THE HYDROGEOLOGY OF LAKE MARIGINIUP, PERTH, WESTERN AUSTRALIA

by J. Hall

ABSTRACT

Lake Mariginiup is one of a series of round or oval lakes and swamps on the Swan Coastal Plain near Perth. The lake is up to 2 m deep and occupies an area of 1.6 x $10^6 m^2$, with reeds and bullrushes occupying the periphery. About 70% of the lake bed is covered with diatomaceous lake deposits up to 2 m thick. The remainder is covered with carbonaceous sand. These lake deposits rest on older Quaternary sands which unconformably overlie Late Cretaceous sedimentary rocks. The lake is in hydraulic connection with a regional unconfined groundwater flow system (Gnangara Mound); and variations in water table levels, together with rainfall and evapotranspiration, affect the level of water in the lake. Groundwater inflow takes place on the eastern side of the lake, through sandy lake deposits, and outflow takes place on the western side of the lake, through lake sediments. Between May 1979 and May 1980 groundwater inflow was estimated to be 1.3 x $10^6 m^3$; and rainfall over the lake, 1.1 x $10^6 m^3$. Evapotranspiration was estimated to be 2.2 x $10^6 m^3$; and outflow to groundwater (derived by difference), 0.2 x $10^6 m^3$. Outflowing water from the lake is more saline than groundwater inflow. Evapotranspiration accounts for about 92% of total water inputs to the lake.

INTRODUCTION

LOCATION AND TENURE

Lake Mariginiup is 25 km north of Perth, and 3 km northeast of Wanneroo (Fig. 1).

The lake is surrounded by freehold and Crown Land, the boundaries of which extend into the lake, and incorporate about 35 per cent of the lake area. A mineral claim for diatomite and peat is also registered for the area of the lake.

CLIMATE AND VEGETATION

The climate is Mediterranean, with hot, dry summers and mild, wet winters. The average annual rainfall is 840 mm, most of which falls during the winter months between April and October. The average daily maximum temperature ranges between 29.5°C, in February, and 17.0°C, in July. The average annual evaporation is 1 707 mm, which exceeds twice the rainfall. The evaporation is highest in January, with an average of 266 mm, and the lowest in June, with an average of 50 mm.

The vegetation in the central area of open water consists of algae and aquatic plants. A narrow band of reeds (*Cladium junceum*) borders the open water. A broad zone of reeds (*Cladium articulatum*) extends to the shores of the lake with a narrow zone of bullrushes (*Typha* spp.) and grasses at the periphery of the present shoreline (Fig. 2a). A few stands of high trees and scrub grow on areas of older, higher shorelines.

The bordering vegetation has been cleared for up to 100 m from the highest shoreline toward the middle of the lake. Most clearing has been done around the southern and eastern shores.

PHYSIOGRAPHY

Lake Maringiniup is one of a series of round or oval lakes and swamps situated in a northwesterly trending depression, the main part of which is near, or at the contact between the Bassendean and Spearwood Dune Systems (McArthur and Bettenay, 1974).

Within this depression, Lake Mariginiup occupies a shallow, circular basin, 1.5 km long and 1.3 km wide, with an elevation between 45 m and 50 m (AHD). The lake is bounded by relatively high sand ridges to the north, west and south, and by lower dunes to the east. A low saddle to the northeast of the lake separates it from a small depression occupied by an intermittent lake, known as Little Mariginiup Lake, which discharges, via a man-made drain, into the main lake during winter.

The areal extent of Lake Mariginiup varies annually as well as seasonally. The outer margin of the lake vegetation, which marks the present mean winter shoreline, is at an elevation of about 42 km (AHD). Within the winter shoreline the lake is approximately 1.3 km long and 1.1 km wide, covering an area of 1.6 km^2. Open water is restricted to an area of 1.4 km^2, while the remainder is vegetated by reeds and bullrushes.

36540—2

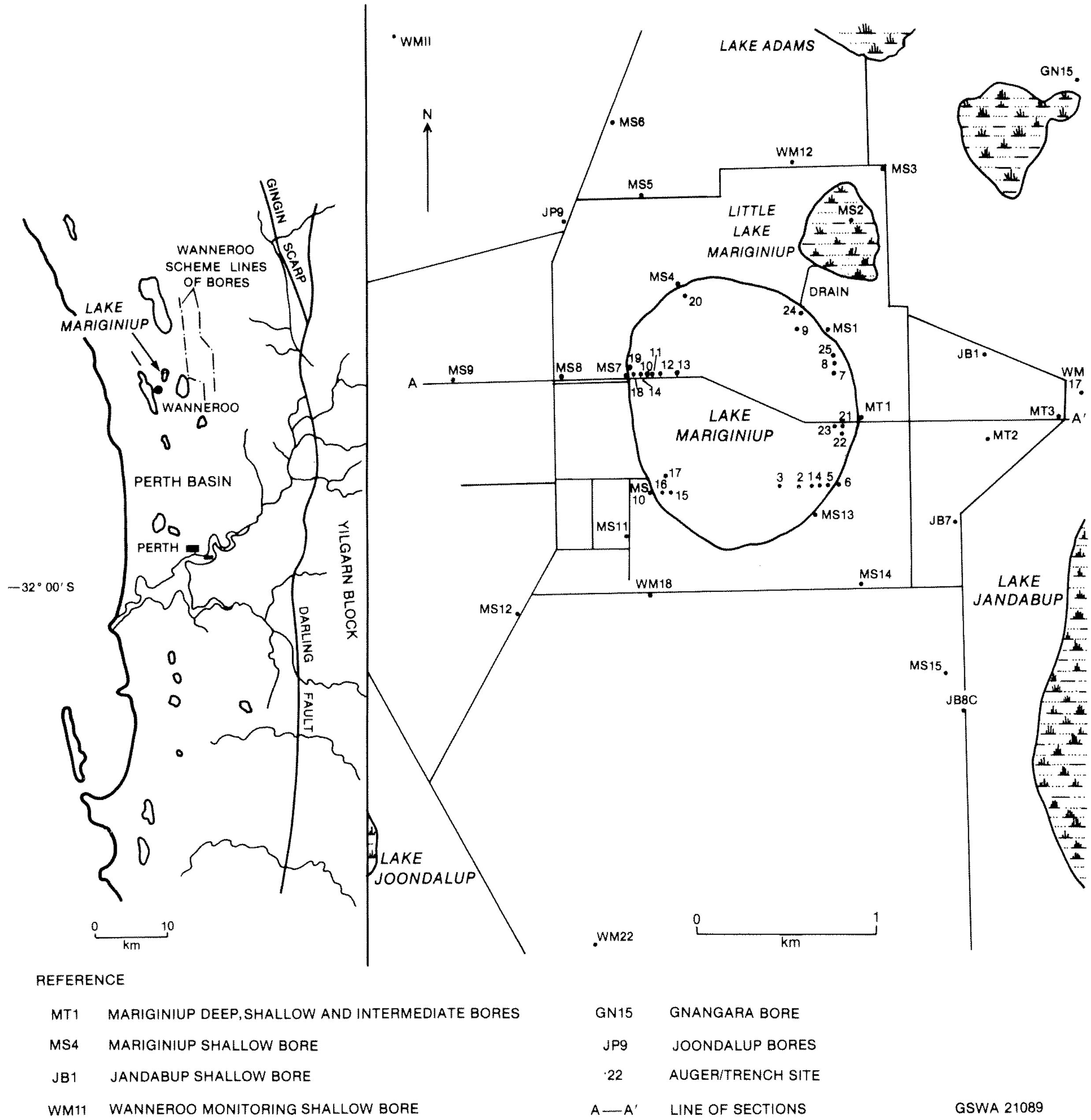

Figure 1. Lake Mariginiup Locality Plan.

The lake bed is relatively flat except on the eastern side, where diatomaceous lake sediments form a mound which is exposed during periods of low water. Accurate bathymetric contours of the lake bed are unavailable, but poorly controlled contours, indicate that the depth of water in the lake probably varies from about 0.5 m to 2.0 m.

Approximately 70% of the lake bed is covered with diatomaceous sediments, and the periphery is covered with carbonaceous sand which extends beyond the present high-water mark in the lake. The extent of carbonaceous sand and the presence of ridges and benches on the eastern side of the lake indicate at least two periods of relatively stable and higher lake water levels in the past.

During summer, when lake water levels are low, springs with well-defined outflow channels and runnels develop along the shore and in the lake bed along the eastern side. These indicate that groundwater discharges into the lake along a broad seepage face. Small runnels also develop in the exposed lake sediments on the western side of the lake, between the zone of reeds and the area of open water, and indicate that a large quantity of water, temporarily held in the reeds and sediments, drains back into the lake as lake water levels decline.

Land owners have excavated three shallow sumps on the western and southwestern shores of the lake and these have permanent water.

