater in-flow required the use of computer modelling techniques to predict potential groundwater in-flow and hence provide the basis for the design of a groundwater management programme. Both an analytical and a two dimensional finite difference model were established covering the general mine area and these models were calibrated against historical data. The two dimensional finite difference model could not adequately reproduce the historical groundwater trends at the site while the more simplified analytical model was successfully calibrated and consequently used to simulate the first six months the dewatering requirements in the open pit.

Schneider, Voigt and Wharton describe the technical and envionmental problems associated with dewatering an open cast lignite mine in New Zealand. Their paper briefly outlines the geological and hydrological setting for the proposed mine near Lake Waikare close to the Waikato River, New Zealand. The three objectives of their investigations are to assess the dewatering requirements and dewatering methods for proposed mine, to determine the effects of dewatering on groundwater levels, surface water bodies and ground surface levels and to collect sufficient data on the groundwater regime for the preparation of an environmental impact study.

The main aquifer is described as an anistropic and inhomogeneous sequence of water bearing sediments that sits above the coal seams. The series of standard laboratory and field tests were conducted on the aquifer to determine its hydrological properties. The authors state that the most useful results were obtained from long term constant rate and constant drawdown tests. The aquifer parameters determined from the tests and evaluated during the calibration of the aquifer model were used to establish transmissivity and storativity domains over the majority of the area under investigation. The boundaries of the aquifer likely to be affected by dewatering measures for the proposed mine were defined for the purpose of numerical modelling and they included as the western boundary the Waikato River, which is an infinite source.

The numerical groundwater model was employed to simulate flow patterns in the undisturbed aquifer and assess groundwater control requirements and their impacts was a two-dimensional finite difference model, utilising a non-uniformly spaced grid of nodes forming acute triangles. This nodal system allowed accurate modelling of the irregularly shape aquifer boundaries.

The simulation covers four characteristic stages of the mining over a 27 year period. The results of the modelling indicated that within the mine perimeter, dewatering bores will need to be placed 70 or 80 metres apart at the beginning of each stage, reducing to 40 to 50 metres when water levels are lowered to near the base of the aquifer.

Modelling results show that most of the water discharged from the bores will be from recharge and throughflow rather than from storage. Also, about half the water stored within the bounds of the mine would not be recovered by dewatering bores but will need to be removed by secondary in-mine dewatering facilities.

The authors highlight a number of technical problems to be faced in the proposed mine, including the difficulties of installing large diameter bores in unconsolidated sediments and the fact that the pumping test results in numerical simulation indicate that the main aquifer cannot be fully depleted, even with large diameter bores, because the strata are often flat lying and isolated beds containing remnant water will result. This, in turn, means that measures such as open ditches or trenches containing drain pipes will be necessary for divertion of water and in some special cases, it may be necessary to install vacuum bores with air tight caps and annular seals, particularly where mine safety is of concern.

The paper by D C Helm on predicting groundwater in-flow in a fissured limestone is a particularly interesting paper. Helm summarises briefly the geological and hydrological conditions at the site in the Kimberley District of Western Australia and then makes predictions on the rate of water in-flow into a proposed underground mining operation. The particular problems facing the investigator in this case study were further compounded by those "real world" constraints of time and the amount of field data available for interpretation, constraints commonly faced the hydrologists when working in the mining industry. As the proposed mining operation is located in a part of Australia affected by the monsoon the investigator had to address the additional problem caused by the seasonality of recharge.

Many conventional diamond exploration holes had been drilled as part of the geological investigations at this potential zinc-lead mine site and conventional injection tests between packers had been conducted on five of these drill holes. One drill hole was selected for detailed analysis because it displayed four highly transmissive zones averaging one every 40 to 50 metres which corresponded with the expected frequency of fracture intersection in the mine and additionally contained the most transmissive individual zone tested on the site.

