$S_t = S\Sigma(\Delta hA)$ where

S_t = change in storage (m^3)

S = Storage coefficient (dimensionless)

Δh = change in head for each grid zone (m)

A = area of each grid zone (m^2)

The change in storage was calculated to be $10^7 m^3$ over the 20 year pumping period, or an average of 500 Ml per year.

2. Leakage

For the southern part of the area where significant leakage is likely to occur, the hydraulic conductivity between the aquifers was calculated to be in the range 3×10^{-3} to $3 \times 10^{-2} m^3 day^{-1} m^{-2}$ (Appendix 4). Knowing the head difference between the aquifers this allows the calculation of the rate of leakage from the confined aquifer. The head difference does not vary much seasonally, however geological consideration suggest that leakage will vary over the area, and this method is unlikely to be as reliable as the depletion method.

The thickness of clays separating the aquifers varies from zero to about 5 metres, and a value of 2.5 metres has been arbitrarily chosen for a test calculation.

The head difference varies from zero to 2 metres in the zone of leakage and a value of 1 metre has been used for the calculation.

Using Darcy's Law, the rate of leakage can be calculated:-

$$Q = K \frac{h}{b} A, \text{ where}$$

Q is rate of leakage through confining bed

K is vertical hydraulic conductivity of confining bed ($0.015\ m^3 day^{-1} m^{-2}$)

h is head difference between aquifers (1 metre)

b is thickness of confining beds (2.5 metres)

($\frac{h}{b}$ = hydraulic gradient across confining bed)

A is area over which leakage is calculated (100 km^2)

Hence Q = $2 \times 10^8 m^3$ $year^{-1}$ or 200 000 Ml per year. This value for leakage is nearly 10 times the estimated rate of extraction from the confined aquifer. The value of head difference can vary by 100% at most and 1 metre seems a reasonable value, but the values of confining bed thickness and hydraulic conductivity can each vary by at least an order of magnitude. A minimum value of leakage of 4.5 x $10^6 m^3$ $year^{-1}$ (4 500 Ml per year) can be calculated selecting extreme values of the parameters (K = 0.003, b = 25). This value represents about 20% of the amount extracted from the confined aquifer. The main uncertainty is the value of K, because only one aquifer test is available for its determination, however the true value of leakage is unlikely to be less than 4.5 x $10^6 m^3$ $year^{-1}$.

3. Discussion

Depletion of the upper aquifer is being nearly balanced by natural recharge from the rivers, and re-circulation of excess irrigation water. This means that the observed change in storage in the unconfined aquifer is not a measure of leakage, but of the disparity between leakage from the aquifer and recharge to it. The low transmissivity of the aquifer between recharge zones along the rivers and the flanking irrigation areas requires that a steep hydraulic gradient be developed towards the areas where leakage is occurring.

APPENDIX 4

RECALCULATION OF AQUIFER TEST DATA (J. Sinclair)

RE-EVALUATION OF 1969 AQUIFER TESTS

INTRODUCTION

Partially complete tests were carried out on DM4, located beside the Bremer River, near Langhorne Creek. These may have been flooded out, so arrangements were made to move to another site further from the river. Successful aquifer tests were then performed at two sites, one near Langhorne Creek, and one near the Bremer River in the south of the area (Figure 47).

METHOD

The transmissivity and storage coefficients of a leaky artesian aquifer with fully penetrating wells, without water being released from storage in the aquitard and constant discharge conditions, and the hydraulic conductivity of the overlying aquitard were determined from aquifer test data by following the type curve graphical method.

The family of curves ($\frac{r}{B}$) used were NON STEADY STATE LEAKY ARTESIAN TYPE CURVES, which plot $W(u, \frac{r}{B})$ against $\frac{1}{u}$.

The drawdown data are plotted against the corresponding values of time on double logarithmic paper. A comparison with the WALTON family of type curves shows that the plotted points fall along a curve for $\frac{r}{B}$.