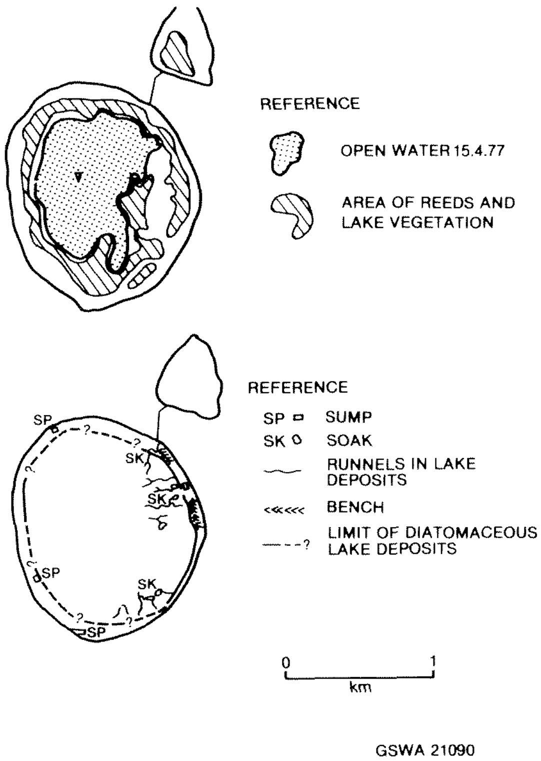

Figure 2. Physiographic features of Lake Mariginiup.

INVESTIGATION

An investigation programme to determine the hydrogeological environment of lakes likely to be affected by MWA (Metropolitan Water Authority) groundwater pumping schemes was proposed by Allen (1976). The present investigation of Lake Mariginiup is a modification of the original proposals.

OBSERVATION BORES

Twenty-four observation bores were drilled at 18 sites around Lake Mariginiup between November 1978 and February 1979. A proposed deep bore in the centre of the lake was not drilled owing to high costs and anticipated on-site difficulties. The bores were drilled by private contractors using cable-tool rigs, and ranged in depth from 9.0 m to 61.5 m, with an aggregate depth of 577.5 m. Details of these bores together with 12 MWA monitoring bores in the area are summarized in Table 1.

Deep, intermediate and shallow bores were drilled at three sites designated by the prefix "MT" (e.g. MT1D is the deep bore at site 1, MT1I is the intermediate bore at site 1). Shallow bores were drilled at the remaining sites, designated by the prefix "MS" (Fig. 1).

At the "MT" sites, the deep bore was drilled first. Lithological samples were taken at 2 m intervals and, after penetration of the underlying Cretaceous sediments, bottom-hole samples were collected for palaeontological examination. Each deep bore was geophysically logged (natural gamma ray) to aid in the definition of stratigraphic boundaries and the correlation of lithological samples.

One observation interval was selected near the bottom of each deep bore, at the base of the "superficial formations". Class 9, 80 mm PVC casing, with bottom cap, 3 m sump and 2 m slotted interval was run into each deep bore. The annulus was filled with very coarse sand to 0.5 m above the slotted interval, and then cement grouted back to the surface.

For each intermediate bore an interval near the middle of the "superficial formations" was selected and the slotted casing installed in the same manner as it was in the deep bores. The shallow bores were drilled to about 7 m below the water table. Class 9, 80 mm PVC casing with the bottom 7 m slotted and no sump was installed, and sand packed to the surface.

All bores were fitted at the surface with 152 mm protective steel casing set into a concrete base. This casing was fitted with either hinged caps or magnetic caps flush with ground level. Each bore was developed by bailing.

LAKE-DEPOSIT CORING

As part of the initial proposal (Allen, 1976, a series of cored holes was to be drilled in the lake bed. However, attempts at lake-bed coring at Lake Jandabup, in 1977, proved to be costly and mostly unsuccessful (Allen, 1979) and it was not attempted in Lake Mariginiup.

AUGERING AND TRENCHING

In March 1978, and October 1981, a number of auger holes were drilled and trenches excavated around the shores of the lake to determine groundwater movement and to examine lake sediments. (Fig. 1)

WATER SAMPLING

All bores were developed and on completion of development, in May 1979, the bores were pumped, using a portable submersible pump, and air-free samples were collected for standard chemical analysis. Water from the lake was sampled and analyzed at the same time (Table 2a). The bores were again sampled and analyzed in April 1980. (Table 2b).

All chemical analyses were made by the Government Chemical Laboratories.

WATER-LEVEL OBSERVATIONS

The natural surface and top of casing, for all bores, were levelled to the Australian Height Datum (AHD).

Synoptic groundwater levels have been monitored monthly in all observation bores since May 1979, and the results recorded in the MWA computerized groundwater record systems (GROWLS).

TABLE 1(a). SUMMARY OF CABLE TOOL DRILLING RESULTS—LAKE MARIGINIUP PROJECT BORES

Bore name	*Commenced*	*Completed*	*Natural surface (m AHD)*	*Steel casing (m AHD)*	*Total depth (m)*	*Slotted interval (m bns)*	*Water Level (m AHD) April 1980*	*Chloride (mg/L) April 1980*	*Status*	*Base superficial formations (m bns)*	*Comments*
MT1 D	27/11/78	4/12/78	45.359	45.359	52.0	45.0—47.0	42.90	101	Deep	48	?Poison Hill Greensand at base
MT1 I	4/12/78	6/12/78	45.285	45.285	27.0	22.0—24.0	42.87	123	Intermediate		—
MT1 S	6/12/78	7/12/78	45.254	45.254	9.0	2.0— 9.0	42.56	33	Shallow		—
MT2 D	3/1/79	12/1/79	49.520	50.102	61.5	54.0—56.0	43.57	106	Deep	59	?Poison Hill Greensand at base
MT2 I	12/1/79	16 1/79	49.490	50.068	29.0	24.0—26.0	43.52	90	Intermediate		—
MT2 S	16/1/79	18/1/79	49.430	50.038	18.0	11.0—19.0	43.46	88	Shallow		—
MT3 D	24/1/79	5/2/79	50.962	51.524	61.0	54.0—56.0	43.94	83	Deep	57.5	?Poison Hill Greensand at base
MT3 I	6/2/79	8/2/79	50.942	51.499	36.0	30.0—33.0	43.90	101	Intermediate		—
MT3 S	8/2/79	9/2/79	50.882	51.487	13.0	6.0—13.0	44.56	123	Shallow		—
MS1	7/12/78	18/12/78	44.366	44.366	9.0	2.0— 9.0	42.56	27	Shallow		—
MS2	8/12/78	9/12/78	44.083	44.083	9.0	2.0— 9.0	43.20	61	,,		—
MS3	9/12/78	11/12/78	53.731	53.731	19.0	8.5—19.0	43.61	111	,,		—
MS4	13/12/78	14/12/78	44.126	44.726	9.0	2.0— 9.0	41.46	300	,,		—
MS5	21/12/78	22/12/78	52.522	52.522	18.0	11.0—18.0	41.95	57	,,		—
MS6	31/1/79	1/2/79	54.361	54.370	22.5	15.5—22.5	40.25	114	,,		—
MS7	18/12/78	19/12/78	43.300	43.835	9.0	2.0— 9.0	41.00	525	,,		—
MS8	14/12/78	16/12/78	58.992	59.273	28.5	21.0—28.5	38.34	200	,,		—
MS9	16/12/78	18/12/78	59.369	60.098	28.5	21.5—28.5	38.16	52	,,		—
MS10	18/1/79	19/1/79	42.842	43.495	9.0	2.0— 9.0	41.09	374	,,		—
MS11	19/1/79	20/1/79	49.476	50.095	19.5	11.0—19.5	38.36	340	,,		—
MS12	23/1/79	29/1/79	66.616	67.218	38.5	31.0—38.0	37.86	na	,,		—
MS13	11/12/78	12/12/79	43.389	43.949	9.0	1.0— 9.0	42.31	47	,,		—
MS14	12/12/78	13/12/79	50.801	50.834	16.0	8.0—16.0	42.73	63	,,		—
MS15	22/1/79	24/1/79	62.995	63.230	26.5	19.2—26.5	43.19	35	,,		—

TABLE 1(b). SUMMARY OF DRILLING RESULTS—OTHER BORES USED IN STUDY

Bore name	*Commenced*	*Completed*	*Natural surface (m AHD)*	*Steel casing (m AHD)*	*Total depth (m)*	*Slotted interval (m bns)*	*Water Level (m AHD) April 1980*	*Chloride (mg/L) April 1980*	*Status*	*Base superficial formations (m bns)*	*Comments*
JB1	11/5/77	12/5/77	52.31	52.89	15.5	9.0—15.5	43.82		Shallow		—
JB7	9/7/77	11/7/77	57.06	57.63	22.0	10.0—22.0	43.50		,,		—
JB8C-WM21			55.79	55.80	na	na	43.22		,,		—
JB11C	14/4/77	15/4/77	63.18	63.22	20.0	18.0—20.0	na		,,		—
WM17			49.88	49.90	15.8	0—15.8	na		,,		—
GN15			49.79	53.03			46.61		,,		—
WM11			65.63	65.64	40.2	0—40.2	37.52		,,		—
WM12			56.43	56.50	25.6	0—25.6	43.02		,,		—
WM18			54.55	54.56	27.4	0—27.4	38.44		,,		—
WM22			65.48	65.52	41.4	0—41.4	37.42		,,		—
JP9			45.22	45.78			—		Fully penetrating	57.5	Poison Hill Greensand at base—used only for lithological information

bns = below natural surface; AHD = Australian Height Datum

TABLE 2(a). STANDARD ANALYSES OF GROUNDWATER AFTER BORE DEVELOPMENT (MAY 1979)

