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BERRI EAST GROUNDWATER INTERCEPTION SCHEME HYDROGEOLOGICAL INVESTIGATION

ABSTRACT

Recent departmental investigations at Berri East indicate that saline groundwater flux from the Loxton Sands aquifer to a 2 km reach of the River Murray is of the order of $13Td^{-1}$.

INTRODUCTION

Interpretation of river profile sampling in January 1986, indicated that saline ground water may be entering the right bank of the River Murray between Santos Quarries and Lock 4.

Engineering and Water Supply Department (E&WS) engineers estimated that this salt flux is of the order of $40Td^{-1}$, and attributed a significant portion of it to the 2 km reach north of Berri township, where the water table exhibits a steep gradient directed towards the river.

The DME was subsequently requested to investigate in detail the hydrogeology of the area between BE6 and Santos Quarries, and to specifically determine aquifer properties

- confirm water table gradients towards the river
- determine the salinity distribution
- determine groundwater chemistry and the potential for tube well screen precipitation and clogging
- determine optimum tube well design.

This report evaluates data from both the DME drilling and investigations in the Berri East area, (Fig. 1. App. 2) and E&WS drilling primarily in the alluvial sediments on Martins Bend, carried out during the first half of 1986.Table 1, App. 1 outlines the relationship between the drilling program numbers and the unique unit numbers. Fig. 2, App. 2 shows the location of all relevant wells in the Berri area.

SUMMARY OF INVESTIGATIONS

The original program was designed on the basis that interception may only be required along the reach of the river between BE6 and Santos Quarries, the southern limit of the scheme to be determined by E&WS drilling.

The original program (Fig. 3, App. 2) consisted of the drilling of one production well and three observation wells (DME 1,2,3) for aquifer testing, and four observation wells (DME 4-7) for water table information and salinity profile determination.

DME 1 was planned as a double completion well penetrating both the Loxton sands (unconfined aquifer) and the Murray group limestone (confined aquifer) to determine the confining layer thickness, the pressure head of the Murray group, and its response to pumping from the Loxton Sands.

DME 7 was also located to act as a control point for a geophysical survey designed to locate the flushing front.

Cable tool drilling was utilized to obtain reliable strata and water samples.

Falling head permeability tests (slug tests) were to be carried out on all wells, and Geophysical logging on selected wells.

After completion of the first two holes, it became apparent that the aquifer was significantly thinner than anticipated (for DME 1, 3, about 7 m, compared to 15 m at BE6), and coupled with the falling head hydraulic conductivity (K value) of $1.5md^{-1}$ the viability of a groundwater interception scheme became doubtful.

The program was therefore extended (Fig. 4, App. 2) by deleting test pumping and well design evaluation in favour of an additional two wells to better define aquifer geometry and water table gradient.

447SULTS

Results of field and laboratory investigations are presented in the appendices, which also include copies of borelogs from the E&WS drilling program.

HYDROGEOLOGY

Regional Hydrogeology

Berri East project area lies within the Murray Basin. Precambrian basement at a depth of ~700m is overlain by a Tertiary-Quaternary sequence of sediments. The formations relevant to this study include the Murray group limestones, overlain by the Bookpurnong Beds and Loxton Sands.

Local Hydrogeology

DME & E&WS drilling undertaken in the area has produced a comprehensive knowledge of the hydrogeology outlined in the following table. Aquifer systems are defined on the basis of lithology and hydraulic characteristics, aquifer boundaries are not necessarily stratigraphic boundaries.

Age	Boundary Elevation m (AHD)	Formation	Lithology
Quaternary	~40-45m	Dune Sand	Red brown silty Quartz Sand.
Quaternary	30-35	Blanchetown Clay	Grey to red brown clay and sandy clay. Low permeability clays causing drainage problems in irrigation areas.
Pliocene	3-13	Loxton Sands (Pliocene Sands unconfined aquifer system)	Yellow brown, clayey quartz sands, upper coarse, lower fine-medium, lower micaceous, salinity 10-30,000 mgl^{-1} hydraulically continuous with the River Murray in the study area.
Pliocene	10	Bookpurnong Beds (Confining Layer)	dark grey green glauconitic micaceous clays, silts and quartz sands.
Miocene		Pata Limestone (Murray group confined aquifer system).	Brown grey sandy clay and limestone, salinity 18-19000mgl^{-1}.