The conceptual model used by Helm in producing a groundwater in-flow prediction was one using equivalent fracture flow rather then an equivalent porous medium model. The equivalent fracture flow model offered two advantages for this site, one being that the transmissivity of individual fractures was estimated and hence possible sudden bursts of water could be predicted with reasonable confidence while the second advantage was an ability to determine the effect on in-flow caused by the widening and narrowing of fractures around the projected mining activities.

Working from his model, Helm made predictions of both the in-flow from individual fractures, as a function of depth, and of the average flow into the mine, as a function of the rate of face advance. In developing these predictions, three types of flow were distinguished, namely pressure-induced flow, gravity flow and the long term flow in response to regional recharge.

Considering these three papers, two relate to open cut operations where the authors reported the use of two-dimensional finite difference models, allbeit under very different groundwater conditions, with one group being happy with the reported results and the other group using a more simplified analytical model in preference to the finite difference model.

Each of these first three papers represents the very early stages of mine planning. It would be interesting to receive follow-up papers outlining the operational verification of the predictive models used at those minesite and, if possible, an indication of the financial savings (or losses) resulting from the application of those predictions to the operations.

The paper by Rozkowski and Witkowski deals mainly with the methods and results of hydrological investigations into the filtration and storage properties of the Carboniferous sandstones in the Upper Silician Coal Basin (USCB) in Poland. The stated objective of the paper is to develop a hydrological model of the deep Carboniferous aquifers in the USCB to predict the chemistry of the water as well as the sources, magnitude and zones of possible in-flows for proposed mines.

The paper briefly discusses the general geology of the USCB and puts forward interesting information on the relationship between the effective porosity, specific yield and permeability with depth and also discusses the chemistry of the groundwater. The authors postulate, based on their chemical analysis and isotope data, that these waters were probably mainly Tertiary epigenetic waters forced into the coal bearing horizons as a result of compaction and geodynamic pressure during the Carpathian orogeny.

The authors's conclusions are that the hydrological parameters of the deep aquifers in the USCB can be estimated using field laboratory techniques, that the deep Carboniferous aquifers have very poor permeability and low storage coefficients and that the deep mines (below 700 m) in the USCB will produce only small quantities of highly mineralized non-renewable groundwater saturated with methane.

The theme of groundwater sources in coal mining operations is continued by Judell and Anderson in their paper dealing with investigations into predictability of the volumes and, chemical characteristics of mine waters in the Sydney basin, Australia. In their paper the authors addressed three specific questions, namely, what are the causes of acidic mine waters in the coal fields in the Sydney basin? what are the correlations between the qualities of mine waters and individual seams? and thirdly, how can the volumes and characteristics of mine waters in that area be predicted?

The authors approached this problem by taking four coal seams of economic importance and gathering water quality and quantity data on these coal seams. The investigators collected data from a number of different operating collieries in each seam and determined the method of entry of water into the operating collieries, the chemical characteristics of the waters and looked at the natural surface waters, roof waters and the mine waters for each of the seams.

As a result of their detailed investigations, the authors concluded that the characteristics of the mine water encountered in the collieries studied were a result of a number of different phenomena including the paleo-environment of the different coal seams, the topography of the area in which each colliery is located, the depth of the mine, tectonic movements which have resulted in faulting and the volumes and characteristics of the local ground waters.

They broadly defined the mine waters into acidic waters, which were evident in collieries operating in two of the seams namely the Katoomba and Lithgow seams, and non-acidic and saline waters encountered at collieries operating in the Lithgow, Balli and Great Northern seams.

The authors attribute the mine water acidity to its percolation from the surface or from aquifers with little or no contact with carbonaceous sediments. This results in the water reacting with pyrite in goafed areas to produce a reduction in pH, a process accelerated when the pH reaches approximately 3.0 and bacterial growth is promoted.

The non-acid waters were considered to be primarily the result of reaction of various amounts of carbonaceous rocks with the natural surface and groundwaters prior to their entering into the mines. These alkaline waters neutralise the acids formed by the reaction of water with pyrite, preventing a significant reduction in pH and therefore inhibiting acid producing bacteria.

