8. REFLUX BRINES

8.1 Introduction

The Parilla Sand aquifer, beneath the three discharge lakes Tyrrell, Wahpool and Timboram, does not contain the typical 3-5% TDS regional groundwater. Instead over an area covering some 300 square kilometres, the aquifer is filled with brine, varying in salinity from about 9% up to 29% (290,000 mg/l). The brine may be separated into two distinct groups, based upon salinity and location (Figure 8.1).

(1) Tyrrell brine. The salinity range is from about 200,000—290,000 mg/l. This brine saturates the entire Parilla Sand aquifer beneath Lake Tyrrell, and has been found at depth in bores one kilometre west of the lake, where it underlies the inflowing regional groundwater.

(2) Timboram—Wahpool brine. The salinity of this system is from about 95,000 mg/l to 125,000 mg/l. It occurs beneath regional groundwater in the area between Lake Wahpool and Lake Tyrrell and directly underlies lakes Timboram and Wahpool.

It is shown in Chapter 12.3.6 that the brines in the Tyrrell Basin have accumulated within the last 32,000 years.

Although having different salinities, the brines and the regional Parilla Sand water are similar in chemical composition, with the major ionic ratios retaining the same strong resemblance to seawater as noted previously in the case of the regional groundwater (Table 8.4). The restriction of the brines to that part of the aquifer beneath the respective lake systems and their downbasin shadow zones (Figure 8.1), when coupled with their compositions, indicates that the brines are derived from lake waters whose chemical composition was largely determined by the chemistry of the inflowing regional groundwater. Following a degree of evaporitic concentration in the playa lake environment, the lake waters infiltrated through the lake floor into the groundwater system to form groundwater brines.

8.2 General

The recharge of saline waters into groundwater systems is a widespread problem in oil producing areas (Fryberger, 1975), where oilfield brines may escape from evaporation pits and contaminate underlying aquifers. However, the downward seepage of naturally occurring hypersaline brines from lakes and lagoons into groundwater systems has also received much attention as a consequence of the process of seepage reflux dolomitization (Adams and Rhodes, 1960). Seepage reflux is the term used by Adams and Rhodes for the downward seepage of hypersaline brines through the floors of coastal lagoons, following the evaporative concentration of inflowing seawater. They used the process to explain dolomitization of underlying limestones by magnesium enriched bitterns formed in the lagoons. The process was used by others, notably Berner (1971), Murray (1969), Deffeyes et al. (1965), and Lucia (1972) to explain areas of dolomitization in near coastal situations. In these cases the refluxing brines returned seaward via the groundwater systems, in one instance underflowing less dense seawaters moving landward toward the coastal lake system (Deffeyes et al., 1965).