Bore	GCL Lab No.	pH	Turbidity (APHA units)	Colour (APHA units)	Odour	E.C. (mS/m @ 25° C)	Sat. Index (Langlier @ 20°)	TDS (E.C.) (a)	TDS (Calc) (a)	Free CO_2 (a)	Total Hardness (a) (b)	Total Alk (a) (b)	Ca (a)	Mg (a)	Na (a)	K (a)	CO_3 (a)	HCO_3 (a)	Cl (a)	SO_4 (a)	NO_3 (a)	SiO_2 (a)	B (a)	F (a)	Fe (a)	Mn (a)	As (a)	Cu (a)	Pb (a)	NH_4 (a) (c)	NO_3 (a) (c)	P (a)	Remarks (Pumped samples after . . .)
MT1 D	82419	5.6	2100	210	nil	43	-3.5	280	230	186	55	37	9	8	62	5	nil	45	103	9	<1	12	0.1	<0.1	2.2	0.4	<0.01	<0.02	<0.01	0.19	<0.02	0.15	2 hours @ 21.6 m^3/d
MT1 I	82420	5.5	1400	280	H_2S	47	-3.8	300	250	171	57	27	8	9	68	4	nil	33	121	4	<1	11	0.11	<0.1	0.45	0.02	<0.01	<0.02	<0.08	0.37	<0.02	0.04	1½ hours 21.6 M^3/d
MT1 S	82421	5.4	2.1	660	nil	17	-5.3	110	90	64	27	8	1	6	21	3	nil	10	32	16	<1	7	0.08	<0.1	0.28	<0.02	<0.01	0.06	0.02	0.20	0.06	0.51	as above
MT2 D	86632	5.8	190	220	H_2S	45	-3.0	290	240	155	59	49	12	7	60	4	nil	60	108	2	<1	14	0.1	<0.1	1.8	0.03	<0.01	<0.02	<0.01	0.42	<0.02	0.07	as above
MT2 I	82631	5.7	150	1120	nil	31	-4.3	200	170	80	21	20	2	4	52	1	nil	24	83	3	<1	9	0.13	<0.1	0.42	<0.02	<0.01	<0.02	<0.01	0.24	<0.02	0.05	as above
MT2 S	82630	5.5	300	740	nil	33	-4.2	210	180	164	40	26	3	8	47	1	nil	32	86	5	<1	9	0.09	<0.1	0.66	<0.02	<0.01	<0.02	0.01	0.24	<0.02	0.06	as above
MT3 D	82722	7.2	50	110	nil	67	-0.3	430	360	24	208	194	70	8	51	3	nil	236	90	1	<1	15	0.07	0.1	0.47	0.02	0.01	<0.02	<0.01	0.37	<0.02	0.07	2 hours @ 21.6 m^3/d
MT3 I	82721	5.6	1800	130	H_2S	42	-3.4	270	220	176	56	35	11	7	57	4	nil	43	98	5	<1	12	0.09	<0.1	0.75	0.02	<0.01	<0.02	<0.01	0.40	<0.02	0.06	as above
MT3 S	82720	5.3	70	210	H_2S	46	-4.3	290	240	200	53	20	5	10	66	3	nil	24	120	7	<1	11	0.14	<0.1	0.57	<0.02	<0.01	0.02	<0.01	0.48	<0.02	0.02	as above
MS1	82516	4.9	4.9	500	nil	15	-5.6	100	80	176	21	7	2	4	19	1	nil	9	31	11	5	6	0.1	0.1	0.4	<0.02	<0.01	0.17	0.03	0.12	1.2	0.47	as above
MS2	82517	5.4	9.9	174	nil	32	-4.5	200	170	96	39	12	4	7	45	2	nil	15	79	13	<1	10	0.09	0.1	0.31	<0.02	<0.01	<0.02	0.01	0.13	<0.02	0.02	as above
MS3	82518	5.6	12	174	nil	33	-4.3	210	170	80	32	16	3	6	45	2	nil	19	79	10	2	9	0.09	<0.01	0.59	<0.02	<0.01	0.02	0.01	0.12	0.70	0.01	as above
MS4	82345	6.1	3.1	200	H_2S	123	-2.5	790	650	102	123	64	15	21	193	7	nil	78	313	35	<1	15	0.09	0.1	0.58	0.04	<0.01	0.05	<0.01	0.75	<0.02	0.04	as above
MS5	82515	5.6	17	163	nil	24	-4.2	150	130	75	47	15	4	9	26	1	nil	18	52	12	7	11	0.07	0.01	0.82	<0.02	<0.01	0.02	0.01	0.06	1.9	0.01	3 hours @ 14.4 m^3/d
MS6	82514	5.8	95	310	nil	45	-3.5	290	240	95	48	30	6	8	69	2	nil	37	113	5	<1	10	0.07	0.01	0.52	0.02	<0.01	<0.02	0.01	0.22	<0.02	0.04	3 hours @ 14.4 m^3/d
MS7	82346	5.9	0.5	150	nil	168	-2.4	1080	900	214	175	85	24	28	272	7	nil	103	469	20	<1	13	0.08	0.1	0.50	0.04	<0.01	0.02	<0.01	0.69	<0.02	0.05	2 hours @ 21.6 m^3/d
MS8	82840	6.0	4.1	74	nil	97	-2.6	620	520	104	149	52	20	24	122	9	nil	63	205	67	22	15	0.08	0.1	0.75	0.02	<0.01	0.02	<0.01	1.11	4.3	0.01	6 hours @ 4.8 m^3/d
MS9	82841	6.1	370	21	nil	36	-2.7	230	220	68	58	43	15	5	47	1	nil	52	51	26	27	15	0.05	<0.1	<0.05	<0.02	<0.01	0.02	<0.01	0.20	6.0	0.04	6 hours @ 4.8 m^3/d
MS10	82417	5.8	0.8	170	H_2S	133	-2.7	850	690	240	141	76	17	24	207	9	nil	92	352	11	<1	9	0.11	<0.1	0.66	0.03	<0.01	<0.02	<0.01	0.70	<0.02	0.02	2 hours @ 21.6 m^3/d
MS11	82513	5.8	18	158	nil	133	-2.9	850	680	209	131	66	13	24	202	9	nil	80	361	4	<1	13	0.13	0.0	0.49	0.02	0.01	<0.02	0.01	1.60	<0.02	0.02	3 hours @ 14.4 m^3
MS12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	not sampled
MS13	82723	5.7	99	140	nil	30	-3.6	190	170	108	38	27	7	5	42	2	nil	33	50	32	<1	12	0.08	0.1	0.47	0.02	<0.01	<0.02	<0.01	0.13	<0.02	0.05	2 hours @ 21.6 m^3/d
MS14	82418	5.9	15	42	nil	45	-2.8	290	250	174	113	55	19	16	45	2	nil	67	73	39	8	8	0.06	0.1	0.09	0.02	<0.01	0.20	0.01	0.09	1.8	0.01	2 hours @ 21.6 m^3/d
MS15	82842	5.3	2.9	89	nil	15	-4.8	100	90	70	12	7	1	3	22	1	nil	8	27	10	12	10	0.08	0.1	0.28	<0.02	<0.01	0.05	<0.01	0.02	2.6	0.01	6 hours @ 4.8 m^3/d
LAKE MARIGINIUP	81244	6.8	5	170	nil	223	-1.3	1430	1160	35	245	110	32	40	329	17	nil	134	589	52	<1	13	0.03	0.01	0.11	0.02	0.01	0.02	0.01	0.14	0.02	0.07	Sample taken on southern shore of lake

(a) = mg/L (b) = as $CaCO_3$ (c) = Nitrogen as

TABLE 2(b). STANDARD ANALYSES OF GROUNDWATER (APRIL 1980)