A point where $W(u, \frac{r}{B})$ and $\frac{1}{u}$ are simple is chosen as the match point. Then the co-ordinates of this point are read from the observed data sheet. The appropriate numerical values are introduced into the following equations, allowing the calculations of the aquifer parameters.

$$T = \frac{Q}{4\pi s} W(u, \frac{r}{B})$$

$$S = \frac{4Tut}{r^2}$$

$$K' = \frac{(\frac{r}{B})^2 \; T.b'}{r^2}$$

leakage coefficient $(\frac{1}{c}) = \frac{K'}{b'}$

where T = transmissivity (m^3/day/m)

Q = pumping rate (m^3/day, originally gallons per hour)

s = drawdown (m)

$W(u,\frac{r}{B})$ = well function of u, $\frac{r}{B}$

S = storage coefficient (dimensionless)

t = time (days)

r = distance to observation well from pumped bore (m)

K' = vertical hydraulic conductivity of confining layer ($m^3 day^{-1} m^{-2}$)

b' = thickness of confining layer (m)

RESULTS

Results are shown in the tables below.

	WELL	DRAWDOWN s (feet)	TIME x(min)	curve match points $\frac{r}{B}$	$W(u,\frac{r}{B})$	$\frac{1}{u}$
	DM1*					
1000 min	DM2	0.40	4.4	0.1	1	1
Q=30,810 GPH	DM3	0.62	4.9	0.05	1	10
1450 min	DM3*					
Q=26,216 GPH	DM1	0.625	1.15	0.01	1	1
	DM2	1.0	6.0	0.2	1	1
1300 min	DM5*					
Q=26,300 GPH	DM6	1.35	3.6	0.000	1	10

*indicates production well

Meter readings were not recorded for the pump test on DM5, so a visual estimate of pumping rate was made from the discharge rate curve.

SUMMARY OF RESULTS

AQUIFER PARAMETERS

Pumped Well, time	well	Transmissivity $m^3/day/m$	Storage Coefficient
DM3			
1450 min (24hr 10 min)	DM2	750	8.41×10^{-4}
	DM1	1 200	1.02×10^{-3}
DM1			
1000 min (16hr 40 min)	DM3	1 400	4.71×10^{-4}
		1 300	(5.76×10^{-4}) (Roberts, 1972)
	DM2	2 200	7.95×10^{-4}
		2 250	(8.4×10^{-4}) (Roberts, 1972)
DM5			
1300 min (21hr 40 min		560	1.675×10^{-4}
		490	(2.33×10^{-4}) (Roberts, 1972)

CONFINING BED DATA

Observation Bore	Depth		thickness (feet)	hydraulic conductivity $m^3 day^{-1} m^{-2}$
DM1	23'- 38'	clay	15'	3.1×10^{-2}
	38'- 58'	dry sand	20'	
DM2	62'- 77'	clays	15'	9.61×10^{-3} DM3 pumped
				2.97×10^{-3} DM1 pumped
DM3	50'- 60'	clay	10' } 13 ft	
	60'- 63'	dry sand	3'	3.43×10^{-3}
DM6	50'-112'	clay	62'	0.00 (no leakage detected)

Aquifer thickness (feet)

Bore	Depth Range	Thickness	
DM1	93'-265'	172 ft	52 m
DM2	92'-240'	148 ft	45 m
DM3	85'-250'	165 ft	50 m
DM5	127'-214' + ?	88 ft ?	27 m
DM6	122'-215' + ?	93 ft ?	28 m

Leakage Coefficient is measured in day^{-1}. It may be defined as the rate at which water will leak from a unit area of the confining layer per unit drawdown in the aquifer proper. It is the inverse of hydraulic resistance.

i.e. leakage coefficient $(\frac{1}{c}) = \frac{p'}{m'}$

p' = vertical hydraulic conductivity

m' = aquitard thickness

c = hydraulic resistance

DM1 Leakage coefficient = $\frac{3.10 \times 10^{-2}}{35 \times 0.3048} = 2.9 \times 10^{-3}$ $days^{-1}$

$p' = 3.10 \times 10^{-3}$

$m' = 35 \times 0.3048$

DM2 Leakage coefficient = $\frac{2.97 \times 10^{-3}}{15 \times 0.3048} = 6.50 \times 10^{-4}$ $days^{-1}$

$p' = 2.97 \times 10^{-3}$ m^3/day/m

$m' = 15 \times 0.3048$ m

DM3 Leakage coefficient = $\frac{3.43 \times 10^{-3}}{13 \times 0.3048} = 8.66 \times 10^{-4}$ $days^{-1}$

$p' = 3.43 \times 10^{-3}$ m^3/day/m

$m' = 13 \times 0.3048$ m

DM6 Leakage coefficient = 0.00

$p' = 0.00$

$m' = 62 \times 0.3048$

DISCUSSION

Results calculated compare well with those obtained by Roberts (1972). There is one anomaly however; the transmissivity values for DM2 obtained from tests at both DM1 and DM3 differ considerably.