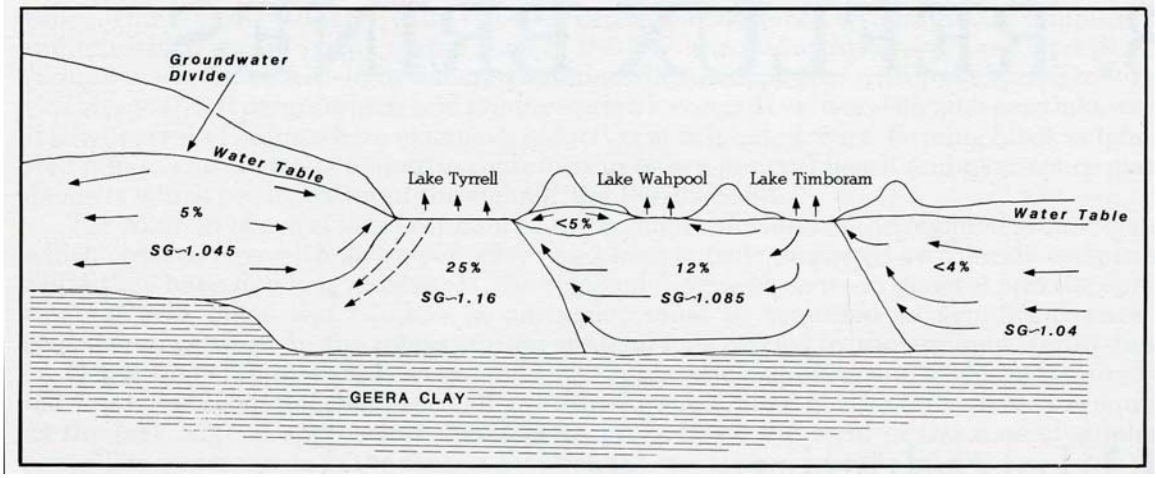

Figure 8.1 - Groundwater flow systems and salinities in the Tyrrell Basin

Figure 8.2 - The Bimbourie 4/5 piezometer nest, looking towards Lake Tyrrell situated about 1 km to the east. At this site, after passing through a broad transition zone, the Tyrrell reflux brines were encountered at a depth of 60 m

Although until now restricted to a coastal setting, the process of brine recharge or reflux is essentially the same for certain southeastern Australian playa lakes and the larger boinkas in their continental setting. Instead of seawater, the water sources are direct precipitation, surface runoff, and groundwater inflow, while the salt source is essentially from the inflowing groundwater. The salt is returned to the groundwater system as a concentrated brine solution after a period of evaporitic concentration in the lake environment. For the purpose of this work, the term reflux or seepage reflux is used to describe the return (or reflux) of brines into an aquifer system, following the evaporitic concentration of salts in a lake which is itself partially fed by groundwater discharge. Brines formed in this manner are termed reflux brines; those beneath Lake Tyrrell are the Tyrrell reflux brines; and those beneath Lake Timboram and Lake Wahpool are called the Timboram–Wahpool reflux brines.

After their return to the aquifer, the brines may again continue to pass downbasin, being gradually diluted by the regional groundwaters as they flow either toward a terminal sump, or, as in the case of this study, toward the Murray River, where they may finally discharge to the surface and eventually be lost to the sea. The downbasin migration of the brines may be interrupted by further cycles of evaporitic concentration in lake systems: this is the case with the Timboram–Wahpool reflux brines, which re-emerge as springs along the eastern shoreline of Lake Tyrrell.

8.3 The Association of Groundwater Brines with Discharge Landscapes

The presence of high salinity groundwaters beneath discharge lakes and complexes is not restricted to the Tyrrell Basin, but is found in similar landscapes throughout northwestern Victoria. Examples of groundwater brines from the Raak and Pink Lakes boinkas are given in Table 8.1. A further analysis, that of the average Timboram–Wahpool reflux brine from the Tyrrell Basin, is added for comparison.

TABLE 8.1 - Groundwater brines from beneath the Raak and Pink Lakes boinkas (mg/l)

	TDS	**Cl^-**	**Br^-**	**HCO_3^-**	**SO_4^{2}-**	**Ca^{2+}**	**Mg_2^+**	**Na^+**	**K^+**	**Fe^{2+}**	**SiO_2**	**pH**
Raak Boinka												
Goonegal 10001	96353	53000	-	221	8230	641	3338	30560	351	1	10	7.3
Bitterang 8001	122170	68000	170	37	8987	550	3800	40250	360	2	10	6.2
Bitterang 8001	123555	68400	-	36	9740	497	3923	40340	408	1	9	6.5
Pink Lakes Boinka												
Mamengarook 1	110000	53750	126	162	7570	325	2510	33000	293	1	3	7.2
Mamengarook 3	106000	52275	127	9	6120	280	2130	31900	320	1	1	5.8
Timboram Reflux Brines												
Average	114312	64642	176	111	8023	815	4735	35460	333	1	13	6.9

8.4 Hydrochemistry of the Tyrrell Reflux Brine

Table 8.2 shows the general chemical character of the Tyrrell reflux brines. It is based on twelve analyses of groundwater, all having salinities greater than 200,000 mg/l. The samples came from varying depths (6 m to 70 m), from bores distributed along the western shoreline of the lake, and from one bore on the eastern edge of the lake. The table clearly shows the close chemical relationship between the reflux brines and the regional groundwater found in the Parilla Sand. It thus adds a further dimension to the conclusion drawn from lake water chemistry see Chapter 101 that virtually all waters in the basin have a chemistry based on that of the regional groundwater.