Bore	GCL Lab No.	pH	Turbidity (APHA units)	Colour (APHA units)	Odour	E.C. (mS/m @ 25° C)	Sat. Index (Langlier @ 20°)	TDS (E.C.) (a)	TDS (Calc) (a)	Free CO_2 (a)	Total Hardness (a) (b)	Total Alk (a) (b)	Ca (a)	Mg (a)	Na (a)	K (a)	CO_3 (a)	HCO_3 (a)	Cl (a)	SO_4 (a)	NO_3 (a)	SiO_2 (a)	B (a)	F (a)	Fe (a)	Mn (a)	As (a)	Cu (a)	Pb (a)	NH_4 (a) (c)	NO_3 (a) (c)	P (a)	Remarks (Pumped samples after . . .)
MT1 S	81568	4.8	1.9	560	nil	18	-6.0	100	100	—	27	6	1	6	22	3	nil	7	33	21	< 1	7	0.05	< 0.1	0.24	< 0.02	<0.01	<0.02	0.01	0.16	0.02	0.20	
MT1 I	81569	5.0	180	76	nil	47	-4.3	260	240	—	58	21	10	8	65	2	nil	25	123	9	< 1	11	0.10	< 0.1	0.34	< 0.02	<0.01	<0.02	0.01	0.43	<0.02	0.10	
MT1 D	81570	5.1	380	65	nil	41	-4.1	230	210	—	51	27	9	7	59	2	nil	33	101	8	< 1	12	0.07	< 0.1	0.66	< 0.02	<0.01	<0.02	<0.01	0.33	0.02	0.06	
MT2 D	81653	5.4	64	96	nil	44	-3.6	240	230	271	57	34	13	6	60	3	nil	41	106	8	< 1	14	—	< 0.1	1.6	0.03	<0.01	<0.02	<0.01	0.32	<0.02	0.09	
MT2 I	81654	5.1	40	810	nil	34	-5.4	190	180	95	21	6	2	4	57	< 1	nil	7	90	11	< 1	8	—	< 0.1	0.29	< 0.02	<0.01	<0.02	<0.01	0.22	0.02	0.02	
MT2 S	81655	4.9	38	620	nil	33	-5.6	180	170	101	32	4	3	6	49	1	nil	5	88	10	< 1	9	—	< 0.1	0.35	< 0.02	<0.01	<0.02	<0.01	0.21	0.02	0.01	
MT3 S	81647	5.4	4.8	500	H_2S	46	-4.6	250	250	72	51	9	4	10	71	3	nil	11	123	19	< 1	10	—	< 0.1	0.56	< 0.02	<0.01	<0.02	<0.01	0.37	0.02	0.02	
MT3 I	81648	5.5	59	170	nil	40	-3.7	220	210	133	56	21	11	7	56	2	nil	25	101	9	< 1	12	—	< 0.1	0.40	< 0.02	<0.01	<0.02	<0.01	0.31	<0.02	0.02	
MT3 D	81649	6.7	1.6	35	nil	64	-0.7	350	350	79	214	199	71	9	46	3	nil	243	83	2	< 1	16	—	< 0.1	0.62	0.02	<0.01	<0.02	<0.01	0.30	<0.02	0.05	
MS1	81650	4.9	0.90	440	nil	14	-5.9	80	80	—	19	2	3	3	20	< 1	nil	2	27	14	4	6	—	< 0.1	0.28	< 0.02	<0.01	0.02	<0.01	0.07	1.1	0.42	
MS2	81651	5.0	1.4	150	nil	26	-5.3	140	140	—	28	6	3	5	38	1	nil	7	61	16	< 1	10	—	< 0.1	0.15	< 0.02	<0.01	<0.02	<0.01	0.08	<0.02	0.01	
MS3	81652	5.1	1.5	130	nil	43	-4.6	240	220	—	56	13	6	10	57	2	nil	16	111	14	4	9	—	< 0.1	0.52	< 0.02	<0.01	0.02	0.01	0.13	1.0	0.02	
MS4	81566	5.5	0.94	220	H_2S	118	-3.1	650	630	—	123	72	15	21	188	9	nil	88	300	34	< 1	14	0.05	< 0.1	0.38	< 0.02	<0.01	0.02	0.01	0.47	0.04	0.06	
MS5	81656	4.9	27	150	nil	26	-5.3	140	140	151	47	6	4	9	30	1	nil	7	57	13	11	11	—	< 0.1	0.64	< 0.02	<0.01	0.02	0.01	0.06	2.5	<0.01	
MS6	81443	5.0	5.6	300	nil	47	-4.4	300	240	—	50	25	8	68	67	2	nil	30	114	14	< 1	10	0.08	< 0.1	0.20	< 0.02	<0.01	<0.02	<0.01	0.23	< 0.02	0.01	
MS7	81510	5.5	0.65	290	H_2S	212	-2.7	1170	1030	—	185	102	25	30	327	9	nil	124	525	40	1	13	0.16	< 0.1	0.46	0.03	<0.01	<0.02	0.01	0.62	< 0.02	0.05	2 hours @ 14.4 m^3/d
MS8	81681	5.6	28	100	nil	88	-3.1	480	480	246	118	49	16	19	121	6	nil	60	200	47	22	15	0.05	< 0.1	0.36	0.02	<0.01	0.04	0.01	0.89	4.9	<0.01	
MS9	81682	5.7	350	54	nil	39	-3.0	210	220	192	61	48	16	5	50	< 1	nil	58	52	26	31	15	0.05	< 0.1	0.46	< 0.02	<0.01	0.07	0.01	0.04	7.0	0.01	
MS10	81511	5.6	1.0	140	H_2S	144	-2.9	790	720	—	132	82	15	23	224	9	nil	100	374	12	< 1	8	0.11	< 0.1	0.24	0.03	<0.01	0.06	0.01	0.42	< 0.02	<0.01	2 hours @ 14.4 m^3/d
MS11	81444	5.4	1.0	210	nil	132	-3.3	240	630	—	108	61	12	19	201	7	nil	74	340	7	< 1	11	0.12	< 0.1	0.38	0.02	<0.01	<0.02	<0.01	1.2	< 0.02	0.01	
MS12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	not sampled
MS13	81567	5.3	6.5	93	nil	29	-4.4	160	170	—	37	17	5	6	41	2	nil	21	47	39	5	13	0.05	< 0.1	0.29	< 0.02	<0.01	<0.02	0.01	0.11	1.2	0.04	
MS14	81445	5.6	2.5	19	nil	42	-3.1	270	230	—	105	45	19	14	38	3	nil	55	63	47	6	9	0.05	< 0.1	0.05	< 0.02	<0.01	<0.02	<0.01	0.04	1.6	<0.01	
MS15	81683	5.1	33	46	nil	20	-5.0	110	110	—	23	11	3	4	27	< 1	nil	13	35	15	13	10	0.06	0.1	0.28	< 0.02	<0.01	0.12	0.01	0.05	3.3	0.01	2 hours @ 9.6 m^3/d

GEOLOGY

SETTING

Lake Mariginiup is situated within the Perth Basin. It occupies a shallow, circular depression in the Quaternary "superficial formations", which unconformably overlie Late Cretaceous sedimentary rocks. The lake contains a thin sequence of lake deposits.

STRATIGRAPHY

The near surface stratigraphic sequence at Lake Mariginiup is summarized in Table 3.

TABLE 3. STRATIGRAPHIC SEQUENCE, LAKE MARIGINIUP

Age	Formation		Maximum thickness (m)	Lithology	Comments
Quaternary	"Superficial formations"	Lake Deposits	2	Diatomite, peat carbonaceous sand	
		? DISCONFORMITY			
			70	Sand; fine to coarse, minor ferruginous sand, clay and gravel	
UNCONFORMITY					
Late Cretaceous	?Poison Hill Greensand		4+	Glauconitic sandstone	Formation not definitely identified

CRETACEOUS

?Poison Hill Greensand

Glauconitic, silty sands were intersected at the base of bores MTD, MT2D and MT3D on the eastern side of the lake, and in bore JP9 on the northwestern side of the lake. Palaeontological evidence (Backhouse, 1979; Cockbain, 1979; Hooper, 1972) suggests that these sands belong to the Poison Hill Greensand (Fairbridge, 1953).

The formation is unconformably overlain by the "superficial formations". The total thickness of the formation is not known, but exceeds 4 m in bore MT1D.

QUATERNARY

"Superficial formations"

The "superficial formations" consist of sands and lake deposits.

Sands: The sands of the "superficial formations" consist of an unconsolidated sequence of shallow-marine and eolian deposits. The upper part predominantly consists of poorly to moderately sorted, fine to coarse sand containing minor clay and scattered heavy minerals and feldspar. The lower part consists of very poorly sorted, very fine to coarse sand, and gravel, ranging in thickness from about 4 m to 10 m and containing clay, heavy minerals, and scattered feldspar and phosphatic pebbles.

An irregular and discontinuous bed of variably cemented ferruginous sand, ("coffee rock") occurs at and below the water table on the eastern side of the lake.

The unconformity with the Poison Hill Greensand occurs at an elevation of between about -3 m (AHD) and -10 m (AHD), and the thickness of the "superficial formations" ranges from 45 m to 70 m depending on the topography.

Lake Deposits: At the periphery of the lake, the deposits consist of fine- to medium-grained carbonaceous sand and peat, up to 1 m thick, which grades into carbonaceous diatomite toward the central part of the lake. The maximum thickness of diatomite intersected while augering was 1.6 m, but it is probably about 2 m in the middle of the lake. The lake deposits disconformably overlie the sands of the "superficial formations".

A low mound of diatomite on the eastern side of the lake was probably formed by the prevailing westerly wind during periods when the level of the lake was very low.

STRUCTURE

A geological cross section through Lake Mariginiup is shown in Figure 3.

The Poison Hill Greensand is believed to be flat lying, but the unconformity with the overlying "superficial formations" is undulating.

The "superficial formations" are essentially flat lying, but the upper surface of the basal sands and gravels appears to parallel the unconformity surface.

The lake deposits form a thin veneer on the lake bed but are thicker in the middle and on the eastern side of the lake where the mound of diatomite occurs.