To determine the thickness of the upper confining bed, well logs were consulted, and deductions made according to water level cut information and stratigraphy. The upper sequence is complex, and values used are approximate.

CONCLUSIONS

An average for the transmissivity of the confined aquifer in the central southern part of the basin is approximately 1 500 m^3/day/m. Storage coefficient is about 6.5 x 10^{-4}.

Further to the north, transmissivity decreases markedly, to 500 m^3/day/m, and storage coefficient is about 2 x 10^{-4}. The aquifer is thinner at this location.

No leakage would seem to occur through the upper confining layer in the northern part of the area. Although the leakage coefficient varies for the 3 wells in the southern part of the basin, the range is consistent (2.9-0.07 x 10^{-3} $days^{-1}$).

APPENDIX 5

ESTIMATION OF WATER CONSUMPTION OF EVAPORATED CROPS FROM AERIAL PHOTOGRAPHS

Colour aerial photographs flown in March, 1976 were used to measure the area of irrigated crop for the 1975-76 season. A fairly good differentiation of land use could be determined upon inspection of the photographs. Uncertain areas (whether or not irrigated, and the type of land use) were clarified on field trips.

The irrigated paddocks were traced from the photographs directly onto a transparent map of corresponding scale (1:20 000). They were traced again onto good quality paper, then cut out, the weight of paper representing an area of land. By weighing several sheets of paper of known area, to obtain an average, it was possible to determine the area of irrigated land from the weight ratio.

Some error occurred when tracing the areas from the photographs to the map. Aerial photography becomes distorted at the edges due to lens aberrations so the fit of photographs at their edges was not perfect. One could expect an under-estimation of irrigated area in the results obtained.

Results are tabulated below. Figure 15 shows the distribution of irrigated land in March 1976.

TABLE

Areas of Irrigated Land

LAND USE	AREA (km^2)
Bremer River area : lucerne	18.3
Angas River area : lucerne	4.9
Mosquito Creek area : lucerne	0.9
TOTAL : Groundwater irrigated lucerne	24.1
Lake Alexandrina irrigated lucerne	1.4
Vineyards (mainly river flooding)	4.7
Orchards (mainly river flooding)	1.7
TOTAL AREA IRRIGATED	31.9

ESTIMATE OF VOLUME OF WATER WITHDRAWN

The total lucerne area irrigated with water from the Tertiary aquifer is 24.1 km^2.

The value used for the water requirement of lucerne is 1 042 mm (Holmes and Watson, 1969). The average annual rainfall at Langhorne Creek is about 375 mm, and the balance (670 mm) is provided by irrigation.

$$\text{Water consumption} = \begin{array}{c}\text{irrigation}\\ \text{intensity}\end{array} \times \begin{array}{c}\text{irrigated}\\ \text{area}\end{array}$$

$$= 0.675 \times 24.1 \times 10^6$$

$$= 16.2 \times 10^6 m^3/\text{year}$$

$$= 16\ 000\ \text{Ml/year}$$

The value of 16 000 Ml/year is the estimate of water provided for lucerne evapotranspiration in an average year. The amount of water applied will be greater because it is virtually impossible to apply exactly the correct amount of water, and an excess must be applied to leach salt from the plant root zone. The actual amount of water applied to lucerne in the area has never been measured, but it is probably in the range 800 to 1 200 mm, or 20 000 to 28 000 Ml $year^{-1}$ over the entire irrigation area.

A figure of 25 000 Ml $year^{-1}$ is used here; an error of $\pm$ 30% is highly probable for the estimate of extraction from the confined aquifer until better methods are used.

APPENDIX 6

DISCUSSION OF THE GROUNDWATER SYSTEM PRIOR TO THE COMMENCEMENT OF MAJOR IRRIGATION

It is instructive to consider the probable groundwater system prior to the large scale irrigation withdrawals (i.e. before about 1960).

The cones of depression in both aquifers south of Langhorne Creek can reasonably be attributed to irrigation pumping, and prior to their formation groundwater flow would have been in a southerly direction throughout the area.

One well near the lake is known to have flowed until 1963, and a component of decreasing upward leakage from the confined into the unconfined aquifer is inferred for that period. Information from local farmers suggests that water levels in the confined aquifer near the lake were 1.5 metres above ground level before irrigation commenced.