TABLE 8.2 - Reflux brines from beneath Lake Tyrrell (average of twelve samples with salinity > 200,000 mg/l)

	Regional Parilla water (mg/l)	Reflux brines (mg/l)	Concentration ratio of Parilla water	Ion excess with respect to bromide
Bromide	64.2	347	5.41	1.00
Chloride	19,757	130,956	6.61	1.23
Sulphate	3,188	15,452	4.85	0.89
Calcium	470	514	1.09	0.20
Magnesium	1,353	7,099	5.24	0.97
Sodium	11,077	77,159	6.96	1.29
Potassium	113	660	5.84	1.08
Silica	56	11	0.20	0.04
Bicarbonate*	249	105	0.42	0.08
TDS	36,263	223,549		

*Average of only four samples

The average salinity of the brine in Table 8.2 is about 224,000 mg/l; however, waters furthest from the transition zone around the brine have a salinity closer to 250,000 mg/l, and at times reach 280,000 mg/l. The density of the brine ranges from about 1.14 to 1.19 g/cm^3, averaging about 1.16 g/cm^3.

The Cl/Br ratio (377), although slightly higher than in the regional waters (Table 8.4), proves that re-solution of a pre-existing halite body is not the source of the brine. Were the latter process operative, virtually no magnesium and very little bromide would be expected (cf. Holster, 1966). Instead, the Cl/Br and Cl/Mg ratios suggest that the primary source of the brine was evaporitic concentration of an oceanic type water (in this case the inflowing regional Parilla Sand water), with some addition of halite (see Chapter 10). The brines, like the regional waters, are essentially, a sodium–magnesium–chloride–sulphate water. The bulk of the ions show a 5 to 7 times concentration when compared with the regional Parilla waters. The most soluble ions, Br^- , Mg^{2+} and K^+, are 5.2 to 5.8 times concentrated.

A comparison of the chemistry of the refluxed brine with that of the parent regional groundwater enables some understanding of the geochemical processes operating within the intervening playa lake environment prior to outseepage. Bromide has again been chosen as an index with which to compare the concentrations of other ions with those of the parent regional groundwater. The choice is supported by the similar degrees of concentration shown by other bittern ions (magnesium and potassium), neither of which is significantly precipitated until after halite. The Mg/Br ratio for the Tyrrell reflux brines is much the same as that for the parent regional groundwater (Table 8.4), showing that in the lake environment there was no significant loss of bromide through concentration in organic-rich muds (Mun and Bazilevich, 1962). The Cl /Br and Na/Br ratios show that there is some addition of NaCl to the reflux brine (see below).

Table 8.3 shows the character of the reflux brines at the Bourka 2/3 (4) piezometer nest, south-western Lake Tyrrell, where the Bourka 4 bore was sampled over a 50-hour period while continuously pumping. The salinity changes during this period were insignificant.

TABLE 8.3 - Chemical analyses from the Bourka 4 bore

Time after pump started:	5 minutes	25 hours
TDS (mg/l)	268,003	271,506
Chloride	147,000	146,800
Bromide	343	436
Carbonate	Nil	Nil
Bicarbonate	118	106
Sulphate	23,300	26,900
Nitrate	25	25
Calcium	550	573
Magnesium	8,840	8,880
Sodium	86,700	86,800
Potassium	1,000	1,000
Iron—total	10	6
Iron—Soluble	5.0	2.5
Silica	31	11
pH	6.4	6.6
S.G. at 20°C	1.17	1.17

*Date Sampled, 24.2.81; aquifer level, 17-23 m; yield, 10.43 Us.

On the basis of the bromide ion concentration, there is a major loss of calcium, bicarbonate and silica, and a minor loss of sulphate. The loss of calcium and bicarbonate is readily explained by the formation of evaporites, calcite and gypsum during the process of evaporitic concentration. The formation of gypsum would also account for the lower sulphate concentration, although the loss is much less than that of calcium: this reflects the excess of SO_4^{2-} over Ca^{2+} in the regional groundwater.

As a consequence of the removal of calcium, the Mg/Ca ratio in the reflux brines has been raised to 14:1 (ionic ratio) or 23:1 (molar ratio). The reflux of magnesium rich hypersaline waters is the mechanism proposed for the dolomitization of calcareous sediments in near coastal environments by Adams and Rhodes (1960), Deffeyes et al. (1965), and others previously cited. The Tyrrell data shows that the same reflux process occurs in a continental setting, and all that may have prevented the formation of dolomites within the aquifer beneath the lake is the presence of a siliceous rather than a calcareous aquifer. It is suggested, therefore, that the process of seepage reflux dolomitization need not be restricted to coastal settings, but may occur in semiarid to arid continental settings beneath large playa lakes.