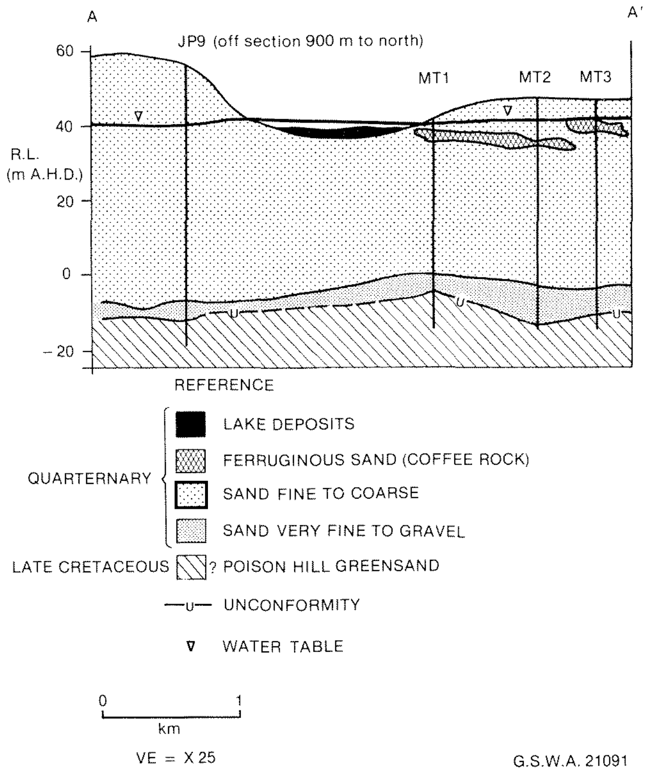

Figure 3. Geological Cross Section A-A' of Lake Mariginiup.

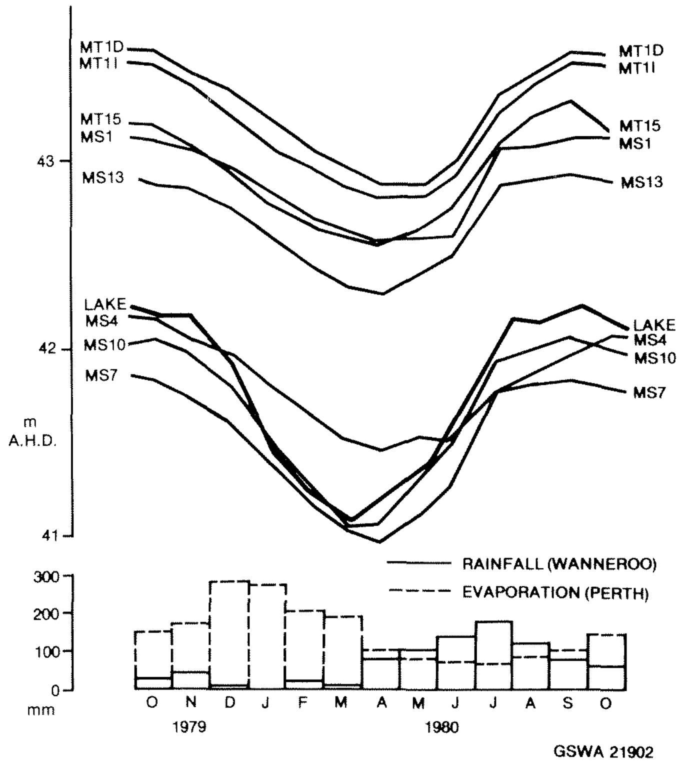

Figure 4. Hydrographs of selected bores and Lake Mariginiup.

HYDROGEOLOGY

LAKE—GROUNDWATER INTERACTION

Lake Mariginiup is in hydraulic connection with the unconfined groundwater which forms part of the Gnangara Mound regional flow system.

At present, the elevation of the water table on the eastern side of the lake is higher than that of the lake bed, so that groundwater inflow, together with rainfall, maintains the lake.

The elevation of the water table on the western side of the lake is lower than the water-level of the lake, so that some water not lost by evapotranspiration leaves the lake by outflow as groundwater.

Water also enters the lake via a narrow drain on the northeastern side of the lake from Little Mariginiup Lake.

VARIATIONS IN WATER TABLE AND LAKE WATER LEVELS

The water table and water-level of the lake vary in phase (Fig. 4), but the water-level of the lake responds to a greater extent to periods of high rainfall or evapotranspiration than does the water table.

The water table and water-level of the lake are highest at the end of winter (usually in October), and lowest at the end of summer (usually in April).

CONFIGURATION OF THE WATER TABLE

Water-table contours for the end of winter 1979 and the end of summer 1980 (Figs 5 and 6) show that the water table has a generally uniform gradient on the eastern side of the lake, except where flow converges toward the lake. On the western side of the lake, the water table has a generally flatter gradient than on the eastern side, except for a narrow zone adjacent to the lake which has a very steep gradient, and flow diverges outward, away from the lake.

The configuration of the water-table contours has the same general shape for summer and winter, but the greater seasonal response of water-levels of the lake than of the water table (refer to the previous section) affects the areas through which groundwater onflow to the lake and outflow to groundwater from the lake takes place, and thus the configuration of the water-table contours up and downstream from the lake. For example, in summer, when the water-level of the lake declines at a faster rate than the water table, groundwater inflow is diverted from a wider area than in winter, when the water-level of the lake rises at a faster rate than the water table.

The steep hydraulic gradient at the western margin of the lake (Figs 5 and 6) suggests that the aquifer is not homogeneous. A possible explanation is that the hydraulic conductivity of the "superficial formations" beneath the western side of the lake is less than that for the rest of the aquifer.

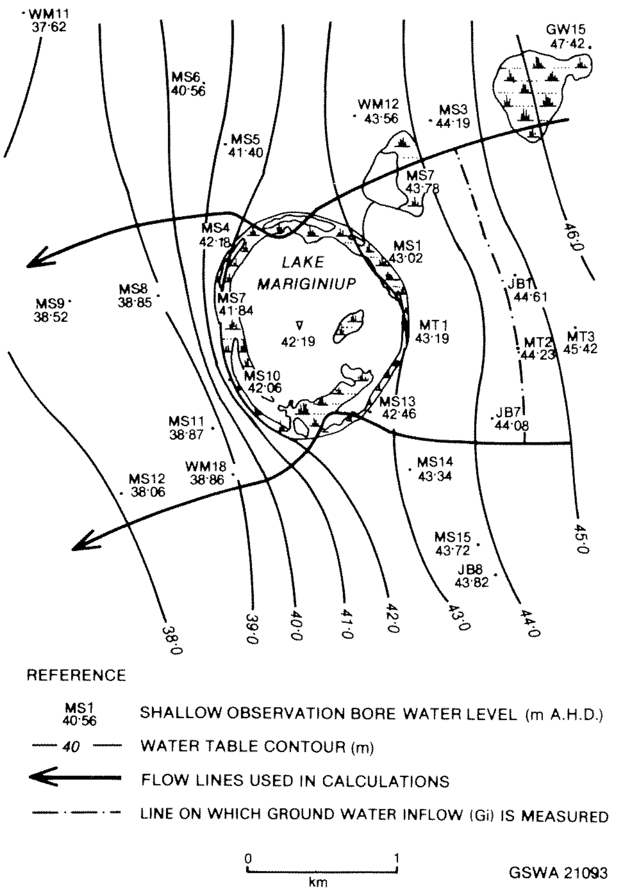

Figure 5. Water Table Contours of Lake Mariginiup for October 1979.

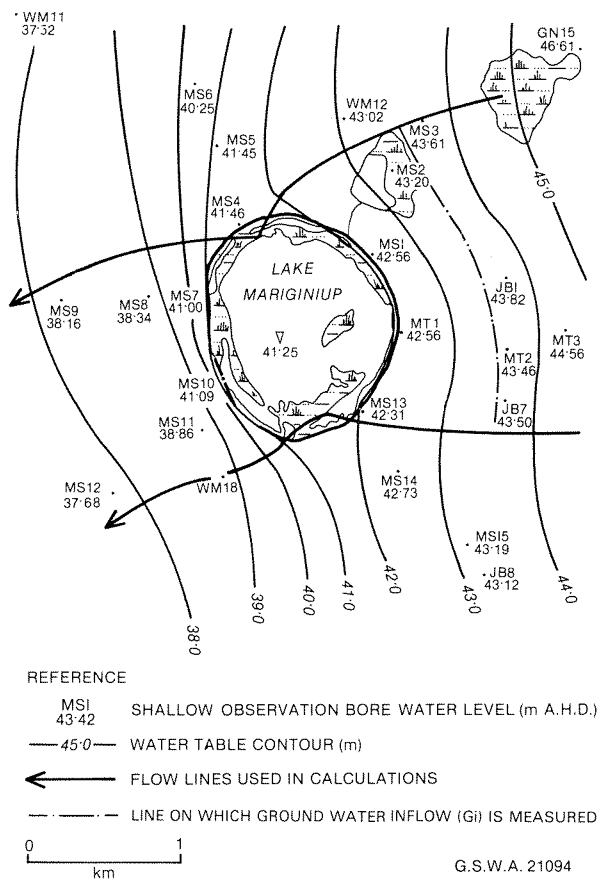

Figure 6. Water Table Contours of Lake Mariginiup for April 1980.

