Investigation Techniques General Report

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The six papers submitted for consideration during this session include two dealing with techniques for measing rock mass behaviour, including permeability, in boreholes, one describing the use of surface geophysical methods to delineate pollution plumes in groundwater together with analytical modelling of the plume, and one presenting a biological tracer technique applied to the determination of the origin of water entering underground mine workings.

A paper describing dewatering at a base metal mine in Queensland includes an account of the investigation techniques employed to establish a conceptual model as a basis for the evaluation of various dewatering strategies. Of considerable interest is the use of a field gravity survey to delineate a zone of highly weathered rock which forms the major aquifer at the site.

The final paper outlines a study in which hydrogeological, geotechnical and geochemical techniques were employed in the prediction of behaviour of a mine waste disposal site.

In "The Application of Production Testing to the Assessment of Potential Water Flows in Coal Seams", the authors describe a tool, suitable for use in conventional exploration diamond drill holes, which is designed to perform tests similar to the Drill Stem Test commonly used in the oil and gas exploration industry. Pneumatic packers isolate the interval to be tested and a "point sink" is created by expelling water from the drill rods with compressed air via a check valve. The air pressure is then evacuated leaving the drill rods at a lower pressure than the test interval. At this point a control valve is opened and water flows from the test interval into the drill rods. The flow rate, which varies with time, is measured by converting a transducer pressure reading at the base of the drill rods to a head and thence a volume. Pressure in the test interval is measured by a second transducer, which, if the author's figure 2 accurately represents the design of the tool, is located below the control valve and just above the top of the test interval.

Test interval pressure returns to the static value at a gradually declining rate which depends on the permeability of the test section but is retarded by the constriction of the flow path through the instrumentation capsule.

The pressure in the test interval is analogous to the drawdown in a pumped well and clearly during a production test both drawdown and discharge are constantly changing, albeit at a very low rate for a test in a low permeability interval.

Conventional well discharge testing theory relies either on constant discharge or constant drawdown to simplify otherwise very complex analytical procedures. One appropriate method of analysis for this production test data would be the same as that employed when analysing the Rising Head bailer test (slug test).

All tests on a single borehole require assumptions regarding the boundary conditions and these assumptions are usually slightly different for each analytical formula applied. The methods used by the authors to analyse the Greta and America Creek Seam results must be regarded as approximate since the flow rate in both cases was only approximately constant, in fact for the Greta seam test the approximation is only valid for a very short period after 0.5 hours during which there is very little change in the "drawdown". In the case of the America Creek seam the drawdown and discharge are both almost constant in which case Logans approximation could be applied:-

$$K = \frac{1.22Q}{swD} \quad \text{(Kruseman \& Deridder, 1970)}$$

where sw = constant drawdown
D = aquifer thickness
Q = discharge (constant)

Using data from figure 6 the above formula results in a value of 0.116×10^{-8} m/sec for K.

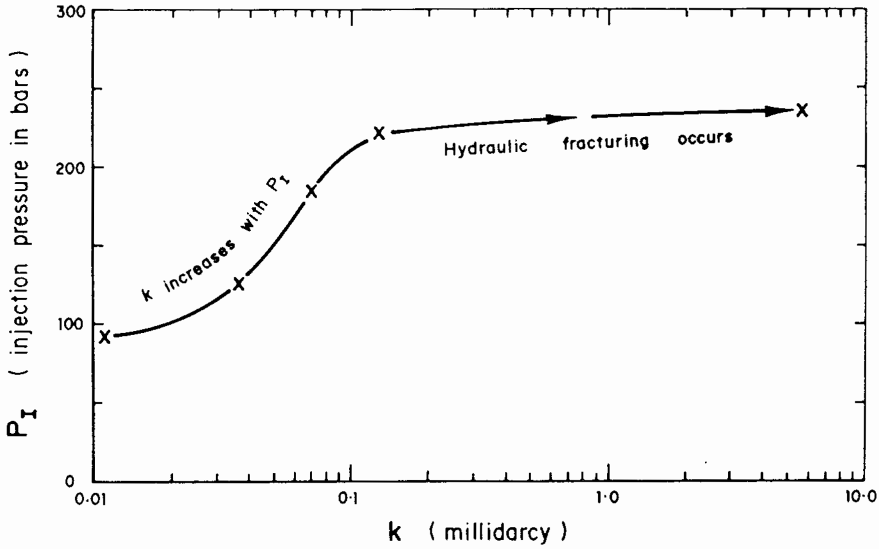
The "choke" effect of the control valve noted by the authors in the Greta seam test is probably related to the high flow rate. There is a pressure difference related to the flow rate across the valve in all tests. This pressure drop may be a source of error in the interpretation of injection tests carried out with the production test tool unless the test inerval transducer is used to record the injection pressure.