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In the case of the Lithgow seam, three of the four collieries investigated had dominantly alkaline waters while one colliery had acidic waters. This was attributed to the relatively thin cover of roof strata, the existence of a confined aquifer containing low alkalinity water above the seam and the relatively rapid ingress of surface water through joints, etc not permitting significant contact with the carbonaceous sediments in the overlying strata.

No evidence was found regarding the amount or morphology of pyrite in the Katoomba seam being significantly different from the coals in the Lithgow, Bulli or Great Northern seams.

The authors conclude that predictions of the quality of mine water and prediction of water in-flow are determined by the processes the coal seams have been subjected to, both during formation and after formation. The authors state that the quality of mine water can be predicted prior to development of a colliery if sufficient scientific and engineering data are gathered during exploration.

The paper by Mackay and Wiechers outlines the development of a user friendly computer programme to simulate the water quality in underground gold mine service water circuits. The paper describes the complex water chemistry that exists in an underground gold operation and then outlines the unit processes that gold mine service water passes through and the effects these have on the quality of the water.

The computer programme (AQUA-Q) models each of these processes i.e. the stope leaching, mine water neutralization, blending and desalination to produce the overall simulation of the underground mine service water circuit. The model allows the user to build a network of unit processes, each element of the network being specified by the user and the simulation being allowed to run for a time span determined by the user. The programme is designed to run on an IBM PC or compatible micro-computer and can handle a network of up to 50 unit processes (modules) and up to 90 connecting links. Illustrations of the simulation being applied are included in the paper and in their concluding remarks the authors state that the predictions of average daily water quality at various points within the mine water circuit agreed well with the measured values for an operating gold mine.

The programme as developed has served a useful purpose as a research tool as well as having the ability to assist in design and operation of mine water circuits for water quality management. The AQUA-Q programme is currently being further developed with simulations being tested against operating data from numerous mines and the various modules in the programme being further refined to include additional parameters. The authors advise that after this further development the software package will be issued for general use.

While this model (AQUA-A) has been specifically developed for an underground gold mine, its applications would appear to be much more general within the mining industry. The possibility of using this model in the type of study undertaken by Judell and Anderson for the Sydney basin coal seams appears to be a logical way forward in the prediction of quality of waters from mining areas. Such a predictive tool is becoming increasingly more important as mining projects are subjected to detailed scrutiny in the environmental impact studies.

Havasy and Vincze present a paper on simulating gas injection as a dewatering aid in an underground coal operation. The objective of their predictive model was to determine the practicability of dewatering a porous aquifer above a long wall mining operation by using gas (compressed air) injection. The authors, in a sound piece of lateral thinking, used a finite difference model developed for the oil industry which they modified to match underground conditions.

The simulation task attempted by Havasy and Vincze was the dewatering of a porous aquifer in the roof of a longwall face, by the injection of compressed air. The model used was considered suitable for the problem of dewatering aquifers with low transmissivities. A total of six variations of the model were run, four using horizontal strata and two inclined strata, and various arrays of compressed air injection wells and water extraction wells were used.

From the results of the simulations, the authors concluded that gas (compressed air) injection was not an effective technology in the case of horizontal strata as the gas exhausted towards the production wells of the strata being dewatered. With the inclined strata they concluded that gas injection into top layers of the aquifer increased the velocity of dewatering. However, these conditions very rarely exist in the Hungarian coal mining industry.

The authors concluded that based on the results of simulation modelling and of some experience gained, the application of numerical modelling to the problem of dewatering by gas (compressed air) injection is reasonable. While they did not have the opportunity to verify their simulated results with actual data they state that the phenomena observed in practice could be qualitatively matched to the simulation results. They further concluded that the technique of dewatering by gas injection would not be warranted even under advantageous hydrogeological conditions.