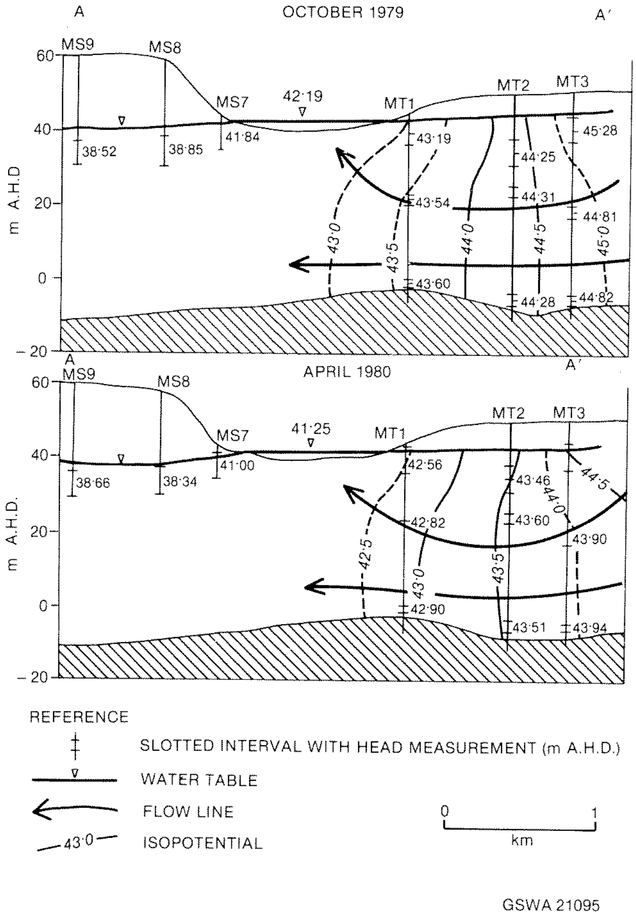

Figure 7. Hydrogeological Section A-A' of Lake Mariginiup.

GROUND FLOW SYSTEM OF THE LAKE

Sections, approximately parallel to groundwater flow and including shallow, intermediate and deep head measurements from three sites on the eastern side of the lake, are shown in Figure 7.

The sections show that groundwater enters the eastern side of the lake by upward flow from the upper half of the aquifer. This was confirmed in auger holes and trenches on the eastern side of the lake, which detected increasing heads with depth and, in some cases, small artesian flows. The groundwater inflow occurs along a broad seepage face marked by channels and runnels on the eastern shore.

Outflow occurs on the western side of the lake. It is inferred to be by downward flow, as indicated by decreasing heads with depth observed in auger holes and trenches. The thickness of the flow section is presumably less in summer than in winter, when outflow to groundwater is less, owing to higher evapotranspirative losses and less rainfall input.

CONFIGURATION OF SALINITY CONTOURS

Figure 8 shows the contours of salinity measured at the water table in March 1979 (Table 2). The configuration of the salinity contours demonstrates the

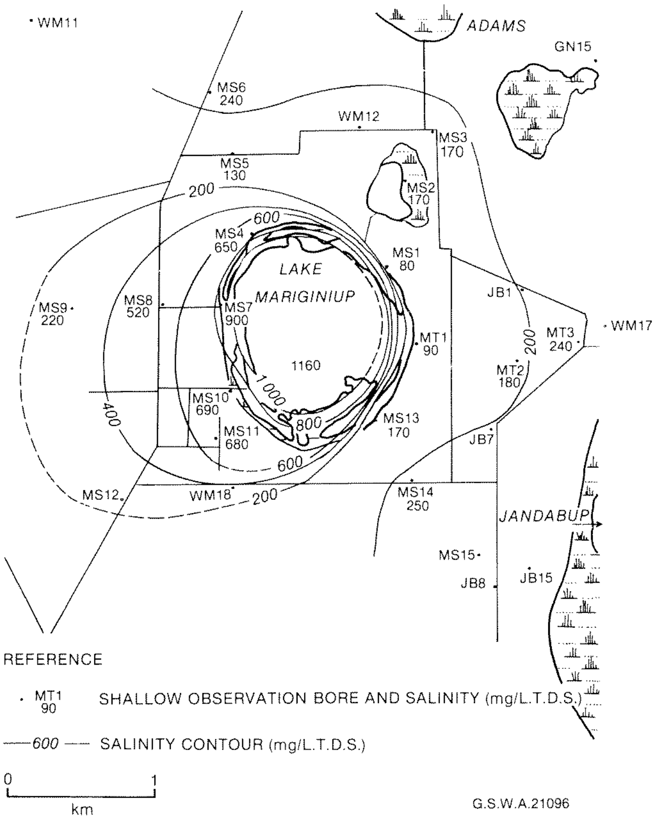

Figure 8. TDS Salinity Contours of Lake Mariginiup, May 1979.

effects on the adjacent groundwater of evapotranspiration from the lake. Groundwater flowing into the lake, at the water table, is very fresh (less than 200 mg/L TDS), but the water in the lake and water outflowing from the lake is more saline (up to about 1 200 mg/L TDS) owing to the concentrating effect of high evapotranspirative losses from the lake. Outflow from the lake has a downward component so that the salinities at the water table will be somewhat lower (up to 700 mg/L TDS) than those at depth.

TRENDS IN LAKE WATER-LEVELS 1971-1980

Rainfall, maximum and minimum lake levels, and annual groundwater abstraction rates from the Wanneroo Scheme bores for the period 1971-1980 are shown in Figure 9. (Note that the time scale for the minimum lake levels is a year out of phase with the time scale for the maximum lake levels). In attempting to correlate rainfall with the lake levels it is necessary to consider the minimum lake levels following the rainfall period. These occur in the following year, usually March or April.

The maximum and minimum lake water-levels reflect the rainfall, but the variations in the maximum lake water levels are more subdued owing to the shape and depth of the lake.

Groundwater abstraction from the Wanneroo Scheme bores commenced in 1976, reaching full production in 1980 (approx. 12.2 x $10^6 m^3/a$).

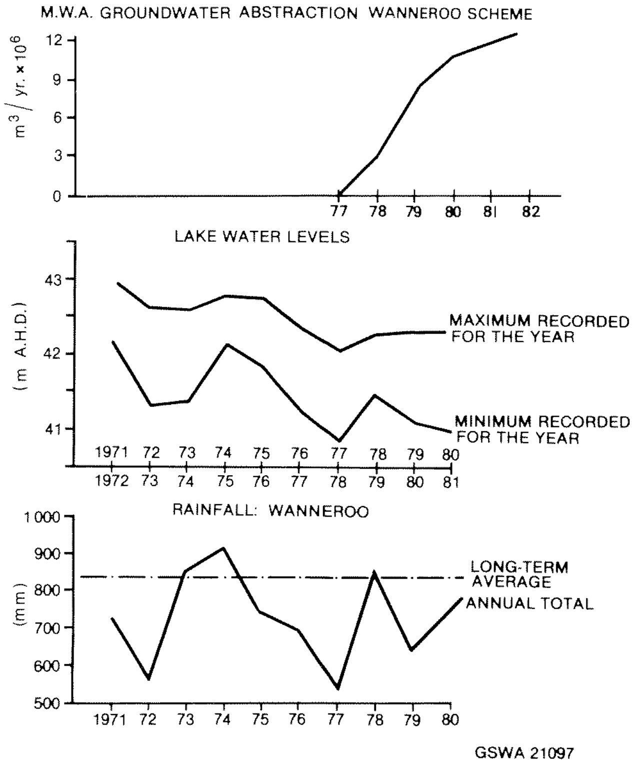

Figure 9. Rainfall, lake water levels and MWA groundwater abstraction, Lake Mariginiup, 1971-1980.

Apart from a possible dampening of maximum and minimum lake level fluctuations, this abstraction has had no apparent effect on the lake water-levels.

For comparison, lake water-levels for Lakes Jandabup and Joondalup (Fig. 1) are shown in Figure 10. These show similar responses to those at Lake Mariginiup.

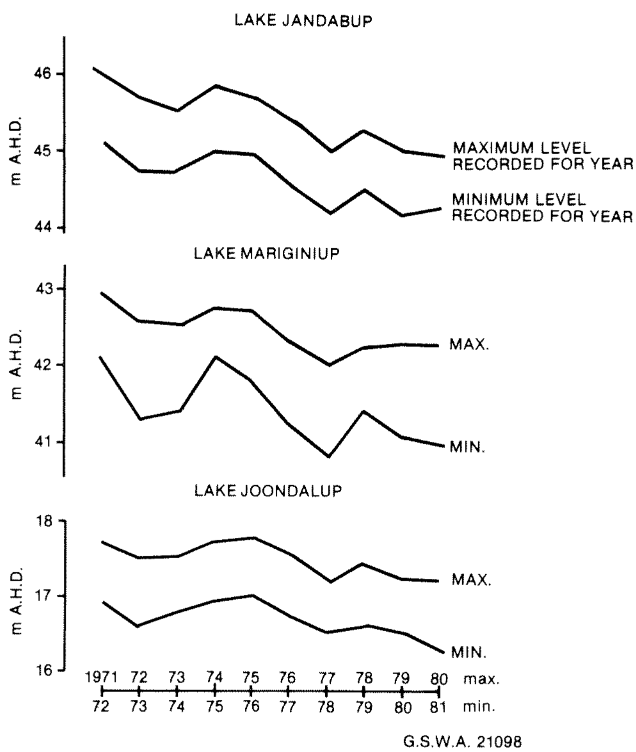

Figure 10. Hydrographs for Lakes Jandabup, Mariginiup and Joondalup, 1971-1980.