1. Confined Aquifer

Recharge would have occurred mainly in the north and north-west, from the rivers, with a small component of intake from the unconfined aquifer in the north where the head difference was appropriate. Outflow would have been beneath the lake, with some upward leakage into the unconfined aquifer in the southern part of the area.

2. Unconfined aquifer

Recharge would have occurred along the northern sections of the rivers, and along Mosquito Creek. The southern sections of the rivers may have been responsible for less recharge than at present, because water levels are known to have fallen several metres recently creating greater storage capacity. Another source of recharge would have been upward leakage from the confined aquifer.

Discharge along the lake margin could have been expected (and local farmers report that springs did exist). Higher groundwater levels than at present would have allowed a larger area for evaporative discharge.

With relatively saline water recharging the aquifer, and some evaporative discharge it is understandable that very high salinities could occur, and it may be that modern high salinity zones are an indication of areas of maximum evaporative discharge from the aquifer prior to 1960.

The probable system is shown diagrammatically on Figure 38, together with the modern situation for comparison.

APPENDIX 7

STATISTICAL TREATMENT OF SALINITY DATA

SALINITY DATA

Time/salinity data was treated statistically using the following relationship:-

Salinity = $(a_o \pm s_o) + (a_1 \pm s_1)$ (year - 1970), where

a_o : salinity, 1970 (estimated from regression line)

a_1 : yearly change, positive increasing (estimated from regression line)

r^2 : "goodness of fit" between regression line and field data

Syx : one standard deviation from regression line, in salinity

s_o : one standard deviation from a_o estimate, in salinity

s_1 : one standard deviation from a_1 estimate, in salinity

The results are presented overleaf, followed by the field data.

Well	readings taken (No. of years)	Simulated Salinity 1970 (mg/1) a_o	yearly change (mg/1) a_1	regression coefficient r^2	standard error along salinity line $s=a_o+a_1x$ (co-variance) Syx	standard error on a_o s_o	standard error on a_1 s_1
BRM101	5	3160	160	0.39	365.60	600.75	115.61
102	7	3250	35.45	0.01	910	687	154.1
103	5	3170	-92.6	0.41	246	326	63.9
104	6	3070	51.5	0.15	360	287	61.8
105	6	5390	-131.4	0.35	373	430	89.3
106	4	3820	41.0	0.06	249	626	111.5
107	6	3740	104.4	0.33	438	349	75.1
108	4	5610	20.0	0	780	1618	349
109	5	5084	81.0	0.37	294	246	61.1
110	6	4417	14.3	0.02	226	211	54.1
111	3	3980	121.4	0.79	134	359	61.9
112	5	2290	118.3	0.99	28.4	31.1	6.2
113	3	1730	200.0	0.92	81.7	236	57.7
114	2	2266	83.33				
115	7	3490	62.0	0.24	292	221	49.5
116	4	2540	-5.0	0	168	423	75.3
117	4	1000	657.1	0.96	293	540	99.0
118	7	5015	16.4	0.05	211	138	32.7
119	3	5330	50.0	0.11	204	874	144.3
120	6	4180	-165.7	0.38	445	512	106.4
121	3	2960	139.3	0.08	1002	2541	463.9
122	7	2910	26.4	0.34	106	69	16.4
123	7	4930	275.0	0.13	1662	1405	314.1
124	2	1575	+175				
125	4	3590	-45.0	0.12	189	475	84.7
126	1	2350					
127	3	2730	100.0	0.92	40	175	28.9
128	7	2250	46.4	0.49	111	76	21.0
129	7	3800	81.9	0.53	224	146	34.6
130	1	3350					
131	4	3935	30.0	0.01	543	1364	243.0
132	1	6600					
133	4	4865	70.0	0.11	309	775	138.0
134	2	450	500				
135	4	3975	0.0	0.0	237	595	196.1
136	4	5315	-55.0	0.15	208	523	93.1
137	4	3265	-5.0	0.0	189	475	84.7
138	4	4275	-50.0	0.09	248	621	110.7
139	4	3700	-29.0	0.04	213	534	95.1
140	7	3080	51.4	0.26	244	171	38.9
141	7	4530	-60.0	0.17	209	523	93.3
142	3	5225	-125.0	0.25	306	1097	216.5
144	3	4775	-175.0	0.64	184	658	129.9
145	4	3930	15.0	0.01	275	689	122.8
146	8	3830	26.2	0.10	211	136	32.5
147	3	1930	75.0	0.96	20	87	14.4
148	2	3800	100				