During a series of injection tests related to an in-situ coal gasification project in Belgium, Ledent (1981a) showed that at very high injection pressures the permeability of coal increased with increasing injection pressure (P_I) until hydraulic fracturing occurred (Fig. 1). This was attributed to the compression of gas and coal resulting in a widening of the fractures. He also reported (Ledent, 1981b) that using the analytical techniques he describes in his paper the permeability calculated from injection tests are more than twice those obtained from the post injection decay phases of the same tests.

From the mine water point of view it is clear that high pressure injection testing will result in high values of K.

Underground mine water inflows are driven by hydraulic gradients between ambient groundwater pressure and the sink provided by the mine workings. It seems logical that the field determination of K should be carried out under similar conditions thus the Production Test described by the authors appears to be a very suitable means of measurement of K in connection with mine water problems and should be used in preference to injection tests at elevated pressures.

Singh, Crellin and Reed in "Borehole Instrumentation for Groundwater Investigations in Underground and Surface Coal Mine Environments" describe two instruments employed in the measurement of rock mass displacements, piezometric pressure and permeability.



Data from well 11 at Thulin (after Ledent, 1981a)

FIGURE 1 Variation in coal permeability with injection pressure.

Monitoring changes in both the rock mass and the groundwater is a very desirable objective in an environment where mining induced stress changes influence both the rock mass and the groundwater, the former by displacements and the development of fractures, the latter by changes in permeability and pressure distribution.

Two borehole instruments are described, a modified tension wire extensometer (TWE) capable of detecting lateral and vertical rock mass movements with chambers installed to permit the determination of permeability, and a magnetic extensometer/piezometer (MEP) suitable for the measurement of vertical settlement of backfill and groundwater recovery in the fill. The TWE is therefore suited to both underground and surface mining applications and the MEP to surface mining.

The formula given for the calculation of K from the TWE instrument requires an assumption regarding the ratio of permeabilities normal to and parallel to the borehole and should read:

$$K = \frac{q \ln\left(\frac{2m\ell}{d}\right)}{2\pi l H}$$

Given a suitable measuring method it may be also possible to use the permeability chambers as piezometers between permeability tests thus providing additional information on the changing local distribution of water pressure within the system.

Two case studies are discussed, the first concerned with changes in permeability around a roadway as a face advances towards the instrumented site. Three boreholes, each ten metres long containing five permeability measuring compartments were drilled at a site some 160 m behind a retreating coal face and six sets of permeability measurements were made at various stages of retreat of the coal face. A pattern of changing permeability was recorded and presented in the author's figure 6. The position of the drillholes relative to the retreating coal face is not clear from figures 5 and 6 and the observed permeability changes are difficult to interpret without knowing if the coal face lies to the left or right of the roadway depicted in Figure 6. Although rock mass deformations are not described in this paper it is presumed that such changes were recorded at the same time as the permeabilities with obvious benefits to the level of understanding of the interaction between hydrological and geotechnical phenomena.