Aquifer geometry is illustrated in fig. 5, App 2. This quasi three dimensional diagram indicates the variable elevation of the Loxton Sands - Bookpurnong Beds contact, and the watertable surface.

Confining Layer

There has been some doubt as to the effectiveness of the Bookpurnong beds as a confining layer in the project area.

Results from laboratory testing of cores collected during drilling gave K values of ~10^{-3}-$10^{-7}md^{-1}$ (Table 2, App. 1). It should be recognized that these values are estimates of the vertical hydraulic conductivity. As cores are compacted during drilling, or have been recompacted before testing the values are probably high, however they may be accepted to indicate that the Bookpurnong Beds in the project area act as an effective aquitard. This is further demonstrated by the head differences in the double completion well DME 1. The potentiometric level of the Murray group occurs at EL 17.34 m (AHD), 2.88 m above the water table at this location.

The situation may be different beneath the alluvium at Martins Bend. Cobb (1986) states "The valley fill deposits reach or nearly reach the top of the Murray Group as indicated by highways department drilling for the proposed Berri bridge, consequently the potential exists for Murray group groundwater to discharge into the valley fill deposits and upward leakage".

Since none of the E&WS bores penetrated to the Murray Group, information on the leakage potential and stratigraphy at this location is unknown.

It may be assumed however from the available E&WS logs, showing fine sands, silts and clay, that the potential is low, but further investigations are warranted.

Hydraulic Conductivity of the Loxton Sands

Estimates of hydraulic conductivity of the Loxton Sands were made from slug tests and by comparing sieving results with those from holes drilled at Noora, 20 km east of Berri, where an invesigation reported by Williams (1976) involved pumping tests to determine aquifer properties.

Slug test results are shown in Table 3, App. 1, DME bores generally intersected a fine material with a k value range (allowing a 50% error) of 0.5-2.5md^{-1}. A coarser material located in DME 7,9 gave a range of 2-6md^{-1}.

Due to the decision not to carry out pump testing at Berri it was considered valid to extrapolate results from the Noora investigation to Berri East. Comparison of sieving analyses signatures (App. 4), indicates that DME 7, 9 are the only wells that compare favourably with CTL 7A, 9A, 10A. In general the Berri East wells show higher percentages of silt and clay (5-30%), the governing factor in hydraulic conductivity.

The results from Noora are summarised in the following table.

BORE	K md^{-1}	Lithology
CTL 7A	4-5.2	Coarse material, low silt, clay content (o-20%)
CTL 9A	0.26-0.78	fine sands, high silt, clay content (5-30%)
CTL 10A	2.1 -2.9	coarse material, low silt, clay content (1-5%)

Williams (1976) recommends a Transmissivity value of 100m^{2}d^{-1}, corresponding to a K value of 4md^{-1}, and comments that this is likely to be a maximum value. Consequently the values stated above for Berri East are probably acceptable values.

Water Quality

Fig. 6, App. 2 shows the groundwater salinity distribution in the project area. Presented in Table 4 App. 1 are results from wells sampled by bailing and pumping in this program. Fig. 6 includes results from E&WS drillholes most of which were pumped.

Water stratification during drilling of DME wells was observed on only a small scale, and has been interpreted as being primarilly due to losses from drilling water, rather than stratification in the aquifer.

It should be noted that DME 5,8,9 sampled on 1/7/86 exhibit a lower salinity than determined at the time of drilling. Similarly BE 17,19 gave samples of low salinity on 1/7/86 compared to those determined at the time of drilling.

Results from DME 5,8,9 are inaccurate and further pumping will be undertaken, however the results from BE17,19 may be explained by leakage from the river giving lower salinities, not representative of groundwater flowing to the river.

It can be assumed that evaporation from the shallow watertable has produced the high salinities observed around Martins bend.

For calculation purposes it is recommended that a value of 20,-30 000 mgl^{-1} be used for groundwater contained within the Loxton Sands.

Watertable Contours

Fig 7, App. 2 shows the water table contours. The surface as plotted includes reliable data from this program (Table 5, App. 1) and from E&WS drilling.

The plot also includes water levels taken from Cobb (1986), extracted from the observation records and borelogs, for E&WS piezometers drilled in the 1970's and DME wells drilled in the late 1960's.