WATER BALANCE

A water balance is an accounting of all water entering and leaving a finite water system. For Lake Mariginiup the water balance can be expressed by the equation:

$$Gi + R + V_{79} = D + E + V_{80} \quad (1)$$

where Gi = groundwater inflow to the lake
R = rainfall on the lake
V_{79} = volume of the lake in 1979
D = outflow to groundwater, from the lake
E = evapotranspiration from the lake
V_{80} = volume of the lake in 1980

Groundwater abstraction by land owners in the immediate vicinity of Lake Mariginiup is not monitored and bore records are not complete, but aerial photography suggests that there are problably no more than ten private bores around the lake. Assuming that ten bores pump at an average of 200 m^3/d (probably an overestimate), the annual abstraction is less than $0.1 \times 10^6 m^3$. This figure is insignificant in the water balance so the effects of groundwater abstraction by private bores have been disregarded.

Annual flow via a drain from Little Mariginiup Lake was estimated to be less than $0.1 \times 10^6 m^3$ and has also been disregarded.

Outflow to groundwater and the volume of water in the lake in 1979 and 1980 cannot be estimated directly because of the lack of sufficient groundwater-head data on the western side of the lake and reliable bathymetric contours. However, by selecting a period when the lake water-levels at the beginning and end are essentially the same, there is negligible change in lake storage.

Equation (1) may then be rewritten as:

$$Gi + R = D + E \quad (2)$$

and outflow to groundwater may be estimated by difference.

Estimates of the components of the water balance have been evaluated for the period May 1979 to May 1980, when the lake water-levels were virtually the same at 41.421 m and 41.408 m (AHD) respectively.

GROUNDWATER INFLOW

Groundwater inflow to the lake may be estimated by using the form of the Darcy equation:

$$Q = KbIL \quad (3)$$

where Q = groundwater inflow (m^3/d)
K = hydraulic conductivity (m/d)
b = aquifer thickness (m)
I = hydraulic gradient (dimensionless)
L = width of flow section (m)

An estimate for Q is obtained by evaluating this equation for an end of winter and end of summer situation and averaging the values. Hydraulic conductivity is assumed to be a uniform 30 m/d on the eastern side of the lake. The other components of Equation (3) are measured on the water table maps and hydrogeological sections for October 1979 (end of summer) and April 1980 (end of winter). (Figs 5 to 7). They are measured on lines midway between the 44 m and 45 m contours (October 1979) and the 43 m and 44 m contours (April 1980), where the isopotentials are near vertical and groundwater flow is horizontal.

The aquifer thickness is taken as 27 m. Figure 7 shows that groundwater flow into the lake is from the upper half of the aquifer.

Hydraulic gradients were measured at a number of points between the flow lines bounding the flow section at the water table, and mean gradients of 2.3×10^{-3} and 1.8×10^{-3} were calculated for the end of winter and end of summer. However, as Figure 7 shows, the hydraulic gradients at the water table are steeper than those at depth. Analysis of the distribution of hydraulic gradients with depth indicates that the mean hydraulic gradient through the upper half of the aquifer is approximately 70% of that at the water table. The hydraulic gradients measured at the water table have therefore been adjusted to 1.7×10^{-3} and 1.3×10^{-3}.

The flow section widths (L) measured between the bounding flow lines are 2.1×10^3 m and 2.2×10^3 m for the end of winter and end of summer respectively.

The groundwater flows for the upper part of the aquifer through the line of section for October 1979 and April 1980 are:

$$Q_{(OCT)} = 30 \times 27 \times 1.7 \times 10^{-3} \times 2.1 \times 10^3$$
$$= 2.9 \times 10^3 m^3/d$$

and

$$Q_{(APR)} = 20 \times 27 \times 1.3 \times 10^{-3} \times 2.2 \times 10^3$$
$$= 2.3 \times 10^3 m^3/d$$

and the average daily flow is

$$Q = 2.6 \times 10^3 m^3/d$$

This value, however, underestimates the actual groundwater inflow to the lake because it takes no account of the increase in groundwater flow, due to net rainfall recharge to the shallow groundwater, between the line of measurement of the components of Equation (3) and the lake shore.

This was determined by applying the percentage net rainfall recharge to the rainfall for the period over the area between the lake shore, the line on which the components of groundwater inflow were calculated, and the bounding flow lines (Figs 5 and 6).

The percentage net rainfall recharge for the area was estimated from the ratio of the chloride concentration of rainfall to the chloride concentration of the groundwater at the water table. The mean annual chloride concentration of rainfall, in Perth, was 12.0 mg/L in 1973 and 10.7 mg/L in 1974 (Hingston and Gailitis, 1977). The average of these two values, 11.4 mg/L, is assumed to be the rainfall chlorinity for May 1979 to May 1980. The average chloride concentration of groundwater at the water table in the area under review was about 50 mg/L (Fig. 11) and the percentage net rainfall recharge was:

$$(11.4/50) \times 100 = 23\%$$

The rainfall for the period was 704 mm (Table 4) and the mean area was about $1.6 \times 10^6 m^2$ and therefore the net rainfall recharge to groundwater inflow was:

$$= 0.23 \times 0.704 \times 1.6 \times 10^6$$
$$= 0.3 \times 10^6 m^2$$

The groundwater inflowing to the lake for the period May 1979 to May 1980 becomes:

$$Gi = (2.6 \times 10^3 \times 366) + (0.3 \times 10^6)$$
$$= 1.3 \times 10^6 m^3$$

RAINFALL

The rainfall component (R) was estimated by applying the total rainfall for the period may 1979 to May 1980 (Table 4) to the area of the lake.

The area of the lake is approximately $1.6 \times 10^6 m^2$ so:

$$R = 0.704 \times 1.6 \times 10^6$$
$$= 1.1 \times 10^6 m^3$$

EVAPOTRANSPIRATION

Evapotranspiration from the lake is the sum of direct evaporation from the open water surface and transpiration by vegetation within the area of the lake. It is assumed to be 80% of the pan evaporation. Table 5 shows the pan evaporation for Perth.

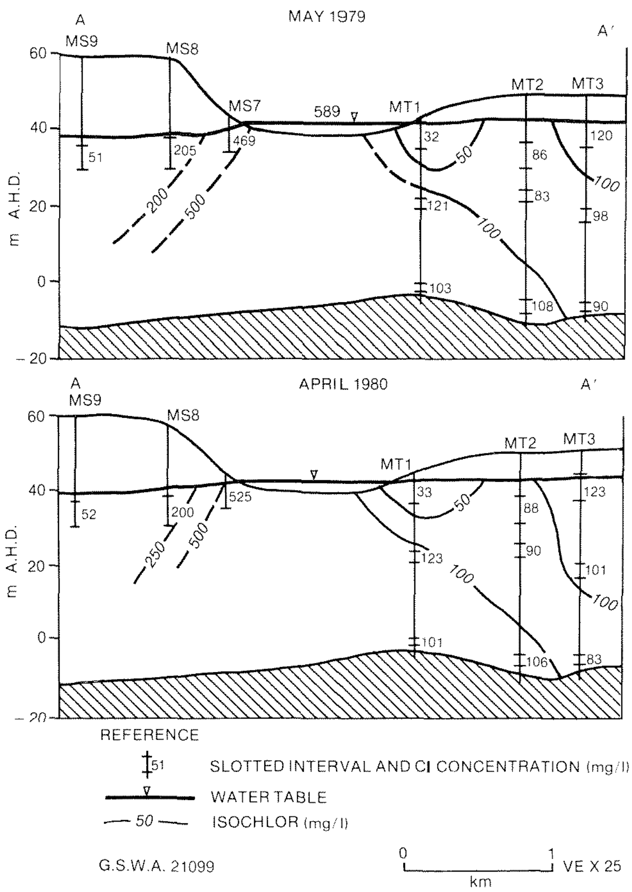

Figure 11. Isochlor Section A-A' of Lake Mariginiup.

The evapotranspiration (E) component was estimated by applying the pan evaporation for the period May 1979 to May 1980 to the area of the lake:

$$E = 1.749 \times \frac{80}{100} \times 1.6 \times 10^6$$

$$= 2.2 \times 10^6 m^3$$

BALANCE

By substituting the estimates for the components of the water balance into equation (2), the water balance is:

$$(1.3 + 1.1) \times 10^6 = (D + 2.2.) \times 10^6$$
$$2.4 \times 10^6 = (D + 2.2) \times 10^6$$

The outflow to groundwater (D), obtained by difference, is $0.2 \times 10^6 m^3$.

