Burra Copper Mine - A Comparison of Historic and Modern Dewatering

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ABSTRACT

Burra mine was operated in the 19th century as an underground mine, dewatered by Cornish Beam Engines. The history of mining operations was characterised by a series of shut-downs due to fluctuating copper prices, labour shortages and policy decisions.

The mine was re-opened as an open pit in 1971 and was dewatered using pumped wells and pumping from old drives.

Drawdown and discharge history is described and analysed using a non-darcian flow approach.

The importance of turbulent flow in this dolomitic karstic environment is clearly indicated by the marked departure from the behaviour predicted by the D'Arcy equation at relatively low discharge rates for the historic mine and at higher rates of discharge for the modern open pit operation.

The influence of the geometry of the mine workings on the discharge required to achieve a given drawdown is also clearly demonstrated.

The Burra Mine is located in South Australia, 150 kms north of Adelaide. A copper deposit occurs at the contact between a dolomite and a diapiric breccia and is associated with an elongated zone of volcanic intrusions and hydrothermal alteration. Although only a small mine, Burra was discovered and opened at a very critical stage in the evolution of the economy of South Australia.

19th Century Dewatering

The dewatering history of the original underground mine can be reconstructed from the half-yearly reports of the mining company which described the ordering, shipment from the United Kingdom, and installation of several Cornish Beam engine pumps with individual capacities ranging from 3 270 to 11 000 m^3 per day.

Dewatering occurred in 3 distinct phases.

1849-1852 Initial opening of the mine to the 40 fathom level (454 m EL) required a discharge of 3 270 m^3 per day to produce a drawdown of 37 m.

In October 1852 the discovery of gold in Victoria reduced the Burra workforce from 1013 to 100 men and the pump was stopped to reduce costs which meant that ore could only be extracted from above the water table (491 m EL).

1855-1868 The return of miners to Burra and rising copper prices justified dewatering of the existing workings and development work on the lower levels. A discharge of 8 100 m^3 per day produced some 78 m of drawdown and held the water level at about the 60 fathom level (413 m EL).

Low copper prices in 1862 led to a reduction in interest in the deeper levels of the mine and the decision was made to restrict mining activity to above the 55 fathom level. Pumping concentrated on maintaining the water level at the 60 fathom level until in October 1868, the pumps were gradually stopped and the mine allowed to flood.

1870-1877 Surface structures were demolished and the area prepared for open cut mining which commenced in December 1870. Pumping was recommenced to lower the water level to the base of the open cut (472 m EL) but the available ore was soon exhausted. The company then decided to explore the potential of the deeper levels and the pumping rate was increased to a maximum of 14 000 m^3 per day which enabled the workings to extend to the 100 fathom level (346 m EL), a drawdown of 145 m. Lack of high grade ore and falling copper prices forced the closure of the mine in 1877.

The discharge/drawdown relationship demonstrated during the development and operation of the underground mine is similar to that shown by a partially penetrating slim well with increasing degrees of penetration despite the complex geometry of the workings with many km of drives and extensive stoped areas. Fig 1 demonstrates this relationship.

It is believed that this similarity in behaviour is due to the fact that dewatering established a cone of drawdown which only intersected the workings at the lowest levels close to the shaft bottoms where the pumps intakes were located.

20th Century Dewatering

Before reopening the mine as an open cut in 1971 the developer consulted old company records and concluded that a dewatering capacity of 13 090 m^3 per day would be sufficient to draw down the water level to below the bottom of the proposed open pit of 440 m EL. It was intended to instal a large capacity submersible pump in the original dewatering shaft but after 100 years of neglect the shaft was found to be unsafe.

As a second option, dewatering wells intersecting drives close to the shaft at the 50 fathom (438 m EL) and 60 fathom levels (413 m EL) were drilled and cased with great difficulty due to unstable ground conditions. Electric submersible pumps were installed but could not deliver their maximum yield because of migration of collapsed material and fill into the well casings.