The second case history describes the use of MEP and TWE instruments in the monitoring of movements and water pressures in an open cast coal mine backfill. In this application the MEPs measured vertical movements at mine sites as well as providing piezometric information from the solid strata below the fill. Multiport piezometers recorded piezometric changes in the fill allowing a correlation between water level recovery and settlement. Perhaps this could also be achieved by utilising the permeability measuring compartments in the TWE instruments with relatively minor modifications. The TWE installations were considered by the authors to be superior to MEPs since lateral displacements could be measured as well as vertical movements such as settlement or heave.

The results obtained by monitoring using the instrumentation described should not only assist in our understanding of the processes occurring in the field but could lead to the establishment of standards for the placement of fill to minimise settlement effects which are usually exacerbated by groundwater recovery.

In their paper titled "Borehole and Surface Geophysical Monitoring, and Simple Modelling of Groundwater Polluted by Waste Leachates", Davis, Barber and Buselli describe a case study on a domestic waste disposal site in Western Australia. Electrical geophysical methods (including SIROTEM, a transient electromagnetic system developed by CSIRO in Australia) were used to outline the probable extent of a pollution plume. Water samples from a number of monitoring bores provided chemical confirmation of the location of the plume. A simple analytical model is then used to predict future development of the plume which can be confirmed by geophysics and water sampling.

Electrical surface geophysical methods can be a very useful tool in tracing pollution plumes where there is sufficient contrast between the properties of the polluted and natural groundwater and where the target is sufficiently large. One of the major problems in most work of this nature is the lack of geophysical work over the site in its natural state to serve as a baseline against which to compare surveys after waste disposal has commenced. In countries with marked seasonal differences in climate it is worth considering baseline geophysics at the extremes of wet and dry conditions to establish baseline data. It is worthy of note that the authors report such background geophysical work at a proposed waste disposal site in the Perth area.

The reported geophysical work does outline a low resistivity plume emanating from the southwest end of the waste disposal site. This plume is confirmed by a number of monitoring wells which show elevated values of dissolved ions and a five to tenfold increase in conductivity.

The assumption of constant groundwater flow velocity in the model of plume development may lead to some problems in prediction in an aquifer which almost doubles in saturated thickness along the flow path. The groundwater gradient may be approximately 2 to 3 m per kilometre in a southwesterly direction but unless considerably more recharge occurs over the thicker part of the sand sequence the gradient at the SW corner of the area depicted in Fig. 1 is likely to be approaching half of that in the northeast beneath the disposal site. Thus the groundwater velocity may reduce in a southwesterly direction by a similar amount. It would be useful to accurately determine groundwater gradient and if possible take actual gradients into account in the model.

Compensating errors in estimates of dispersivities and gradient may be producing good correlation between model and field for the present time however significant deviation could occur if the gradient changes down the flow path. The proposed tracer study should assist in better defining the dispersivities and the hydraulic gradient should be obtainable from the monitoring bores unless there are pumped wells in the area distorting the potentiometric surface.

The concept of combined geophysics, modelling and field hydrogeological and hydrochemical monitoring is excellent and future developments at Morley and the yet to be commissioned site to the north are awaited with interest.

The new site should in fact prove to be more amenable to interpretation, given a similar simple geological environment, with a good set of background electrical properties for the unpolluted aquifer.

Whitfield and Anderson's paper "The Role of Algae in the Investigation of Water Inflow into a Coal Mine" must be read in a context of the existence of a Dams Safety Committee which mediates between the Sydney Metropolitan Water Sewerage and Drainage Board and the various mining companies which own leases extending beneath dams and reservoirs forming part of the major water supply system in the area. The organisations involved seek to avoid damage to surface structures, such as dams, and to maintain the integrity of the surface storages.

The minewater inrush at Wongawilli has already been described at the Second IMWA Congress (Wilson, 1985) and reference was made in that paper to some work on algae found in the mine water but little detail was provided.

In the Sydney Basin underground coal mines, an inrush of 100,000 litres per hour is considered to be a very major inrush although the daily volume of 2.4 megalitres is only the discharge of a single irrigation bore in many parts of Australia.

