Mine Dewatering and Water Disposal Bendigo Goldfield

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ABSTRACT

The Western Mining Corporation mining lease on the Bendigo Goldfield measures 5km x 18km with more than 20 anticlinal folds parallelling the long north-south boundaries.

Numerous closely spaced shafts and extensive underground workings on the reef lines along the folds flooded with groundwater following the progressive abandonment of the field.

Preliminary water sampling and assessment demonstrated that a major dewatering programme and acceptable disposal methods were necessary to dewater interconnected old workings in areas of interest prior to any underground work taking place.

A field wide geohydolic investigation was undertaken to establish geohydraulic parameters, groundwater recharge rates and water qualities.

Data from the field investigation together with estimates of the volume geometry of the submerged workings as obtained from old mine plans, production history, and limited pump testing results were used with an appropriate analytical model to obtain estimates of water discharge rates required to reach various dewatering targets.

Water disposal options were limited by relatively high salinities, arsenic levels, contained hydrogen sulphide, and the mine locations within the urban areas surrounding Bendigo.

Direct disposal to the surface drainage system could not be considered, treatment to acceptable discharge standards was not economically feasible, and it was necessary to adopt a strategy of collection, containment, and evaporation.

The intensive settlement in the surrounding district together with terrain considerations and availability of the large area requirement necessitated transfer of the dewatering flows to a downstream site some 4km from the

northern lease boundary. The transfer has been affected underground via a convenient interconnected line of old workings to the urban outskirts where the water is repumped and flows under controlled conditions in a creek channel until transferred to holding/evaporation ponds.

Detailed water balance calculations were used to size the volume and evaporation area requirements for the ponds.

The evaporation areas are extensive due to the low nett rates applicable in this region.

It was also necessary to address the pond structural requirements to prevent seepage and future decommissioning of the ponds to contain the residual salts.

The system is such that additional areas for underground development can also be readily dewatered.

Initial dewatering of the Williams United Area has been achieved and the results are discussed.

Reference is made to earlier work on dewatering of old mine workings at Stawell in Victoria.

INTRODUCTION

To obtain bulk samples for assay from the New Chum line of lodes accessed by the abandoned Williams United Shaft workings, it was necessary to dewater to a depth of 100m below shaft collar level. To suit the proposed timing schedule and to establish a dewatering rate, adequate information was required about the hydraulic properties of the aquifers enclosing the deposit, geometry of the flooded mine workings and the hydraulic interconnectedness between groups of old workings along the New Chum line of reef and in the parallel Garden Gully line of reef, some 400m east of the New Chum workings.

It was also necessary to establish an environmentally acceptable means of transport and disposal of the poor quality pumped water.

This paper describes the results of geohydrological investigations, dewatering designs, the planning and implementation of the water extraction, transport, and disposal system.

CLIMATE

The Bendigo area enjoys a continental temperate climate experiencing predominantly winter rains. The 10, 50 and 90 percentile annual rainfalls are 350mm, 540mm and 690mm.

Average annual evaporation is 1250mm.

HYDROGEOLOGY

The Bendigo Goldfield is about 5km along and 4km across strike. The rocks comprise a suite of shales, slates and thinly bedded sandstones of Ordovician Age, which are intensely folded and faulted. Major faults are parallel to fold axes with an approximate bearing of 340^{0}. These sediments have been extensively intruded by quartz veins and reefs.

The sediments are relatively impermeable. However, minor permeability of the massif does exist due to fracturing of the more competent rocks sandstones, quartz veins and lodes and to some extent the slates. By the nature of the formation, it might be expected that these rocks would be anisotropic. In addition to the fracture system permeability which seems to exist at least to the base of exploration drilling (190 - 200m), it is probable that the upper 20m or so of oxidised and leached material will have generally higher permeability and storativity than the general body of rocks below this horizon.

It is also possible that high permeability may exist over quite small distances associated with bed separation or fault plane dislocation.

TOPOGRAPHY

Overall relief is not great with a 70m fall from south to north but is more pronounced in the southern part of the field. There is well defined drainage comprising Bendigo and Myers Creek. The study area is drained by tributaries of Myers Creek.