E&WS wells drilled in the river alluvium on Martins Bend may reflect confined groundwaters, probably from more than one 'aquifer' due to the geology of such alluvial sediments, Cobb (1986).

In spite of the problems noted above the contours are considered to be an acceptable representation of the water table surface in the Berri area.

Hydraulic gradients directed towards the River in the Berri East area range between $1.2x10^{-2}$ - $7x10^{-4}$. Of particular interest is the steep gradient between DME9 and the river discussed later. The low groundwater levels at Martins Bend, support the notion of evaporation having produced high salinity groundwater in that area.

DISCUSSION

Estimate of Total Salt Flux

Estimates of total salt flux are calculated for the zones shown on fig. 4, App. 2. The maximum salinity in each zone (rounded to 20-30 000 mgl^{-1}) is used with the highest K value and appropriate gradient to estimate the maximum salt flux to the river. The minimum salt flux is calculated using the same values of salinity and gradient, but the lowest K value.

The sum of the results from the zones is taken to be the total maximum or minimum salt flux to the river within the reach between BE7 and Santos Quarries.

The calculations for Zone 5 are set out below, results only for the other zones are presented.

ZONE 5:

Apply Darcy's Low to Calculate Maximum Flux.

$$Q = AK \left(\frac{dh}{dx}\right) m^3 d^{-1}$$

$$Q = (700 \times 7.9) m^2 \times 6 m d^{-1} \times 0.012$$

$$Q = 392 \; m^3 d^{-1} \times 0.02 \; T m^{-3} \quad \text{(ie salt content)}$$

$$Q = 8 \; Td^{-1}$$

Apply Darcy's Law to Calculate Minimum flux.

$$Q = AK\left(\frac{dh}{dx}\right) \times 0.02\ Td^{-1}$$

$$Q = (700 \times 7.9) \times 2 \times 0.012 \times 0.02\ Td^{-1}$$

$$Q = 3Td^{-1}$$

Tabulated below are the results from Zones (1-5). Results compare well with those obtained by use of the Dupuit approximation,

$$Q = \frac{K(h_1^2 - h_2^2)}{2L}.$$

Zone	Max Salt Flux Td^{-1}	Min Salt Flux Td^{-1}
1	0.3	0.1
2	0.8	0.2
3	0.8	0.2
4	2.7	0.6
5	8	3
	Total 12.6	Total 4.1

All zones except zone 5 show a small salt flux due to low gradients and, or K values.

Zone 5 shows a high salt flux due to the steep gradient and high K value in this area. It is possible that a burried channel of high hydraulic conductivity exists in this area, supported by the general shape of the water contours converging at this site. The intersection of finer material at BE 10,19 will not prevent the inflow to the river, ie the increased gradient will produce a similar flux to that further from the river.

The maximum salt flux of $8Td^{-1}$ relies on the accurate determination of the K value in this area, and as mentioned previously the estimate used is considered to be satisfactory.

Origin of Berri Groundwater Mound

The groundwater mound beneath the Berri Irrigation Area is a direct result of the irrigation and drainage practices carried out since the beginning of this century.

The mound began to build up shortly after irrigation began due to accessions to the regional water table, which may be taken as having been EL 14m (AHD), (Fig. 8, App. 2), Boucaut (1975). Perched water causing water logging of soils also occurred where the Blanchetown clay was present.

In 1922-1923 tile drains were installed to improve drainage, water being disposed of to the river. In the 1920's-1930's drainage wells were sunk into the Loxton Sands, however these had a limited life due to the rising groundwater mound and clogging of the aquifer with salt and silt particles.

The present comprehensive drainage system was built in the 1930's-1940's. Water is collected via tile drains and gravitated to mainly open bottomed caissons at the local point of lowest elevation from which the water is pumped to the Berri Evaporation Basin. The bottom of most caissons is below the water table, however there is minimal loss of collected water.

Accession to the water table is still a major problem as only 50% of farms have any drainage at all. It has been noted that there has been a small recession of the mound ~0.5m in the last few years due to water on order, and improved distribution systems.

Currently 1-2 Ml ha^{-1} yr^{-1} (K Smith, E&WS, pers. comm.) are being lost to the water table, this figure should be taken as an estimate only, as no study has yet been completed.

Flushing Front

Collingham (1986) reports that a 'flushing front' exists, believed to extend from a point north of BE7 trending northwesterly towards the location of DME7.