TABLE 8.4 - Chemical ratios—Tyrrell Basin groundwaters

	Cl/Na	Cl/Mg	Cl/Br	Mg/Br	Ca/Br	K/Br	Mg/Ca
Regional groundwater	1.78	14.6	307	21.1	7.3	1.76	2.9
Tyrrell reflux brine	1.70	18.4	377	20.5	1.5	1.90	13.8
Timboram—Wahpool reflux brine	1.82	13.7	367	26.9	4.6	1.89	5.8
Seawater	1.81	14.9	292	20.0	6.2	5.85	2.9

Magnesium—bromide ratios have remained largely unaltered from the ratio in the regional groundwater, while sodium and chloride ions show significant gains. The total NaCl surplus over that in the regional groundwater is about 18.5% of the total Tyrrell reflux brine; this is interpreted as being a non-groundwater component of the brine. One local source of halite is from the lunette complex developed along the entire eastern edge of the lake. It has been previously shown (Macumber, 1968) that halite, deposited with other evaporite minerals in a lunette sequence, readily undergoes remobilization and collects in low areas adjacent to the lunette.

The decreased Cl/Na ratio, from 1.78 to 1.70, is not considered significant, although this does not preclude the possibility of some minor gain in sodium by interactions with clay minerals, for example (Freeze and Cherry, 1979):

$Na_{0\cdot 33Al2.33}Si_{3.67}O_{10}(OH)_9 + 1/3H^+ + 23/6H_20 <=>$
(Na-montmorillonite)

$7/6\ Al_{2S}i2O_5(OH)_4 + 1/3Na^+ + 4/3Si(OH)_4$ (kaolinite)

(8.1)

Similar reactions may be responsible for the increase in the potassium content, reflected in the rise of the K/Br ratio from 1.76 to 1.90; at the same time the Mg/K ratio falls from 12.0 to 10.7 (not given in the table). These ratios show that there is no preferential sorption of potassium on lacustrine sediments, either while in the lake or during the reflux process.

The reflux brine chemistry shows that, while dissolution of clay minerals may provide additional small amounts of Na^+ and K^+, this addition, in the case of the Tyrrell reflux brines, has very little influence on their gross character. It is concluded therefore that the chemical differences between the Tyrrell reflux brines and the regional groundwater can be explained simply by the normal processes occurring during the evaporative concentration of the regional waters in a lacustrine regime. Some additional sodium chloride has been added, probably from an external source such as the nearby lunette system.

The relatively low silica content of the reflux brine (average 11 mg/l) is in contrast to the relatively high silica content of the regional groundwater, which averages 56 mg/l with values as high as 100 mg/l in some bores. It is normally less than 10 mg/l in the lake water and most commonly less than 5 mg/l. The loss of silica occurs in the spring zone, with the formation of aluminosilicates; this is discussed in detail in Chapter 9.

8.5 Timboram-Wahpool Reflux Brine

The Timboram-Wahpool brines are found occupying the Parilla Sand aquifer from Lake Timboram westward beneath Lake Wahpool to the eastern shore of Lake Tyrrell, where they re-emerge as springs. The chemical character of the brine is detailed in Tables 8.4, 8.5 and 8.6. The average salinity of the brine is about 114,000 mg/l, i.e. about three times that of the regional water, but only half that of the Tyrrell reflux brine. Their specific gravity is about 1.085.