GEOHYDROLOGICAL MODEL

General

The original pre-mining ground water flow system was in sympathy with the surface flow system, with major groundwater drainage lines being sympathetic with Bendigo and Myers creeks. The effect of mining on these systems was to impose a series of "flat pools" corresponding to lengths of interconnected workings. These "flat pools" are easily seen on Figure 1 - their hydraulic gradients are sensibly zero with hydraulic potential intermediate with original groundwater levels at their upstream and downstream extremities. This results in "stepdowns" in the saturated surface in their upstream zones and mounding of the saturated surface in the downstream areas. Thus at its northern end (North New Moon Shaft) the water level in the "Garden Gully flat pond" is approximately 201m AHD whereas groundwater level in drill hole BRC8103, an immediately adjacent hole, is 199m AHD. Similar instances of this phenomenon are shown on Figure 1 for the New Chum "flat pool".

The groundwater flow system is driven by an annual recharge from winter rains which cause groundwater levels to rise from 1 to 1.5 metres annually throughout the study area. This annual recharge is discharged into aquifers of the Riverine plain and eventually to the River Murray.

AQUIFER PROPERTIES

During pumping tests it was observed that for any given time piezometers along strikes exhibited greater drawdowns than piezometers in other directions at approximately equal distances from the pumping bore. This is indicative of the permeability being anisotropic.

Aquifer test results from three borehole tests were analysed using the method for anisotropic aquifers of Kruseman and De Ridder[1]. Results are tabulated in Table 1.