Well	readings taken (No. of years)	Simulated Salinity 1970 (mg/1) a_o	yearly change (mg/1) a_1	regression coefficient r^2	standard error along salinity line $s=a_o+a_1x$ (co-variance) Syx	standard error on a_o s_o	standard error on a_1 s_1
FRL101	3	5430	200.0	0.32	408	898	289
102	5	1640	152.0	0.59	233	313	73.7
103	4	3365	-25.0	0.30	124	114	27.2
104	8	3340	128.1	0.42	397	257	61.3
105	8	3660	151	0.45	445	287	68.7
106	8	1946	51.2	0.52	129	83	19.9
107	5	1937	17.0	0.03	184	303	58.3
108	8	2090	41.7	0.22	210	136	32.5
109	8	3180	133.6	0.71	226	146	34.9
110	6	5090	49.8	0.06	542	354	97.7
111	8	2820	61.6	0.21	318	205	49.1
112	5	4290	82.4	0.16	419	358	109.0
113	7	6160	224.6	0.79	302	228	51.2
114	5	4960	-11.9	0.00	505	385	97.5
115	6	6600	-43.6	0.01	990	794	204.9
116	4	7850	-400.0	0.90	212	532	94.9
117	7	5960	103.6	0.45	271	184	51.1
118	8	7390	41.7	0.09	343	221	52.9
119	8	4820	20.8	0.06	210	135	32.4
120	2	3350	-250				
121	4	5250	-50.0	0.10	240	602	107.2
122	8	2730	43.5	0.36	153	99	23.6
123	6	4840	33.4	0.00	1378	1283	329.5
124	5	3430	55.0	0.12	268	359	84.6
125	7	4140	336.9	0.29	1376	1038	233.0
126	4	3910	-16.0	0.01	208	522	93.0
127	7	5790	78.6	0.32	269	183	50.8
128	8	2970	23.1	0.13	158	102	24.3
129	4	3660	180.0	0.55	255	529	114.2
130	7	3480	31.8	0.83	37	28	6.33
131	5	5080	150.0	0.09	849	1139	268.5
132	7	5260	187.5	0.58	378	258	71.5
133	8	4308	336.9	0.74	523	338	80.7
134	3	6450	-100.0	0.05	612	2195	433.0
135	6	3642	54.0	0.68	96	81	18.5
136	2	4000	-250				
137	2	3250	0				
STY101	4	7389	-741.4	0.83	695	1058	235.1
102	6	1680	44.3	0.48	95.9	110	22.9
103	5	3750	-26.7	0.08	213	245	51.3
104	6	2210	2.86	0.0	148	119	30.7
105	5	4390	68.7	0.50	205	156	39.5
106	2	1830	256.0				
107	6	2850	37.4	0.14	273	218	46.8

WATER SAMPLE CONDUCTIVITY VALUES

Observation No.	State No.	1970	1971	1972	1973	1974	1975	1976	1977
BRM. 101	263007202				3300 (Box 03)	4300	3850	4200	4150
102	263279602	2700		4500 (Box 01)	3900 (Box 01)	2700	2600	2950	4350
103	263355802			3000		3000	2350	2700	2600
104	263278201	3100		3000		3700	3250	2900	3700
105	263276701			5000	5200	5200	4300	4300	4800
106	263277604					4100	3750	4250	4070
107	263277102	4000		3500		4550	3750	4650	4500
108	263278407				4100	5300	5200	4200	
109	263277108	5100		5100		5800	5200	5600	
110	263005801		4500	5100	4200	4700	4250	5640	
111	263200002					4500		4600	4900
112	263207503		2400			2800	2850	3000	3120
113	263004902				2300	2600	2700		
114	263004903					2800			3050
115	263200102	3500		3900	3400	3850	3350	4050	4060
116	263004705					2650	2350	2450	2600
117	263280002				2800		4600	5000	5400
118	263280001	5200	5100	5000	4700		5000	5300	5200
119	263053502						5500	5800	5600
120	263207703			3600	3500	4100	3700	2700	3000
121	263281002					4050	2850		4200
122	263281003	3000	2900	3000	2900		2950	3000	3250
123	263053803		7600 (Box 02)	4300	4500	5650	5500	5850	8800
124	263004605						2450	N.sampled	2800
125	263004302					3550	3150	3300	3350
126	263BK4505						2350		
127	263280103						3250	3300	3450
128	263280107	2300	2300	2300	2300	2600	2350	2600	
129	263281102	3900	3900	4000	3800		4000	4650	4300
130	263281202					3350		NM	
131	263281204					4450	3450	4200	4300
132	263054504					6600	pump not working		
133	263004201					5350	4850	5400	5400
134	263004304						2950	3450	
135	263205602					3150	2700	3000	3050
136	263282801					5250	4800	5000	5000
137	263281302					3150	3450	3100	3250