TABLE 8.5 - Timboram-Wahpool reflux brines

Bore	**Lianiduck 10001**	**Lianiduck 10001**	**Moortworra 10001**	**Moortwoora 10001**	**Eureka 10001**	**Lianiduck 2**	**Average**
Depth (m)		35-48.5	17.5-29	17.5	21-31	48	
TDS (mg/l)	126,900	125,700	120,400	119,700	97,780	95,200	114,300
Chloride	71,005	70,500	69,600	67,400	54,500	53,900	64,600
Bicarbonate	105	244	108	108	18	84	111
Sulphate	8,870	9,140	6,950	8,510	8,020	6,648	8,023
Calcium	1,060	740	865	860	680	687	815
Magnesium	4,825	5,270	4,840	4,835	4,830	3,182	4,735
Sodium	39,600	39,300	37,500	37,400	29,300	29,700	35,500
Potassium	483	310	355	353	245	249	333
Iron-soluble	1	2	1	1	1	1	1
Bromide	185	190	190	189	151	150	176
Silica	17	29	10	10	10	1	13
pH	6.9	7.1	7.1	6.8	6.3	7.1	6.9

The Tyrrell and Timboram-Wahpool reflux brines may be compared by contrasting their respective ionic concentrations with those of the parent regional groundwater. Although this comparison is less rigorous than that in the tables, it does remove the rigidity imposed by choosing any single ion for the determination of a concentration factor.

Tyrrell brine

$$Na^+ > Cl^- > K^+ > Br^- > Mg^{2+} > SO_4^{2-} >> Ca^{2+} >> HCO_3^- > SiO_2$$

← enrichment depletion →

Thus, the Na^+ increase is proportionally greater than the Cl- increase which, in turn, is greater than the K^+ increase etc. Br- and Mg^{2+} have concentrated to essentially the same degree, while Ca^{2+} is greatly depleted by comparison with SO_4^2- (the explanation for this is given above).

Timboram-Wahpool brine

$$Mg^{2+} > Cl^- > Na^+ > K^+ > Br- > SO_4^{2-} >> Ca^{2+} >> HCO_3^- > SiO_2$$

← enrichment depletion →

In most respects the Timboram-Wahpool brines are similar to the Tyrrell brines-being deficient in calcium, silica and bicarbonate when compared with the regional groundwater but with excess of chloride and sodium (Table 8.6). The same processes that produced the Tyrrell reflux brines are apparently also in operation on the Timboram - Wahpool brines. Notable differences between the two brines are the significant increase in magnesium content, not seen in the Tyrrell brine, and the lesser depletion of calcium.

The smaller calcium loss in the Timboram - Wahpool brines compared to that of the Tyrrell brines can be attributed to lower gypsum losses, reflected in the low sulphate depletion. While gypsum is precipitated in the spring zone and in the lake during seasonal evaporative concentration, the lesser degree of concentration in the case of the Timboram - Wahpool brine, prior to its reflux, permits more calcium to enter the groundwater system than is the case with the Tyrrell reflux brines. The Mg/Ca ratio of the latter waters is 13.8, compared to 5.8 for the Timboram - Wahpool reflux brine, and 2.9 for the regional groundwater (Table 8.4).

TABLE 8.6 - Timboram—Wahpool reflux brines (average of six samples)

	Regional Parilla water (mg/l)	Timboram–Wahpool (mg/l)	Conc. factor	Excess factor with respect to bromide
Bromide	64.16	176	2.74	1.00
Chloride	19,757	64,642	3.27	1.19
Sulphate	3,188	8,023	2.52	0.96
Calcium	470	815	1.73	0.63
Magnesium	1,353	4,735	3.49	1.27
Sodium	11,077	35,460	3.20	1.17
Potassium	113	333	2.95	1.08
Bicarbonate	249	111	0.45	0.19
Silica	56	13	0.23	0.08

The origin of the excess magnesium can only be speculated upon without further work; however, there is strong evidence that the source is localized and not introduced by the Lalbert Creek, which feeds Lake Timboram from the south. This is indicated by the analyses of Timboram lake water (Table 8.7), which show higher magnesium—bromide ratios (25—27) in the northern part of the lake away from the Lalbert Creek, but normal ratios (19—20) in the south where the creek enters the lake. This difference was also recorded by McLaughlin (1966) in his detailed analyses of saline waters from northwestern Victoria.

TABLE 8.7 - Magnesium—bromide ratios at Lake Timboram

Sampled from	North end	South end
May-Aug. 1980 - (avg of 5 samples)	25.1	20.0
From McLaughlin (1966)	26.7	19.4

While the high Mg/Br ratio may equally well suggest a bromide loss (perhaps by bromide bioconcentrators), the enrichment—depletion figure for the brines shows that the percentage increase in magnesium is the largest of any ion, including sodium and chloride; abnormally low Cl/Mg ratios support this contention. The data indicates an undoubted and significant pickup of magnesium by the infiltrating lake waters prior to, or during, their reflux into the groundwater system. This may be achieved by several processes, for instance the release of magnesium from clay minerals in a manner similar to that for the release of sodium and potassium by incongruent dissolution and by the congruent dissolution of dolomites.