Sept 1975-Aug 1976 The initial 10 m of drawdown was achieved with a total discharge of 3 300 m^3 per day from 3 wells.

Sept 1976 An additional 2 wells were drilled and equipped bringing the total discharge to 7 658 m^3 per day with a resultant drawdown of an additional 10 m (ie total drawdown 20 m) which had stabilised by early 1978 when the base of the pit was rapidly approaching the water level and more drawdown was needed.

March 1978 One more well was drilled close to the dewatering shaft and the total discharge was increased to just over 10 000 m^3 per day. This produced a total drawdown of 36 m in the old mine workings. By Dec 1978 the drawdown had stabilised 34 m above the level required for complete extraction of ore reserves.

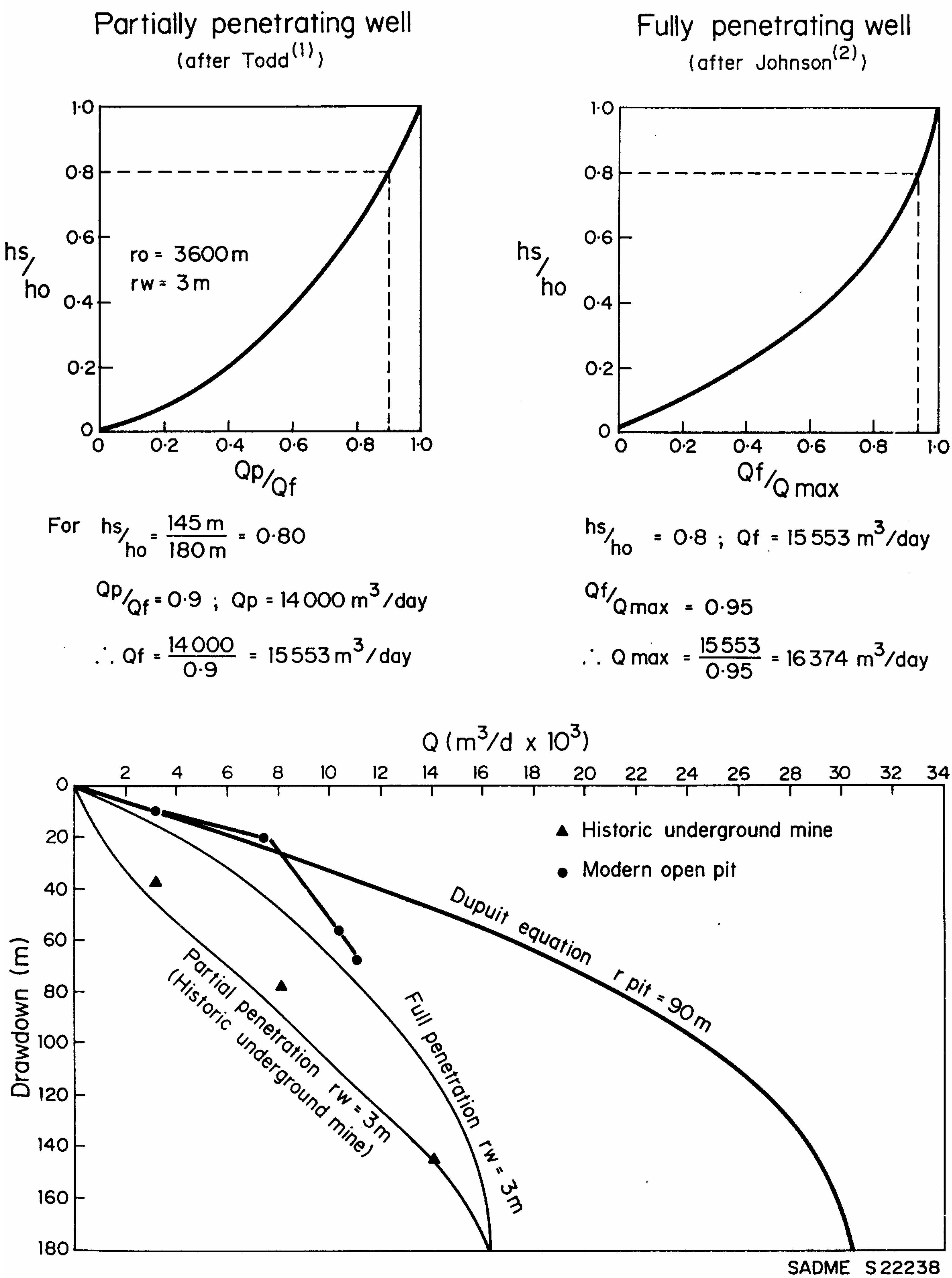

Figure 1. Empirical predictive model – Burra Mine

The South Australian Department of Mines and Energy Groundwater and Engineering Geology Branch was invited to review the dewatering operation and concluded that:-

i. The discharge should be increased.
ii. More dewatering wells near the old shaft were not an option.
iii. Steep hydraulic gradients in the dolomite within the pit area and north of the old mine workings could be a threat to slope stability and also indicated that the majority of inflow into the underground workings was occurring in this area.

Dec 1978 - Feb 1981 Five new wells were drilled in the dolomite at the north end of the pit and the water level was lowered some 21 m with no increase in total discharge since the pumps near the dewatering shaft were becoming less efficient with increasing drawdown.

The last stage of dewatering was achieved with a single well in the bottom of the pit which produced an additional 10 m of drawdown bringing the total to 68 m for a total discharge of 10 800 m^3 per day.

Analysis of Discharge and Drawdown