WATER SAMPLE CONDUCTIVITY VALUES

Observation No.		State No.	1970	1971	1972	1973	1974	1975	1976	1977
BRM.	138	263004103					4250	3850	3800	4100
	139	263004101					3750	3350	3450	3620
	140	263004001	3200	3100		3000	3500	3000	3650	3430
	141	263282601					4450	4000	4150	4200
	142	263055702					4850	4350	4600	
	143	263003902						Pump	under	repair
	144	263003702					4150	3750	3800	
	145	263003002					4200	3750	3900	4200
	146	263003802	3900	3900	3900	3600	4250	3750	3950	4150
	147	263282001						2300	2400	2450
	148	263003701							4400	4500
FRL.	101	360012402			6000	5700	6400			
	102	260009904			1800	2100	2600	2300	2460	
	103	360009903	3300			3400		3300	3110	
	104	360013102	3200	4000	3300	3300	4200	3700	4500	4080 (Box 01)
	105	360002203	3600	3400	4100	4300	5000	3900	4800	4400
	106	360354602	2000	2000	2000	2000	2350	2000	2300	2350
	107	360355502				2000	2150	1750	2100	2110
	108	360002002	2400	1900	2000	2300	2300	2200	2200	2600
	109	360355604	3300	3200	3300	3500	4150	3600	4000	4110
	110	360358401	4900	5800	4800	4700	5800	NM		5400
	111	360358201	2900	2900	3000	2700	3500	2600	3300	5410
	112	360356701	4400		4300	4200	5200	4500		
	113	360014501	6100		6700	6600	7600	7000	7400	7800
	114	360014502	5000		4400	5600	4800	NM		4800
	115	360003601	5500		7200	7600	6900	5950	5600	
	116	360015301					6400	5600	5500	5100
	117	360801501	6000	6100	6200	6015	6700	6100	6800	
	118	360002401	7700	7200	7300	7300	8100	7200	7800	7700
	119	360003701	4900	4800	4900	4600	5250	4700	5000	5000
	120	360357301					2350	2100		
	121	360015801					5100	4800	5200	4800
	122	360358001	2800	2700	2800	2800	3100	2700	3150	3000
	123	360335401		3500	5500	5300	6300	5800	3354	
	124	360358007			3500	3400	4050	3650	3650	
	125	360335501	5000		3500	5500	6500	3600	6800	7200
	126	360358104					4000	3650	3700	3930
	127	360004801	5900	5800	5800	6000	6500	5800	6400	
	128	360360902	3000	3000	3000	2900	3350	2900	3050	3220

WATER SAMPLE CONDUCTIVITY VALUES

Observation No.		State No.	1970	1971	1972	1973	1974	1975	1976	1977
FRL.	129	360336802				4100	4650	4350	4800	
	130	360360701	3500		3500	3600	3650	3600	3700 3800 before pumping	3700
	131	360337801			4600	6700	5700	5400	6000	
		360355403		5500						
	132	360338301	5600	5600	5200	5400	6200	6000	6700	
	133	360337802	5000	4600	4700	4800	5500	5400	6900	7000
	134	360006401					6300	5450	6100	
	135	360337206		3600 (Box 03)	3900 (Box 03)	3800 (Box 03)	3800	N.M.	4000	4000
	136	360360201					3000	2750		
	137	360360202					3250		3250	
STY.	101	639354804			6300		3800	3350	3500	
	102	639354806			1800	1700	2000	1850	1950	1990
	103	639263903			3800	3400	3850	NM	3500	3600
	104	639354809	2300		2100	2100	2400	2100	2300	
	105	639263801	4400		4500	4400	4950	NM	4800	4800
	106	639363501				2600	2856	DRY		
	107	639007201	3000		2800		2850	2850	3510	3000

APPENDIX 8

HYDROCHEMISTRY OF SURFACE WATER AND GROUNDWATER
(FROM WILLIAMS, 1975)