The notion of a flushing front is based on the assumption that irrigation accessions have produced a mound of low salinity water of sufficient dimensions to effectively penetrate the Loxton Sands, producing a narrow transition zone between low salinity irrigation drainage water and high salinity groundwater, moving at low velocity towards the river.

DME personnel consider that in the Berri Irrigation area the groundwater mound is composed of a Low Salinity lense of water floating on the dense saline regional groundwater, spreading out laterally at low velocity down gradient.

Interpretation of drilling and geophysics carried out in the project area support the DME model.

DME drilling to the base of the Loxton Sands intersected saline water at all locations. The elevation of this regional groundwater may be explained by the effect of the vertically building mound, i.e. increase in water level occurs as potentials adjust regionally to the presence of anomalously high potentials beneath the mound.

Salinity distribution indicates that the influence of less saline irrigation water lies to the west of DME 7 overlying saline groundwater at depth. Cobb (1986) notes water of salinity 42 000 EC from EL 17.6-19m (AHD) in well 933, compared to that of salinity 1780-7930 EC bailed above EL 19m (AHD) in well 662, 200m from 933.

The model then of a lense, is supported in part by the salinity results, further support coming from the resistivity survey carried out between well 661, DME 7, 8.

Figs. 9, App. 2 shows the generalised cross-section constructed from the survey results.

The generalized section indicates saline water at DME 7 as proven by drilling. At 661 however the resistivity profile shows a conductive clay layer (4-5 X m^{-1}), underlain by a less conductive layer (10 X m^{-1}) below the water table. Interpretation here is difficult and may be ambiguous, the value of 10 X m^{-1} not necessarily being representative of the entire layer thickness. The bottom layer with a value of 0.2 X m^{-1} probably represents the Bookpurnong beds.

Overall interpretation appears to support the concept of a lense shaped body of low salinity water floating on a thin layer of dense saline groundwater, wedging out between 661 and DME 7.

The situation is complex and it is possible that there is not full connection between lower salinty water in the Loxton Sands and the alluvial sediments at Martins Bend. The original suggestion of a flushing front extending from a point north of BE7 towards the location of DME 7 is a too simplistic interpretation. Final delineation of the groundwater mound and location of its spread will require further drilling and, or geophysical work.

<u>Recommendations for Future Work</u>

Further slug testing and pumping will be carried out to finalise the results of this report, however this further information is not expected to significantly alter the calculations of the salt flux.

The following additional work is recommended should a scheme still be viable based on the interpreted aquifer geometry and calculated salt flux.

1) Drilling to
- determine the extent of the channel intersected at DME 9.
- determine the extent and profile of the groundwater mound.
- determine the nature of the aquitard at Martins bend.

2) Pump testing in areas of both high and low hydraulic conductivity to confirm the values of K used in this report, to test the effects of chemical deposition on tube well screens, and determine optimum well design.

As a general comment, the situation where part of the field hydrogeologcal investigation was carried out by the Soils and Foundations Section of the E&WS Dept, was considered to be unsatisfactory due to some overlap and lack of consistant approach to drilling and sampling.

CONCLUSIONS

Hydrogeological investigations in the Berri East area allow the presentation of an accurate hydrogeological model. A maximum salt flux of 13 Td^{-1} is estimated for the 2 km reach between Berri East pumping Station and Santos Quarries.

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TABLE 1

BORE NUMBERING SYSTEM

UNIT NUMBER	FIELD NUMBER
7029 - 959,960	DME 1
946	DME 3
945	DME 4
948	DME 5
943	DME 6
947	DME 7
944	DME 8
958	DME 9
938	BE 5
939	BE 6
940	BE 7
941	BE 8
942	BE 9
949	BE 10
950	BE 11
951	BE 12
952	BE 13
953	BE 14
954	BE 15
961	BE 16
962	BE 17
963	BE 18
964	BE 19
039	CTL 7A
025	CTL 9A
030	CTL 10A

TABLE 2

PERMEABILITY TESTS (LABORATORY)