The Burra example clearly illustrates the difference between dewatering a developing underground mine by passive methods (ie by allowing the mine workings to operate as a collector system) and redeveloping a flooded underground mine as an open pit.

Owing to the fractured rock karstic aquifer and complex geometry of the mine workings, analysis of the behaviour of the system was initially restricted to a semi-quantitative approach based on the similarity of a partially penetrating well (the developing underground mine) compared with a fully penetrating well (the flooded abandoned underground mine).

An equation presented by Todd[1] relating the discharge from a partially penetrating well to the discharge from a fully penetrating well with the same drawdown

$$\frac{Qp}{Qf} = \frac{\ln(ro/rw)}{(ho/hs)\ln(\pi hs/2rw)+0.10+\ln(ro/2ho)}$$

where Qp = discharge from partially penetrating well for given drawdown
Qf = " " fully " " " same "
ro = radius of influence of well
rw = radius of well
ho = saturated thickness of aquifer
hs = " " at well
(Note: ho-hs = drawdown in well)

was used to prepare a dimensionless plot of hs/ho versus Qp/Qf. When used in conjunction with a plot of hs/ho versus Qf/Qmax after Johnson[2] (where Qmax is the maximum possible discharge from a fully penetrating well), and observed discharges and drawdowns during the historical underground mining phase, an approximate fit (Fig 1) was obtained between observed data and the partial penetration curve. The modern observed value of ro = 3600 m and the unlikely value of rw = 3 m gave the best fit combined with an assumed saturated thickness of 180 m.

Dewatering of the flooded mine during the construction of the open pit was not expected to follow the hypothetical fully penetrating curve of fig 1 because of:-

a. the large volume of water stored in the old stopes and drives of the upper levels; and