HYDROCHEMISTRY

Water samples from various depths in each bore were submitted to AMDEL for full analysis. The results are set out in the table at the rear of this Appendix. Most samples were collected from the Quaternary, Pliocene and Miocene aquifers with two from Cambrian aquifers (DM14, DM21) one from an Eocene aquifer (DM26) and four from the Bremer River at stream gauge sites in July, 1973. Results of analyses were plotted as Stiff diagrams (Fig. 42) and on portions of a Piper trilinear diagram (Fig. 43) and a comparison made between sulphate and chloride proportions (Fig. 44).

a. Stiff Diagrams (Fig. 42)

(i) Surface Water - Bremer River

A distinct pattern emerges for this water. It must be emphasised that the surface water varies greatly in total dissolved solids with time and presumably also in the proportion of different ions present. The high sulphate: bicarbonate ratio may be a result of pollution from the up-stream Nairne pyrite mine. A detailed sampling programme would be necessary to obtain characteristic patterns for the Bremer River.

(ii) Quaternary aquifer

Results for this aquifer are varied. Noticeable in many analyses is the high magnesium:sodium ratio. No distinct pattern emerges. Total salt content is generally highest in water from this aquifer.

(iii) Pliocene aquifer

Results fall in a group, but cannot always be distinguished from those of different aquifers.

(iv) Miocene aquifer

Similar patterns are again noted. Some are almost identical with those of (iii) which suggests natural hydraulic connection between the two aquifers or poor sampling.

(v) and (vi) Eocene and Cambrian aquifers

The samples are too few to show any characteristic pattern.

b. Piper Diagrams (Fig. 43)

The cation diagram shows a random distribution for all waters except Bremer River samples. The mixed anion-cation diagram shows a similar distribution although plots are more dispersed. There is a slight tendency for the Miocene aquifer waters to have a greater bicarbonate proportion which might be expected considering aquifer chemistry.

The anion diagram is the most useful of the three. It shows a distinct grouping of the surface waters and waters from the Cambrian aquifer (although only two samples). The Miocene aquifer waters are generally lower in chloride and sulphate and higher in bicarbonate compared with the Pliocene and Quaternary aquifer waters.

Where waters from each aquifer intersected in the bore were analysed (DM25, DM27) each showed a different chemistry. In DM25, calcium, magnesium and bicarbonate ion percentages increased with depth, sodium and sulphate decreased while chloride varied only slightly. In contrast, with DM27, ion percentages showed random variation.

c. Sulphate vs chloride proportions (Fig. 44)

A plot of the above ion proportions shows that the surface and Quaternary aquifers form a distinct group having a greater abundance of these two ions. Waters from the Pliocene and Miocene aquifers plot together suggesting hydraulic connection in part. The sulphate-chloride ratios are all similar for pre-Quaternary aquifer waters. The Quaternary aquifer waters show a spread of high and low values. Surface waters have a distinctly higher ratio.

Other plots e.g. calcium vs magnesium and sodium plus potassium vs chloride show only an interspersion of ion proportions and are of no use in distinguishing different aquifer waters.

It is clear that far more analyses are required to detect any significant patterns. It is also suggested that samples obtained during drilling may be mixtures from two or more aquifers if sufficient care is not taken. In future, any hydrochemical analyses should be carried out on samples collected, using a portable pump, from bores which obtain their supply from a single aquifer.