Examples of the first situation are:

$K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2 + 11/10H^+ + 63/60H_2O <=>$
(illite) $23/20Al_2Si_2O_5(OH) + 3/5K^+ + 1/4Mg^{2+} + 6/5Si(OH)_4$
(kaolinite)
(8.2)

$6Mg_{0.167}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 2H^+ + 23H_2O <=> 7Al_2Si_2O_5(OH)_4 + Mg^{2+} + 8H_4SiO_4$
(Mg-beidellite) (kaolinite)

(8.3)

The dissolution of dolomite proceeds by:

$$Mg\,Ca\,(CO_3)_2 <=> Mg^{2+} + Ca^{2+} + 2CO_3^{2-}$$

(8.4)

Silica is produced in the clay reactions; potassium is also released during the conversion of illite to kaolinite, while at the same time hydrogen ion is consumed.

The silica content of Timboram lake water ranges from about 1 to 10 mg/l, averaging about 7 mg/l (Table 10.6); the Timboram reflux brines have a silica content ranging from 1 to 29 mg/l, averaging 13 mg/l (Table 8.6). The higher silica content in the reflux brines may indicate an incongruent dissolution process. It is not known whether or not dolomite occurs within the shallow subsurface sediments beneath Lake Timboram as it does at Lake Tyrrell. Any clue to the possibility of dolomite dissolution, which might have been provided by the increase in calcium, is masked by the overall loss of calcium during the formation of gypsum, both in the spring zone and during evaporative concentration of the lake water. Thus, the Mg/Ca ratio rises from 2.9 in the regional groundwaters to 5.8 in the reflux brines. Therefore, the Timboram–Wahpool reflux brines show a similar evolution to that of the Tyrrell reflux brines. An additional feature, not seen in the Tyrrell brines, is the unusually high magnesium content.

The Timboram–Wahpool reflux brines are chemically very similar to the modern Timboram lake waters, especially during high lake level phases (see Chapter 10, Table 10.6). However, in the case of the Tyrrell reflux brines, the chemistry is quite different to the present-day lake waters (see Chapter 10, Table 10.2). Neither reflux brine shows the re-solution character which is diagnostic of the Lake Tyrrell waters and is reflected in high Cl/Br ratios. Indeed, the bromide versus chloride plot for both the Tyrrell reflux brine and the Timboram–Wahpool brine (Figure 8.3) shows that these waters fall directly on the straight evaporative concentration curve, thus proving that re-solution of halite was not part of their evolutionary process.

8.6 Lake Outseepage and the Formation of Reflux Brines

In terms of chloride ratios, the Tyrrell reflux brines are fundamentally different to the present-day lake waters. This indicates that when the Tyrrell reflux brines seeped from the lake into the aquifer, Lake Tyrrell was not a halite producer as at present (with high Cl/Br), but instead was a groundwater throughflow lake, similar to the present-day Lake Timboram (see below).

While, at times of seasonally high lake levels, vertical hydraulic gradients may occasionally favour outseepage, the low Cl/Br ratios in the shoreline piezometers show that there is no significant present-day outseepage of the halite enriched lake waters (Figure 8.4 a, b). Apart from ephemeral occurrences in very shallow piezometers (< 1.0 m deep), only in the adjacent bores Bourka 8001 and 8005, situated on the lake edge at southwestern Lake Tyrrell, do the Cl/Br ratios occasionally reach values of 500. This compares with ratios of 330 deeper within the aquifer, and over 1000 for lake waters (Figure 8.4 c, d); however, in these two instances the raised Cl/Br ratios are very recent changes and are explained by local recharge of halite enriched runoff water (see Macumber, 1983a).