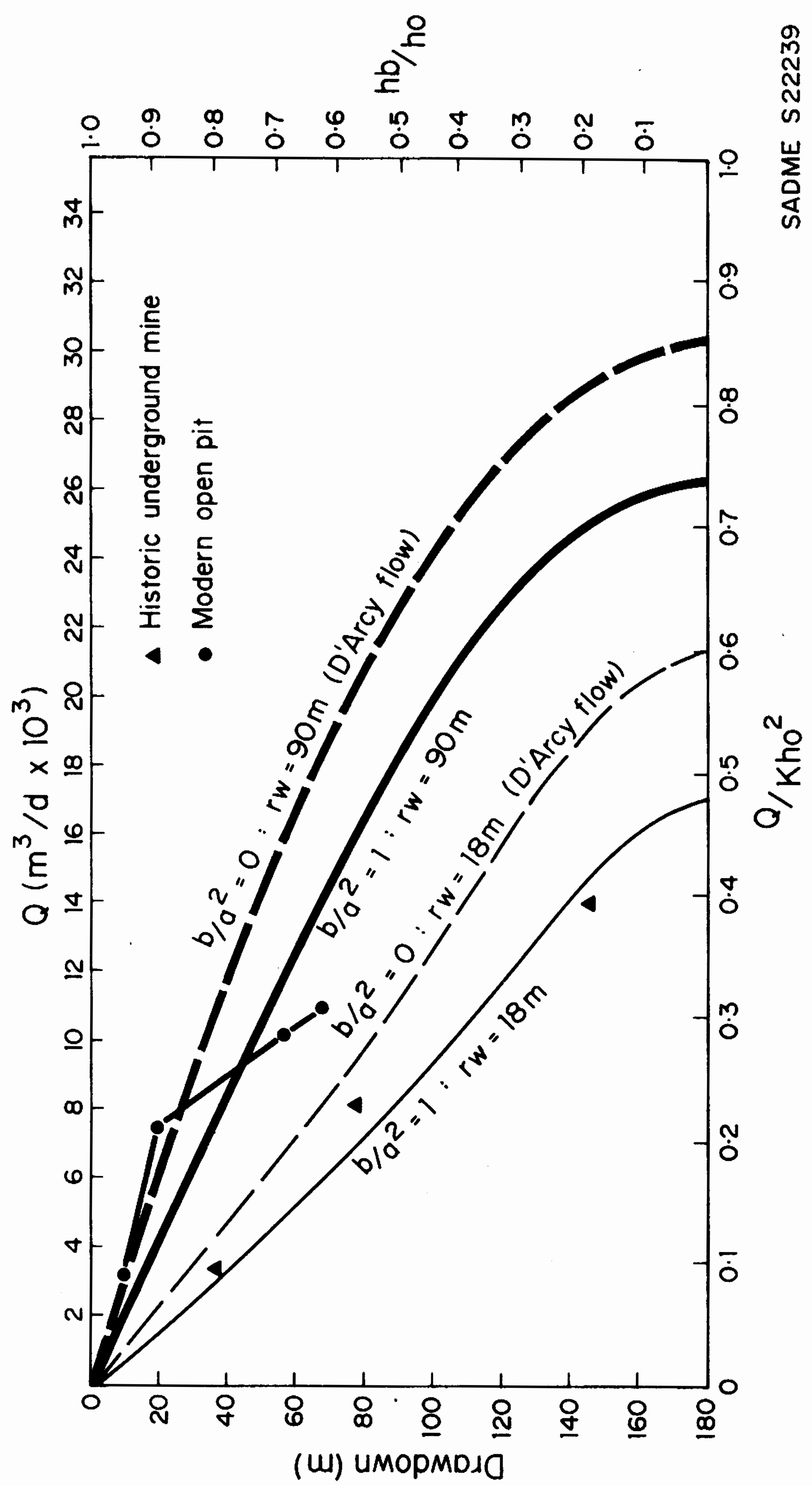

Figure 2. Matching of Burra data to Dudgeon[3] models

b. the much greater well radius created by the extensive upper levels which were now in the saturated zone.

In order to allow for the new, larger rw (estimated to be 90 m) the empirically determined Q_{max} from fig 1 was substituted in the Dupuit equation

$$Q = \frac{\pi k(ho^2-hs^2)}{\ln(ro/rw)}$$

to obtain an estimate of k which could then be used to establish the discharge from a pit of 90 m radius assuming darcian flow.