BORE	INTERVAL SAMPLED	HYDRAULIC CONDUCTIVITY (md^{-1})	SAMPLE QUALITY
DME 1	37.7-38.0	2.23×10^{-7}	Good
DME 4	20.0-20.35	2.59×10^{-3}	Poor
	20.95-21.3	2.0×10^{-4}	Average
	21.88-22.23	1.11×10^{-3}	Average
DME 5	47.5-47.9	9.1×10^{-3}	Poor
	47.9-48.3	7.78×10^{-3}	Average
DME 6	44-44.5	6.0×10^{-4}	Poor
	44.5-45.9	1.14×10^{-3}	Average
DME 7	50-50.4	1.66×10^{-3}	Average
	50.4-50.8	7.72×10^{-3}	Average
DME 8	37-37.4	4.26×10^{-3}	Average
	37.65-38.05	1.46×10^{-3}	Average
	38.05-38.45	6.65×10^{-4}	Average
DME 9	32-32.4	1.48×10^{-7}	Good

TABLE 3

SLUG TEST RESULTS

BORE	INTERVAL TESTED (m)	K(md^{-1})	50% RANGE	RELIABILITY
DME 1 U	30-36	1.69	0.85-2.54	OK
L	51-57	0.21	0.11-0.32	OK
DME 3	27-33	1.10	0.55-1.65	OK
DME 4	17-23	0.06	0.03-0.09	OK
DME 5	37-43	2.78	1.39-4.17	Poor
DME 6	37-43	1.74	0.87-2.61	OK
DME 7	38.5-41.5	4.17	2.09-6.26	OK
DME 8	31-37	5.22	-	Poor
DME 9	24-30	8.64	-	Poor
BE 17	7.2-10.2	0.52	0.26-0.78	OK
BE 19	6.3-9.3	0.66	0.33-1.32	OK

- For areas of low hydraulic conductivity use a range of 0.5 - 2.5 md^{-1}

- For areas of high hydraulic conductivity use a range of 2 - 6 md^{-1}

TABLE 4

AIRLIFT PUMPING RESULTS

BORE	DEPTH (m)	EL(m)(AHD)	ANALYSIS NO.	EC	Mgl^{-1}	pH
DME 1 U	38.0	5	W 3516/86	30 000	21 210	12.17
L	33.5	10	W 3514/86	26 900	18 788	7.19
DME 3	30.0	9	W 3518/86	41 600	30 925	7.38
DME 4	22.5	2	W 3520/86	24 000	16 500	7.89
DME 5	~40.00	10	W 3163/86	11 450	7 535	7.68
Drilling	47.0	3	W 3365/86	25 700	17 787	7.43
DME 6	40.5	8	W 3522/86	35 000	25 248	7.04
BE 6	~25.0	6	W 3168/86	40 200	29 580	7.32

BAILING RESULTS

DME 7	~39	15	W 3838/86	29 900	21 130	7.93
DME 8	~34	12	W 3839/86	13 800	9 140	8.30
Drillng	32	14	W 3323/86	39 400	28 865	7.44
DME 9	~27	13	W 3840/86	16 200	10 855	7.99
Drilling	~27	13	W 3409/86	26 700	18 642	6.94
BE 7	~20	1	W 3841/86	3 720	2 160	8.83
BE 10	~9	8	W 3842/86	18 900	12 787	8.31
BE 17	~10	9	W 3843/86	890	480	8.57
Drilling	~6	13	-	32 000	22 000	-
BE 19	~9	9	W 3844/86	905	485	8.40
Drilling	~5-10	8	-	4 000	2 335	-
7029-260	~38	7	W 3846/86	1 770	995	8.44
" -261	~34	13	W 3847/86	45 600	34 630	8.05
" -152	~45	8	W 3845/86	3 870	2 250	8.25

TABLE 5

WATER LEVELS

BORE	SWL (m)	EL (AHD) (m)	DATE
7029-152	38.89	14.17	1/7/86
7029-260	22.43	22.77	1/7/86
7029-261	26.25	21.12	1/7/86
DME 1 U	28.55	14.46	1/7/86
L	25.63	17.34	1/7/86
DME 3	24.41	14.34	1/7/86
DME 4	11.54	13.71	1/7/86
DME 5	36.68	13.62	1/7/86
DME 6	35.25	14.14	1/7/86
DME 7	33.93	20.26	1/7/86
DME 8	30.64	15.22	1/7/86
DME 9	21.65	18.41	1/7/86
BE 6	14.01	17.16	1/7/86
BE 7	5.58	15.12	1/7/86
BE 10	2.27	15.13	1/7/86
BE 17	4.61	14.68	1/7/86
BE 19	2.78	15.57	1/7/86