TABLE 3 FULL ANALYSIS DETAILS - MILANG BASIN

RECHARGE INVESTIGATIONS

BORE Rept. No.	BORE Temp. No.	State Number	Depth hole (m)	Strata	Analysis No.	Date	T.D.S. mg/l.	pH	Cations (m.equiv/l) Ca++	Mg++	Na+	K+	Anions (m.equiv/l) HCO_3^-	$SO_4^=$	Cl^-	Na/Total cation % (m.equiv)
1	DM-14	639BK6004	7.6	Quaternary	3406/73	21/8/73	2042	7.1	5.7	2.4	22.1	0.6	3.6	5.7	26.1	61.7
2	14	"	44	Cambrian-Kanm.	4660/73	1/11/73	737	7.1	1.4	2.1	9.3	0.3	2.8	0.8	9.5	70.6
3	17	263276205	42.3	Pliocene	760/74	7/2/74	1751	7.7	5.2	5.8	19.8	0.4	4.5	2.5	23.8	63.4
4	18	263050401	30	Cambrian-Kanm.	921/74	18/2/74	824	7.1	2.8	3.0	8.9	0.3	3.2	0.9	10.8	59.6
5	19	263277402	20	Quaternary	1141/74	28/2/74	1459	7.5	4.3	4.3	16.3	0.4	3.6	1.8	20.7	64.4
6	19	"	60	Miocene Lst.	1142/74	28/2/74	1216	7.3	6.2	4.2	11.2	0.4	6.0	1.0	15.2	51.0
7	20	263277705	18	Quaternary	1380/74	5/3/74	2168	7.4	5.9	8.4	23.4	0.6	2.6	1.3	35.2	61.2
8	20	"	24	Quaternary	1381/74	8/3/74	3962	7.9	14.5	19.9	35.9	0.8	2.7	2.6	66.7	50.5
9	20	"	35	Miocene Lst.	1702/74	1/4/74	1254	7.7	5.0	3.1	13.5	0.3	1.1	1.7	19.2	61.6
10	21	263275903	25.3	Quaternary	1533/74	18/3/74	1910	6.9	7.2	7.5	19.1	0.3	3.3	2.5	28.0	55.9
11	22	639264301	14	Quaternary	1699/74	3/4/74	4400	8.4	6.1	12.1	57.7	0.7	3.8	6.8	65.7	75.4
12	22	"	24	Quaternary	1700/74	4/4/74	3979	8.0	9.1	15.8	44.6	0.6	2.7	6.0	61.4	63.7
13	22	"	38	Miocene Lst.	1701/74	4/4/74	1933	7.9	3.5	4.1	25.7	0.3	3.9	2.3	27.7	76.4
14	23	639BK6205	14	Quaternary	1922/74	17/4/74	1570	7.6	2.6	4.3	19.1	0.5	2.9	5.2	18.8	72.0
15	23	"	21	Quaternary	1921/74	18/4/74	2043	7.4	4.1	5.8	24.8	0.5	4.2	4.6	26.9	70.5
16	24	639BK6703	9	Quaternary	2026/74	23/4/74	2060	7.2	5.1	7.1	23.5	0.5	3.6	6.1	25.6	64.9
17	24	"	25	Pliocene	2027/74	29/4/74	1182	8.0	2.8	4.0	13.8	0.4	2.6	1.8	16.3	65.8
18	25	639007703	9	Quaternary	2675/74	3/5/74	2208	8.0	3.8	6.2	27.6	0.3	4.4	5.5	28.3	72.9
19	25	"	26	Pliocene	2676/74	6/5/74	1626	7.3	4.4	6.5	17.3	0.4	2.9	2.4	23.6	60.6
20	25	"	36	Miocene Lst.	2677/74	8/5/74	1486	7.2	5.9	5.4	14.6	0.3	3.6	2.0	21.1	55.6
21	25	"	40	Miocene Lst.	2678/74	7/5/74	1534	7.3	6.4	5.8	14.8	0.3	4.5	2.0	21.1	54.1
22	26	639BK6902	13	Quaternary	2672/74	14/5/74	3397	7.8	2.7	5.3	49.6	0.6	6.2	6.2	45.8	85.3
23	26	"	25.	Quaternary	2673/74	15/5/74	2588	8.0	8.8	10.8	25.3	0.5	3.5	4.7	37.9	55.8
24	26	"	70	Eocene	3108/74	11/6/74	2239	7.6	8.9	8.2	22.1	0.4	4.2	3.2	32.5	55.7
25	27	639BK6603	13	Quaternary	3104/74	4/6/74	2932	7.3	5.5	8.4	36.8	0.5	4.6	4.7	42.0	71.9
26	27	"	26	Pliocene	3105/74	5/6/74	1779	7.4	5.8	6.7	18.8	0.4	2.7	1.2	27.9	59.4
27	27	"	38.8	Miocene Lst.	3107/74	12/6/74	1039	7.8	2.6	2.7	12.8	0.2	4.3	1.4	12.8	69.7
28	Gauge 1 Bremer	639266101	Surface	-	116/73	5/7/73	1411	6.9	3.7	4.7	14.8	0.3	0.8	7.4	15.3	62.8
29	"	"	"		127/73	19/7/73	1212	4.9	3.2	4.4	12.1	0.3	0.7	7.2	12.3	60.4
30	Gauge2 Bremer	639BK6101	"	-	118/73	5/7/73	1437	7.4	3.7	4.8	15.1	0.4	1.2	6.8	16.3	63.2
31	Gauge4 Bremer	639355101	"	-	117/73	5/7/73	1222	7.5	3.1	3.8	13.6	0.3	1.8	4.4	14.8	65.4