TABLE 4. RAINFALL AT WANNEROO

	1979							1980					
	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Rainfall (mm)	154	126	112	41	28	5	4	1	13	3	77	100	704

TABLE 5. CLASS-A PAN EVAPORATION AT PERTH

	1979							1980					
	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Evaporation (mm)	54	59	70	102	156	173	284	273	209	190	101	78	1 794

GROUNDWATER THROUGHFLOW

Groundwater throughflow (i.e. flowing beneath the lake) may be estimated by applying equation (3) to the bottom half of the aquifer. Hydraulic conductivity (K) and width of flow section (L) will be the same as for the groundwater inflow calculations; aquifer thickness is 27 m; and hydraulic gradients (I) are 1.2 x 10^{-3} and 1.0 x 10^{-3} for October 1979 and April 1980 (measured on Fig. 7).

Groundwater throughflow G_T for October 1979 and April 1980, then, is estimated to be:

$$G_{T\,(OCT)} = 30 \times 27 \times 1.2 \times 10^{-3} \times 2.1 \times 10^3 = 2.0 \times 10^3\ m^3/d$$

$$\text{and } G_{T\,(APR)} = 30 \times 27 \times 1.0 \times 10^{-3} \times 2.2 \times 10^3 = 1.8 \times 10^{-3}\ m^3/d$$

with a mean value of:

$$G_T = 1.9 \times 10^3\ m^3/d.$$

For the period May 1979 to May 1980 the throughflow is estimated to be:

$$G_T = 1.9 \times 10^3 \times 365 = 0.7 \times 10^6\ m^3$$

The total groundwater flow beneath the eastern side of the lake (Gi + G_T) is

$$= (1.3 + 0.7) \times 10^6\ m^3 = 2.0 \times 10^6\ m^3$$

Net loss of water from the lake (R-E) is

$$= (1.1 - 2.2.) \times 10^6 = -1.1. \times 10^6\ m^3$$

Therefore groundwater flow through the total aquifer thickness beneath the lake is reduced by

$$\frac{[1-(2.0-1.1)]}{2.0} \times 100 = 55\%$$

CHLORIDE MASS BALANCE

A chloride mass balance is an accounting for all chloride entering and leaving a groundwater system. The chloride in the components of the water balance (Equation 3) affect the mass of chloride in the system, except for evapotranspiration which only affects chloride concentration. The chloride mass balance may be expressed as:

$$Gi\,[Cl]_i + R\,[Cl]_R + V_{79}\,[Cl]_{L79} = D[Cl]_D + V_{80}\,[Cl]_{L80} \quad (4)$$

where $[Cl]_i$ = chloride concentration of groundwater in flowing to the lake

$[Cl]_R$ = chloride concentration of rainfall

$[Cl]_{L79}$ = chloride concentration of the lake water in 1979

$[Cl]_D$ = chloride concentration of the groundwater outflowing from lake

$[Cl]_{L80}$ = chloride concentration of the lake water in 1980

Assuming that the mass of chloride in the lake was essentially the same for the beginning and end of the period, the last terms on either side of Equation (4) may be deleted, so that the chloride mass balance equation becomes:

$$Gi\,[Cl]_i + R[Cl]_R = D[Cl]_D \quad (5)$$

If the chloride mass balance is calculated over the same period as the water balance, the results may be used to check the accuracy of the water balance.

GROUNDWATER INFLOW

Comparison of the isochlor sections (Fig. 11) with the hydrogeological sections (Fig. 7) indicates that the mean chloride concentration of groundwater inflowing to the lake is about 77 mg/L. The groundwater inflow for the period has been estimated to be 1.2 x $10^6 m^3$ so the mass of chloride entering the lake by groundwater inflow is:

$$Gi[Cl]_i = 1.3 \times 10^6 \times 77 = 100\ t.$$

RAINFALL

The mean chloride concentration of rainfall at Wanneroo is 11.4 mg/L and the rainfall input to the lake has been estimated to be 1.1 x $10^6 m^3$, so the mass of chloride entering the lake via rainfall is:

$$R[Cl]_R = 1.1 \times 10^6 \times 11.4 = 13\ t.$$

OUTFLOW TO GROUNDWATER

Assuming that the chloride concentrations in bore MS 7 (Fig. 11) reflect the concentrations of the water outflowing from the lake to groundwater, a mean value of 497 mg/L is used. Outflow to groundwater was estimated by difference to be 0.2 x 10^6 m^3, so the mass of chloride leaving the lake is:

$$D[Cl]_D = 0.2 \times 10^6 \times 497 = 99\ t.$$

MASS BALANCE

If the estimates of the chloride mass balance are substituted into Equation (5), the balance becomes:

$$100 + 13\ t \approx 99\ t.$$
$$113\ t \approx 99\ t.$$

This is a fair balance considering the quality of data used and the assumptions made, and tends to confirm that the water balance estimates are of the right order.

CONCLUSIONS

The water balance is based on limited data, mainly owing to the lack of adequate bores downstream of the lake, and many assumptions. However, the chloride mass balance tends to confirm that the water balance is probably of the right order.

Lake Mariginiup is mostly maintained by groundwater inflow from the upper half of the aquifer and by rainfall.

Outflow to groundwater from the lake is retarded by lake sediments and evapotranspiration removes about 92% of water input to the lake. Consequently the salinity of the lake is considerably higher than that of the groundwater and the outflow forms a plume of saline water downstream of the lake.

The lake is a groundwater sink. The groundwater flow beneath the "superficial formations" is reduced by 55%.

Groundwater abstraction from the Wanneroo Scheme bores has had no apparent effect on the lake. This is not surprising since the nearest production bore is over 3 km to the east and all production bores are screened against the bottom third of the aquifer, intercepting groundwater which flows beneath the lake. However, large-scale abstraction of groundwater from the upper half of the aquifer by private bores in the vicinity, and upstream, of Lake Mariginiup could reduce the amount of groundwater flowing into the lake and thus affect lake water levels.

RECOMMENDATIONS

To improve the water balance, more precise values for outflow, lake storage and their respective chlorinities are needed. However, of more importance are the long-term effects, if any, of groundwater abstraction on the lake, and the following recommendations are made:

(a) Bathymetric contours of the lake should be improved and the present form of monitoring of the lake water-level be replaced by a permanent staff, located near the middle of the lake. This would enable the production of a depth/area/volume rating chart and more accurate measurements of lake water levels.

(b) Some estimate of groundwater abstraction by landowners near the lake should be made.

(c) A rainfall gauge should be placed on the lake shore and measured monthly.

(d) Monitoring of groundwater levels should be maintained on a monthly basis.

(e) Aerial photography should be implemented on an annual basis to monitor broad changes in lake physiography and land use in the vicinity of the lake.

(f) Some measurement of the water contribution to Lake Mariginiup via the drain from Little Lake Mariginiup should be made.

(g) If the above recommendations are adopted, all monitoring should be reviewed annually to determine the likely causes of any changes in the lake.

(h) In all future investigations of this type, intermediate and deep bores should be installed on both the upstream and downstream sides of the lake in question.

REFERENCES

Allen, A. D., 1976, Proposed hydrogeological investigation of selected lakes in the Metropolitan area: West. Australia Geol. Survey, Hydro. Report No. 1361 (unpublished).

—1979, The hydrogeology of Lake Jandabup, Swan Coastal Plain, W.A.: West. Australia Geol. Survey, Annual Report 1979, p.32-40.

Backhouse, J., 1979, Palynology of Lake Mariginiup MT3D bore hole: West. Australia Geol. Survey, Palaeontological Report No. 15/1979 (unpublished).

Cockbain, A. E., 1979, ammonite fragment from Lake Mariginiup MT2D borehole: West Australia Geol. Survey, Palaeontological Report No. 4/1979 (unpublished).

Congdon, R. A., and McComb, A. J., 1976, The nutrients and plants of Lake Joondalup, a mildly eutrophic lake experiencing large seasonal changes in volume: Royal Soc. West. Australia Jour., v.59, pt 1, p.14-23.

Fairbridge, R. W., 1953, Australian stratigraphy: University of Western AustraliaText Books Board, Perth.

Hingston, F. J., and Gailitis, V., 1977, Salts in the rainfall in Western Australia (1973-74): Australia CSIRO Div. Land Res. Management, Tech. Memo 77/1.

Hooper, K., 1972, Microfauna of Joondalup 9-150, core at 196-199 feet: West. Australia Geol. Survey, Palaeontological Report No. 11/1972 (unpublished).

How, R. A., 1978, The environment of the northern Swan Coastal Plain, consideration of faunal changes and recommendations, *in* Faunal studies of the Swan Coastal Plain: The Western Australian Museum.

McArthur, W. M., and Bettenay, E., 1974, The development and distribution of the soils of the Swan Coastal Plain; Australia CSIRO, Soil Publication No. 16, 2nd edition.

Playford, P. E., Cockbain, A. E., and Low, G. H., 1976, Geology of the Perth Basin, Western Australia: West. Australia Geol. Survey, Bull. 124, 311p.