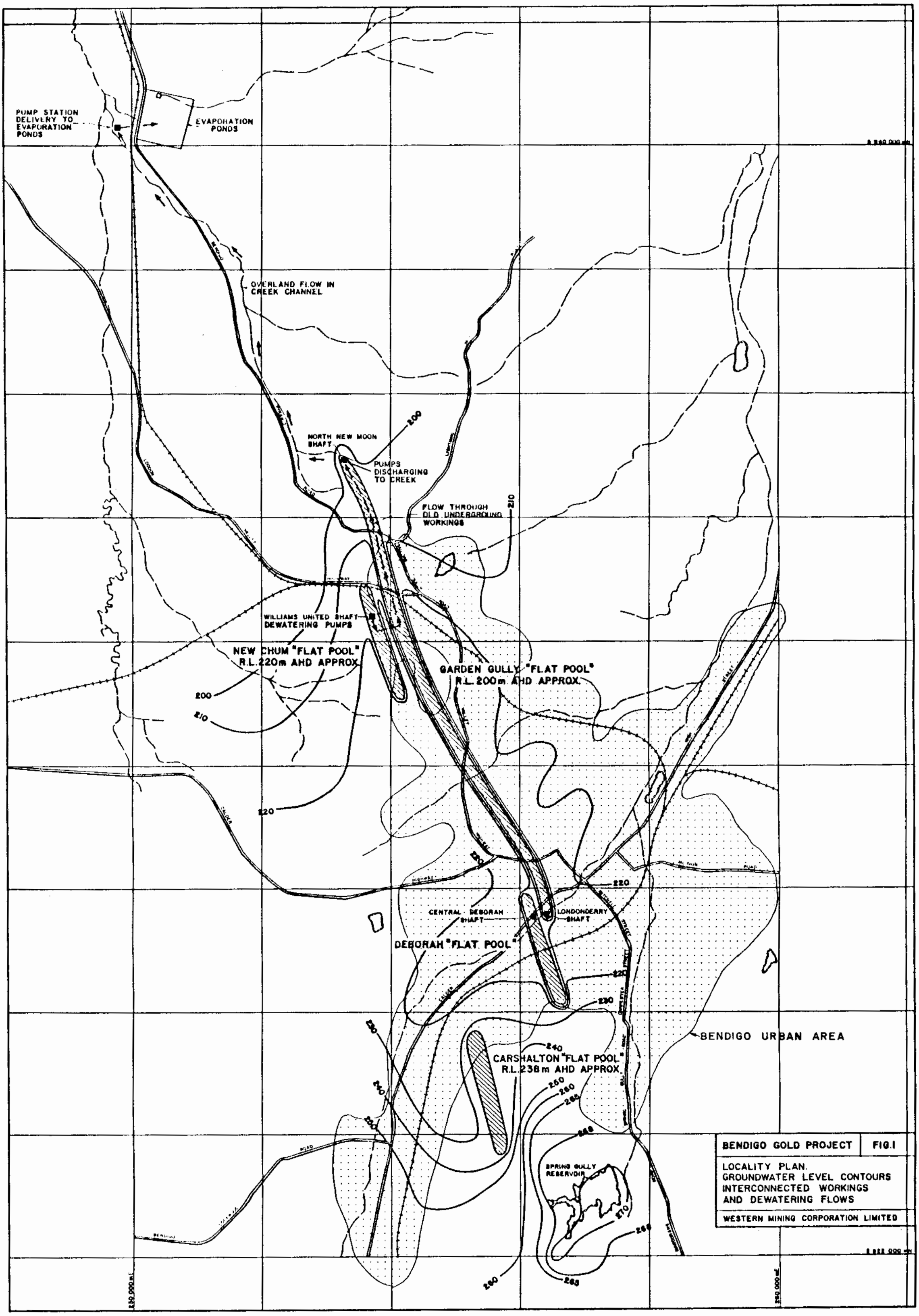
Table 1

Low Yield - Borehole Tests

Pumped Bore	Transmissivity Along Strike m^2/day	Transmissivity Across Strike m^2/day	Location of Bore (Line of Lode)
BRC 7070	4	0.32	Garden Gully
BRC 3062	74	.12	Carshalton
BRC 2060	50	0.02	Nell Gwynne

A storativity of 0.005 was adopted for design calculation, this figure being arrived at from pumping test analysis and a consideration of aquifer geology.

The general model which has emerged from the investigation programme is that of a Water Table aquifer, strongly anisotropic with the major permeability axis in the strike direction.


PUMP STATION DELIVERY TO EVAPORATION PONDS
EVAPORATION PONDS
OVERLAND FLOW IN CREEK CHANNEL
NORTH NEW MOON SHAFT
PUMPS DISCHARGING TO CREEK
FLOW THROUGH OLD UNDERGROUND WORKINGS
WILLIAMS UNITED SHAFT DEWATERING PUMPS
NEW CHUM "FLAT POOL" R.L. 220m AHD APPROX
GARDEN GULLY "FLAT POOL" R.L. 200m AHD APPROX.
CENTRAL DEBORAH SHAFT
LONDONDERRY SHAFT
DEBORAH "FLAT POOL"
CARSHALTON "FLAT POOL" R.L. 236m AHD APPROX.
BENDIGO URBAN AREA
SPRING GULLY RESERVOIR
BENDIGO GOLD PROJECT
FIG.1
LOCALITY PLAN.
GROUNDWATER LEVEL CONTOURS
INTERCONNECTED WORKINGS
AND DEWATERING FLOWS
WESTERN MINING CORPORATION LIMITED

RECHARGE

Average annual recharge/square km of aquifer was estimated to be about 6,000m^3, if a value of 0.05 is adopted for the specific yield of the upper few metres of oxidised material within which the water table fluctuation takes place.

Based upon an average groundwater gradient of 0.0143 and an along strike transmissivity of 4m^2/day in the vicinity of BRC7070 (Williams United Shaft) groundwater flow in this part of the field is about 21,000m^3/annum per km width.

WATER QUALITY

Water samples were taken from both the New Chum and Garden Gully lines of workings. Samples were also taken from bore holes in the country rock. Analysis results from a selection of samples are given in Table 2.

Table 2

	TDS	Ca	Mg	K	Na	Cl	HCO_3	SO_4	As	Fe	Mn
New Chum Workings	7000	260	520	40	1260	2150	2500	900	2	3	1.5
Garden Gully Workings	5200	90	270	35	1450	2200	1770	50	0.8	0.5	0.7
General Groundwater adjacent to these Workings	4760	92	210	55	1390	2530	640	930	0.16	-	-

DEWATERING

Estimates of dewatering rate and total volume of water to be removed were required for three different dewatering times : 3, 6 and 12 months; for a total dewatering depth of 100m below shaft collar (80m of drawdown).

These estimates were based upon the formula given in Huisman[(2)] for unsteady unconfined flow to a fully penetrating ditch pumped at a constant rate and the volume of water stored in the workings down to the required level.

Values of transmissivity and storativity adopted for design purposes were 0.5m^2/day and 0.005 respectivity. A careful estimate of the volume of the old workings was made based upon old mine plans and production records. This calculated volume was increased by 20% to ensure conservatism. Finally, a coefficient of 0.5 was applied to the formula given in Huisman to allow for the fact that the mine merely approximates a fully open fully penetrating trench. Table 3 gives details of these estimates

Table 3

Dewatering Volumes and Rates

Williams United Shaft (New Chum Line)

Dewatering Depth below Surface (m)	Draw down (m)	Length of Mine Workings (m)	Vol. of Saturated Mine Working to 80(m) (m^3 + 20%)	Dewatering Period (Months)	Required Pumping Rate (L/sec) (a) Aquifer	(b) Mine Workings	(c) Total a + b	Total Volume Pumped ($m^3 \times 10^3$)	Inflow at End of Revision (L/sec)
100	80	4,000	340,000	3	17.4	44	61.4	478	11
				6	12.4	22	34.4	535	8
				12	8.6	11	19.6	618	6

RESULTS

Pumping commenced on 29/7/86 and a drawdown of 101m was reached on 29/12/86 with an average discharge rate of 40l/s and total discharge of 534Ml. This result agrees quite well with prediction of Table 3.