Since the Wongawilli Mine lies beneath and adjacent to the Avon surface storage it is understandable that the water supply authority and Dams Safety Committee were concerned over the magnitude of the inrush and anxious to determine the source of the water entering the mine.

Three possible sources of water were considered, old mine workings, the Avon reservoir and local groundwater. Conventional chemical tracers were not employed for a variety of reasons. The three techniques employed were, comparisons of water chemistry, environmental isotope studies (Tritium) and algal composition of water.

In the water chemistry studies it is remarkable that no analytical results are quoted for the local groundwater occurring in the strata above the mine workings which must be considered as a likely source for some of the inrush water via mining induced fractures. The same may be said of the tritium data presented in the paper. Without full analyses and in the absence of analytical values for local groundwater, consideration of the chemical data presented in table 2 of the paper leads to inconclusive results.

Levels of combined Ca and Mg are increased at least ten times in the mine inrush water. Combined Na+K are also increased several fold whilst Cl appears to be of the same order in both Avon reservoir and the mine water thus the inrush water is considerably less fresh than the reservoir water.

Because no tritium values were obtained from local groundwater, table 1 of the paper leads to equally inconclusive results. The most that can be said is that if Avon Storage water is entering the mine then it is mixing with water with a lower Tritium content because the mine water inflow contains 20% less Tritium than the reservoir water.

Comment has been made elsewhere (Armstrong, 1988) on the hydraulic data available from previous papers on the subject (Whitfield, 1986, 1988; Wilson, 1985) which suggests that the water entering the mine workings does not behave, in time, in a pattern consistent with a major direct connection to a constant head source such as is represented by the Avon Reservoir.

The authors, in their discussion, develop the hypothesis that a fracture with an aperture of 50 microns connects the mine workings with the bed of the reservoir and go on to state that "the maximum inflow of 100,000 litres/hour could be sustained by a fracture 50 microns wide and 600 m long".

Under the geometric conditions prevailing at the site and using parallel plate flow theory (which is a very generous approach compared with the type of fracture likely to occur in nature) the minimum fracture aperture emerges as about 400 microns over a 600 m horizontal extent or conversely the discharge from a 50 micron fracture would be of the order of 180 litres per hour assuming that the mine workings extend for 600 m and that the fracture is exposed throughout that length.

The use of any naturally occurring component of the water as a tracer must be undertaken with great care, particularly if that component can be derived from multiple sources. Conclusions drawn from such tracer evidence must be supported by hydraulic models.

The authors have demonstrated in this paper that the range of organisms described do not naturally develop in the underground coal mines of the Sydney Basin but have not eliminated all possible outside sources of algae such as reticulated water used in the mine (which is probably obtained from surface storages).

They have shown that some of the water entering the mine during the inrush was probably derived from the Avon reservoir but the overall exercise failed to determine the relative porportion of reservoir water in the inrush.

A novel techique has been added to the repertoir available for the study of mine water problems which, if used prudently in conjunction with other methods, could be of value in other cases where surface water/groundwater interconnection via fractures or boreholes is suspected.

"Hilton Mine Dewatering, North West Queensland, Australia", by Mutton and Whincup describes the geology and hydrogeology of the recently developed silver-lead-zinc mine 20 km north of Mount Isa. Multiple ore bodies occur within a steeply dipping dolomitic and pyritic siltstone which has been extensively weathered to depths of up to 440 m at the mine site. This leached material, which is also structurally disturbed, forms the Ore Zone Aquifer. The immediate footwall sequence of siltstones is regarded as a second, less significant aquifer. A third zone, lying some 300 to 400 m on the hangingwall side is also defined as an aquifer. At the present stage of mine development little importance is attached to the Hangingwall Aquifer.

Owing to the strong density contrast between the weathered aquifer zone and the underlying fresh ore it was possible to delineate the aquifer geometry by analysing the results of a detailed gravity survey using modelling techniques commonly applied to the definition of orebodies.