For a drawdown of 20 m in the modern open pit, the actual discharge was greater than that predicted in fig 1 due to the slow removal of stored water from the workings.

With increasing discharge, the drawdown began to approach the fully penetrating empirical curve due partly to the lower volume of water stored in the lower drives and also the smaller area available for entry of water into the workings.

Reduced entry area and increased discharge probably resulted in the development of steep hydraulic gradients around the workings due to the transition from darcian to non-darcian flow.

Recent work on non-darcy flow near open pit mines by Dudgeon[3] provides a new way of examining the discharge-drawdown relationship based on the assumption that the original underground workings can be approximated by an equivalent open pit with varying degrees of penetration in an unconfined aquifer.

Dudgeon has developed a finite element numerical model which employs the Forchheimer equation:

$$i = aV+bV^2$$

to predict the behaviour of the flow field close to the walls of a circular open pit with the water level within the pit at pit bottom.

In the distant field, where velocities are small, the darcy flow term (aV, where $a = {}^1/k$) dominates but close to the pit the non-linear term may become significant depending on the magnitude of the non-linear flow coefficient b.

The results of Dudgeon's model calculations are presented as tabulations of combinations of the following dimensionless ratios:

ro/ho; rw/ho; h_b/ho; b/a^2; Q/kho^2

where notation is as before and h_b = height of pit bottom above base of aquifer
a,b = Forchheimer equation coefficients.

The dimensionless curves of figure 2 were constructed from the tables presented by Dudgeon with the exception of the fully penetrating D'Arcy flow which was calculated using the Dupuit equation.

In order to match the dimensionless plot with observed drawdown and discharge it is necessary to select values of rw; ro, ho; k which reasonably represent the situation at Burra and also give values of ro/ho and rw/ho for which data is available in Dudgeon.

Limited well testing indicated a Transmissivity of around 200 m^2/day and experience from the 19th century mining phase indicated that the permeable zone extended to at least 145 m below water table.

A saturated thickness of 180 m was chosen and, for the modern open pit case, the area occupied by mine workings was approximated by a circle of radius 90 m giving a value of 0.5 for the ratio rw/ho for the open pit.

Drawdown during the underground mining phase was matched by trial and error with a series of plots constructed using a range of rw values. The closest fit was obtained with rw = 18 m (ie rw/ho = 0.1) and $b/a^2 = 1$. This b/a^2 value corresponds in porous media terms with a fine gravel but there is no established relationship between b/a^2 and fractured rock properties.

Non-darcy flow during the underground mine dewatering appears to have reduced the discharge required for a given drawdown by 20% compared with the darcian flow estimates over the full period of operation.

The modern open pit dewatering behaviour shows the influence of changing geometry as the water levels decline coupled with the influence of large storage volume.

At the start of dewatering, at low discharge rates, the flow regime appears to be darcian with an equivalent pit radius of 90 m. With increased discharge, the drawdown increases and a progressively smaller equivalent pit radius becomes operative as the less extensive lower levels of the old mine become the major drainage levels. Steep entry gradients develop and the non-darcy flow term begins to influence the discharge rate such that small increases in discharge will produce significant increases in drawdown.

It is predicted that the curve representing b/a^2 = 1:rw = 18 m: would have been reached at Q = 14 000 m^3 per day at which time the old underground workings would be draining as they were in the last century.

The geometry of the old mine workings has influenced the behaviour of the system by storing large volumes of water in the upper, stoped out, levels and also by presenting a progressively smaller exposure to the groundwater mass as the upper levels dewatered and left the less extensive lower levels to act as drainage paths which at high discharge rates induced non-darcian flow.

The now abandoned mine has been developed as an industrial museum.

ACKNOWLEDGEMENTS

The co-operation of the former owners, is gratefully acknowledged, especially the work of Doug MacLean and Graham Sweetman (Mine geologists) and Mr G Armstrong (Manager).

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