Zong Jian presents a paper outlining a method of seeking an accurate formula for estimating discharge developed at the Meitanba Coal Mine in Hunan Province of the Peoples of Republic of china. The workable coal at Meitanba coal mine rests on lower Permian limestone and contains very large volumes of groundwater resulting in total discharges in excess of 8,000 cu metres per hour. The hydrological conditions at the individual pits at the coal mine vary and Zong Jian addressed the problem of developing accurate methods for estimating discharge so that groundwater could be controlled during mining.

By collecting discharge statistics during production and plotting correlation diagrams, a pattern was determined based on the discharge of the pits, the fall in the water table and the area of exploitation or the length of individual drift.

The paper discusses the methods for evaluating various extraction formulas that includes results from the Meitanba Coal Mine for 1976 and 1986 which show the need to vary the estimation formula as hydrological conditions change during the exploitation of the coal resources. Zong Jian then compares the results of the various mathematical checks and concludes that the "method of exhaustion" of arriving at a correct discharge formula is the best method for the Meitanba Coal Mine. The author then applies his "method of exhaustion" technique to other coal mines in China and indivates that the accuracy of this check method holds at these other operations.

Since the development of an accurate formula, the Mietanba Coal Mine has no record of a severe in-pit groundwater flood, enabling the operations to continue in a safe and economic way. During the past 25 years, the discharge of water from the mine has increased some five times while the output of raw coal has multiplied and the unit cost of product has significantly decreased. The author attributes much of this economic success to the development of accurate estimation technique for water discharge.

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In contrast to the numerical models described by the majority of authors in this section, Tomlin and Bicer present a paper on the use of a physical model to predict subsurface strata movement and fracture development resulting from longwall mining at a Turkish undersea coal mine. The information derived from this model was used by the authors to assess the possibility and character of water problems which might develop at the mine.

The selection of a physical model by the authors was because they had a lack of confidence in mathematical models predicting failure and subsequent stress redistribution. They point out that physical models have been used by the mining industry for over 100 years and has proved successful on many occasions.

The Turkish coal field of Zonguldak is characterised by highly complex geology, with the coal measures being heavily folded and seam continuity adversely affected by severe faulting and unconformaties. The coal mine of Kozlu was the mine modeled. Geologically it is a structural dome with the west flank dipping towards the Black Sea at an inclination of 30-40°. Seventeen workable coal seams occur here and there is extensive and irregular multiseam and multipanel extraction, making it difficult to predict the cumulative induced tensile strain and the fractures which may develop.

No aquifers exists within the coal measures at the coal mine, the only possible source of water being the sea.

The geomechanical properties of the strata were studied using core specimens, in order to select the correct synthetic materials for the physical modelling. As the main purpose of the model was to investigate the failure behaviours of the rock mass, two strength parameters were chosen as the fundamental rock chracteristics, namely the uniaxial compressive strength and the tensile strength. The authors provide tabulated information on the properties of the rocks and the synthetic materials selected for the model and outline the extraction process simulated in the model. The authors discuss the use of photogrammetry to measure the horizontal and vertical displacements and the strain calculations.

In discussion, the authors state that the quantitative results from the model are far more realistic than the qualitative results and they point out that, due to lack of field data on strata movement; it is not possible to make a comparison between the actual and the model results. They had anticipated a different caving behavior for the three coal seams investigated, based on the local geology and the model indicated this to be the case.

While this paper concentrates on the geomechanical aspects of mining, it is an interesting compliment to Helm's paper dealing with the fractures in limestones at a zinc-lead deposit. Unlike Helm, who had available to him considerable on-site drilling information, Tomlin and Bicer have used their physical model to predict where fractures may develop so that investigatory drilling can take place and a sound assessment of the risk of sea-water flooding at the coal mines made.

The papers presented in this section show the wide range of hydrological problems in mine planning and the predictive techniques that can be used to address some of them. As an administrator with responsibilities in evaluating mining proposals, I was pleased to see the systematic, scientific approach to the difficult field of hydrological prediction. I look forward to further refinements and developments in this field, particularly with regard to predicting the impact of proposed mines on Australia's often scarse water resources.