Information on the behaviour of the groundwater system during shaft sinking, underground development and a series of pumping tests resulted in the estimation of aquifer parameters which showed a high degree of anisotropy.

A computer model using these aquifer properties satisfactorily reproduces the early observed behaviour of the system and has been used as a predictive tool to investigate various dewatering strategies.

The high values of apparent effective porosity (Basin Yield Factor) necessary to obtain a good calibration for the model over the earlier years probably reflects a combination of dewatering the highly porous, near surface weathered zone and the quasi-steady state conditions prevailing in the early 1970's.

Although the authors state that a groundwater problem was recognised at an early stage of exploration, the paper gives the impression that detailed investigation did not commence until 1980, some 30 years after the first shaft sinking was aborted due to heavy water inflows. In the interim period some groundwater information was obtained from further shaft sinking and development.

This scenario is typical of the Australian Mining industry of the period when mine dewatering expertise was a rare commodity in Australia and the industry applied the "suck it and see" principle.

The Hilton experience illustrates the need for careful investigation of the hydrogeology at a proposed mine site in order to achieve a viable mine design with a minimum of "surprises" during the development phases.

In "A Study of the Potential for Surface and Groundwater Contamination by Arsenic at the Sunbeam Gold Mine"

Straskraba, Shangraw, Silva, House and Pyrih describe investigations based on field and laboratory work, and computer modelling into the anticipated behaviour of arsenic dissolved from spent ore at an Idaho gold mine. They are concerned not with the tracing of the pollution plume but rather with theoretically demonstrating that arsenic will be retained in the soil profile and diluted by the local groundwater to a level which satisfies environmental control agencies in the USA.

The waste disposal site is located in a valley with a relatively shallow water table and varying thickness of alluvial and colluvial soil cover, with a high clay content beneath the poroposed disposal site.

Field permeability tests provided values of hydraulic conductivity for the soils on site and the hydraulic conductivity of the waste was estimated from grain size distribution to be two orders of magnitude greater than that of the soils. The spoil surface was assumed to permit infiltration of all available water from rain and snowmelt on top of the waste.

After completion of the gold mining operation conditions in the spent ore disposal were conservatively assumed to remain unchanged.

Laboratory column leach tests on spent ore showed that a peak value of 5.2 mg/l arsenic would occur in water after flushing by 1.05 to 1.58 pore volumes thereafter decreasing to 1.7 mg/l after 7.35 to 10.5 pore volumes.

The peak value of 5.2 mg/l was expected to occur after 31 years of waste disposal and the long term estimate of arsenic leaving the base of the waste and entering the soil was estimated to be 1.28 mg/l.

Examination of the geochemistry of the site soils indicated that conditions were generally favourable for the fixation of arsenic principally by anion-exchange in the presence of montmorillonite and kaolinite. Absorption and precipitation reactions with soil impurities could also contribute to a reduction in the amount of arsenic dissolved in water reaching the watertable.

Column tests on four soil samples involved the injection of spent ore leachate with >1.33 mg/l arsenic at a rate of 1 ml/min. and the collection and analysis of the effluent. This provided a measure of the ability of the site soils to retain most of the arsenic in the effluent.

Computer modelling then showed that the arsenic content of groundwater leaving the local groundwater basin is expected to be of the order of 0.18 mg/l which would be further diluted to 0.002 mg/l in the downstream Jordan Creek ground water system.

The author's use of a worst case scenario is to be applauded and the environmental agency's acceptance of such a theoretical approach represents a maturity which I feel has yet to be reached in equivalent Australian authorities and which may never be attained by the Australian conservation movement.

When considering the environmental impact of mine waste disposal on the groundwater resource one question which is seldom asked is:- "What is the chemical composition of the natural groundwater which has travelled through the oxidised zone of the orebody in situ?" In many cases the degradation of water quality due to waste disposal may be less than that which naturally occured before mining.

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