The chemical evidence indicating that there is no significant lake outseepage is supported by the potentiometric data, since, under the present regime, potentiometric heads within the shoreline piezometers tapping the reflux brine are higher than the level of the lake floor (see Chapter 12). This shows a general inflow of not only the regional groundwaters and waters from within the transition zone but also of the reflux brines (Table 8.8). The lakeward return of the reflux brines is counter to the general outflow over time, and represents a recent shift in the dynamics of the groundwater flow systems; it is manifested by the reversal of the hydraulic gradient within the brines and the closing of the lake to hydrostatically induced outseepage. This is seen to represent only a temporary aberration of the normal outflow condition, while the system readjusts to these recent changes (see Chapter 12).

While Lake Tyrrell is at present virtually closed to hydrostatically induced outseepage, the hydrological equilibrium is delicately balanced, so that, under the large density differentials existing between the reflux brines and the regional groundwaters, only a small fall in closing groundwater pressures, or rise in lake levels, would result in significant outseepage once more.

Most of the readings in Table 8.8 are above the level of the lake floor, which is at a low of 41.3 m along the western shoreline (except off the southwestern shore opposite the Bourka 2/ 3 piezometer nest, where it drops to 41.1 m). The static levels of many bores fall within the range of lake levels obtained during the seasonal cycle of wetting and drying, i.e. from about 41.1 to 41.9 m—the latter level being attained briefly only during the wettest years. However, because of the high densities of the groundwaters, corrections are needed to accurately compare closing potentials and lake floor levels. It is shown in Chapter 12 that average yearly lake levels of 41.5 m to 41.9 m (AHD) are required to overcome the closing groundwater pressures.

TABLE 8.8 - Potentiometric data from bores in the Tyrrell reflux brines*

Bore	Position	S.G.	TDS	Static level (m AHD)
Bimbourie 4	1 km west of lake	1.17	245,000	41.7
Bimbourie 3	1 km west of lake	1.16	240,000	41.9
SR 78	western shoreline	1.16	235,000	41.9
PierMillan 10001	western shoreline	1.16	237,000	42.6
Bourka 8001	western shoreline	1.16	243,000	41.4
Bourka 3	western shoreline	1.17	265,000	41.3
Bourka 2	western shoreline	1.19	290,000	41.1
Bourka 5	western shoreline	1.16	235,000	41.5
Lianiduck 10002	eastern shoreline	1.15	201,000	43.2

* For locality plan, see Figure 7.5a.

It is likely that, in the past, reflux brine accumulation occurred under both slightly wetter conditions (lake high) and drier conditions (lower groundwater divide). On the basis of upward hydraulic gradients now existing within the reflux brines (Tables 12.9, 12.10, 12.11; Chapter 12.12.4), it seems that the most recent hydrological change, leading to the closure of the lake and the development of the thin halite crust, was one which saw a slight fall in average lake levels. For further discussion on these points see Chapter 12.

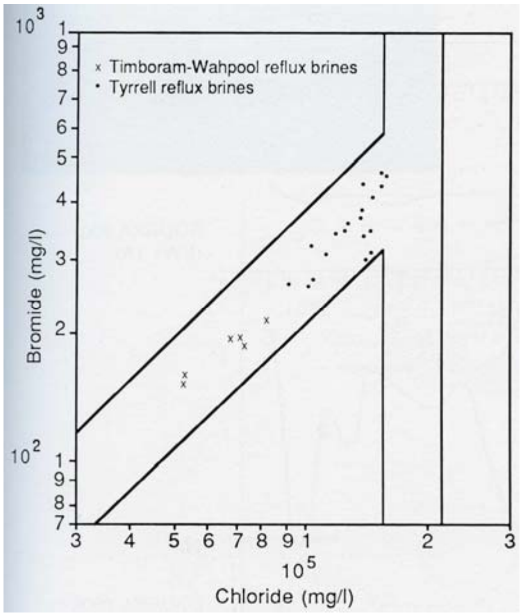

Figure 8.3 - Log bromide versus log chloride for the Tyrrell and Timboram —Wahpool reflux brines.

The distribution of the Tyrrell reflux brines lies in the same field as that of the Timboram—Wahpool brines. This indicates that the reflux brines have evolved from concentrated lake waters which have not undergone a cycle of halite re-solution prior to their outseepage from the lake environment. While this is still largely the case for the Timboram lake waters, it is not so for the present day Tyrrell lake water, which, because of seasonal halite re-solution, always plots in the vertical field of chloride saturation (see also Figures 10.4 and 10.5).