When the derived values for transmissivity ($0.32m^2$/day) and mine storage ($3360m^3$/vertical m) are used instead of the conservative values adopted for design purposes, the calculated drawdown, corresponding to an average discharge rate of 40l/s for a period of 156 days, is 105m which is within 4% of the achieved drawdown.

These results amply illustrate the value of approximate analytic techniques for obtaining design values in groundwater engineering.

WATER COLLECTION AND DISPOSAL

The initial dewatering of the New Chum line of workings at the Williams United Shaft is only the first part of a programme to dewater this and other areas of the Goldfield to far greater depths.

Therefore, the means of collecting and disposing of these initial dewatering flows was required to be adaptable to handling considerably greater volumes over extended periods.

The options considered for disposal of the moderately saline water were:

(a) Treatment for the removal of arsenic and disposal into the creek system.
(b) Desalination to acceptable levels of salinity for direct discharge.
(c) Discharge into closed circuit evaporation ponds.

The desalination option was discarded on the grounds of prohibitive cost combined with inflexibility in sizing, technical difficulties and the problems of reject brine disposal.

Although direct discharge to surface after arsenic removal would not have added to the long term salt load in the creek system it was deemed environmentally unacceptable.

The option of discharge to evaporation ponds with final concentration and containment of the crystalised salts was finally adopted.

This method of disposal had previously proved successful in the dewatering at the Stawell Gold Operation.

Topography, drainage systems, small landholdings and forest areas limited the potential sites suitable for water management and large evaporation ponds to areas beyond the northern end of the field.

Because of the low nett evaporation rate of about 600mm per annum in this region, detailed water balance calculations indicated that ponds of at least 50Ha in area combined with a buffer storage capacity of about 700 ML were required to handle the initial dewatering flows and continuing inflows from the Williams United workings.

A suitable site for ponds was located and purchased at Woodvale some 4km to the north of the mining lease and 5 terraced ponds totalling 52Ha in surface area with storage capacity of 700ML were constructed.

Subsequently a further adjoining area was aquired which can contain an additional 85Ha of ponds required for dewatering of workings at elsewhere in the field.

The pond storage volumes were required to contain the high initial pumping rates particularly in the low evaporation months.

Delivery of the dewatering flows to the evaporation ponds from the Williams United area was achieved by utilising the long section of interconnected underground workings on the adjoining Garden Gully reef structure as an underground conduit The continuity of these workings over a total length of 8km was established during the initial pumping tests and monitoring.

A short length of pipeline was installed from the Williams United Shaft pumps to the Garden Gully line and water discharged via a drilled hole into the old workings. 3km to the north bore pumps also connected to the workings repumped the flow into the creek system for downstream flow to the site of the evaporation ponds. Here a small sill in the creek channel diverted the water to a pump pond for delivery into the evaporation ponds.

The environmental approvals required that flows in the creek system be regulated during various months of the year and provided for bypassing flows downstream if rainfalls reduced overall creek salinity to less than 500g/m^3.

The use of the interconnected underground workings as a conduit avoided the need for pipelines through the highly developed urban area of Eaglehawk, and will also enable throughflow under the city area of Bendigo when dewatering of areas at the southern end of the Goldfield is required.

The large storage volume of these interconnected old workings has been used as a buffer storage by drawing down during months of high evaporation and refilling when creek flows are not permitted, or in low evaporation months.

This has allowed filling of the evaporation ponds for maximum evaporation to be achieved expeditiously whilst maintaining constant pumping rates from the Williams United area.

The evaporation ponds are sited on highly impermeable clays with internal borrow pits used for embankment fill. These borrow pits have been sited to receive the highly concentrated solutions on decommissioning. The final crystalised salts will be contained in these pits and encased with clay capping.

Monitoring bores around the perimeter of the ponds have been provided to detect any seepage but there are no indications of losses in this manner.

(1) "Analysis and Evaluation of Pumping Test Data" by J.P. Kruseman and N.A. De Ridder; published International Institute for Land Reclamation and Improvement, Wageningen, Netherlands, 1970, Bulletin 11.

(2) "Groundwater Recovery" by L. Huisman; published McMillan.

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