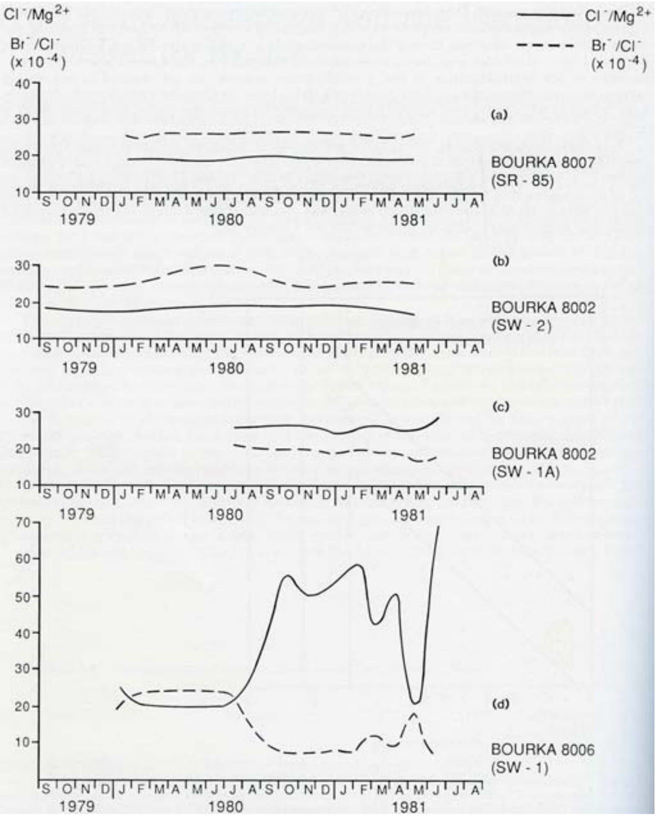

Figure 8.4 - Graphs of Cl-/Mg^{2+} and Br/Cl- in piezometers near the salt works at southwest Lake Tyrrell show variations with time.

The piezometers all monitor the Parilla Sand aquifer at a depth of about 6 m below the water table. Piezometers (b), (c) and (d) are near the lake edge, while (a) is situated about 300 m from the shoreline. Piezometers (a) and (b) show the common (regional) relationships between the various ions, while (c), the closest piezometer to the lake, shows a slightly increased chloride content, which may initially be interpreted as a lacustrine influence. Piezometer (d) shows the regional character up to winter 1980, and then abruptly changes to a Cl- enriched water. The change is, however, not due to intrusion by lake waters but, instead, to a recharge by halite enriched surface water from a nearby ditch (Figure 8.5).

Figure 8.5 - Bourka 8005 site. The bore with pump attached is in the foregound.

A drainage ditch passes alongside the bore and flanks a halite stack in the background. The water table is about 1 m below ground surface and is readily accessible to the saline drainage waters. This explanation is given for the sudden increased Cl- content shown in Figure 8.3(d); a similar process may explain the heightened Cl- content of Bourka 8001, the only other bore to show abnormal ionic ratios, suggesting the possibility of recharge from the nearby lake.

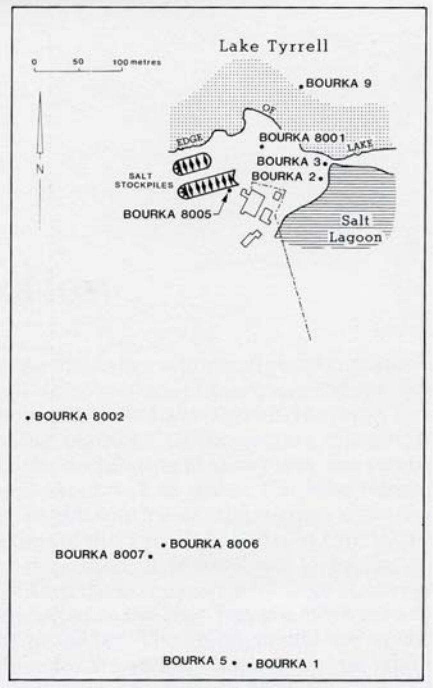

Figure 8.6 - Bore locality plan in the vicinity of the salt works—SW Lake Tyrrell