THE DYNAMIC BEHAVIOUR OF A STRESSED, SEMI-ARID GROUNDWATER BASIN, STREAKY BAY, SOUTH AUSTRALIA

DWLBC
Report

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The Department of Water, Land and Biodiversity Conservation

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The dynamic behaviour of a stressed, semi-arid groundwater basin, Streaky Bay, South Australia

Keith G. Brown and Glenn A. Harrington

Groundwater Assessment
Department of Water, Land and Biodiversity Conservation

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Groundwater Assessment Division
Department of Water, Land and Biodiversity Conservation
25 Grenfell Street, Adelaide
GPO Box 2834, Adelaide SA 5001

Telephone	National	(08) 8463 6946
	International	+61 8 8463 6946
Fax	National	(08) 8463 6999
	International	+61 8 8463 6999
Website	www.dwlbc.sa.gov.au	

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Foreword

South Australia's natural resources are fundamental to the economic and social wellbeing of the State. One of the State's most precious natural resources, water is a basic requirement of all living organisms and is one of the essential elements ensuring biological diversity of life at all levels. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of these resources changes the natural balance and may cause degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of a resource to continue to meet the needs of users and the environment. Understanding the cause and effect relationship between the various stresses imposed on the natural resources is paramount to developing effective management strategies. Reports of investigations into the availability and quality of water supplies throughout the State aim to build upon the existing knowledge base enabling the community to make informed decisions concerning the future management of the natural resources thus ensuring conservation of biological diversity.

Bryan Harris
Director, Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

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EXECUTIVE SUMMARY

Located within the Robinson Basin on the Eyre Peninsula is a small fresh, groundwater lens that has been used to supply the township of Streaky Bay for more than 60 years. Falling water levels and rising groundwater salinity in the last decade indicate that the lens cannot cope with the volume (~250 ML/yr) of water currently extracted from it.

To ascertain the condition and to determine the likely long-term sustainability of the resource, personnel from the DWLBC - Research and Development Group undertook an investigation of the freshwater lens in February 2002. A total of 38 wells were cleaned and sampled for salinity. Samples were also taken from 13 wells and analysed for major ion, stable water isotopes and chlorofluorocarbons.

Results from major ion analyses have highlighted the influence processes such as evaporation, water-rock interaction and mixing has had on the water chemistry in different parts of the lens. Stable isotope data confirm that the highly saline water that surrounds the lens is not seawater, even though it is of a similar concentration. Chlorofluorocarbons (CFCs) in the groundwater were used to estimate average annual recharge to the lens. Collectively, the hydrochemical information, coupled with hydraulic data have been used to create a new hydrogeological model that describes how the lens formed and the subsequent changes that have occurred to the lens over the past ~100 years.

The origins of the freshwater lens can be attributed to the following main factors:

- the topography forms a small basin that acts as a capture zone for rainfall,
- the catchment area for the basin is small however during high intensity rainfall events significant recharge occurs via run-off to the low-lying parts of the basin,
- karst topography have developed in the low lying areas of the sub-catchment, forming a natural recharge zone for the lens. This allows significant recharge to occur very quickly via the preferential flow paths developed in the limestone, thus avoiding the effects of evaporation. This may be particularly important in the capture of run-off during high rainfall events,
- the sub-surface geology does not allow for the lateral inflow of more saline water from aquifers to the east and north-east, and,
- the depth to water is such that the water table is not directly influenced by evaporation.

It is also possible that other freshwater lenses may exist within the Basin.

Prior to the introduction of pumping groundwater would have flowed radially outward away from the recharge zone. Excessive pumping has led to the development of a permanent drawdown cone in the main extraction area. The extraction wells (including the trenches) were originally sited where the best quality water was to be found, in the main recharge area. As a result of extraction, groundwater movement now moves in the opposite direction, moving inward towards the centre of the drawdown cone. The shape of the lens as it is today is thus a manifestation of the current pumping regime and since pumping was introduced, the size of the lens has diminished considerably.

The main outcomes of the investigation were:

- Groundwater hydrographs, chemical trends and distributions of CFC ages and salinity measurements all suggest that the dynamics of the Robinson Lens are completely controlled by rare, episodic recharge events and subsequent pumping of the fresh groundwater resource.

- Recharge rate proportional to the size of the lens (boundary defined as the Electrical Conductivity (EC) = 2500 μS/cm @ 25°C contour) is estimated to be ~11 mm/year. If run-off was deemed important then the recharge rate would be significantly less if the recharge volume was divided over the whole catchment area. It was not possible however to determine the importance of run-off to the recharge flux.
- The expected life expectancy of the resource under the current rate of extraction is approximately a further 10 years. The actual length of time that the freshwater lens can continue to pump at 250 ML/yr is likely to be much less because mixing will occur with the more saline groundwater that surrounds the lens.
- It is estimated based on current trends, that without a significant recharge event Trench 1 will be permanently dry before year 2010 and the salinity as EC will be ~3500 μS/cm @ 25°C (based on an observed long-term trend of +80 μS/cm @ 25°C).

INTRODUCTION

Concern over the salinity increase in the Streaky Bay town water supply, which is sourced from a small freshwater lens located in the Robinson Basin resulted in an investigation into the current state and long term prospects of the groundwater resources of the area. The first two phases of the investigation involved detailed salinity and water level logging in October 2001 (Brown and Harrington, 2001) and bore purging and chemical sampling in February 2002 (Harrington and Brown, 2002). This report presents results of the third and final stage of the investigation, and includes a model for the origin and chemical evolution of the freshwater lens and an estimate of the useable life of the resource.

The freshwater lens is located within a small (<10 km^2) thin aquifer about 10 km south east of the Streaky Bay township. It has been the sole groundwater supply for the town's reticulation system for more than 60 years (to meet demand during the last summer period an additional supply was transported in by truck daily from more than 50 km away). Groundwater extracted from the lens for the purpose of municipal supply began in 1937 with the construction of a small trench. It was followed by the construction of another trench in 1947 (Reed, 1990). Since then two small bore fields (the southern and western) and two wells (Bore 485 and Bore 20) have been added to the system.

There are approximately 65 wells in the current groundwater observation network but the majority of the wells were constructed in the mid-1980s and the network is generally in poor condition. This coupled with inferior sampling methods has created reliability issues with the historical salinity data record (Harrington and Brown, 2002).

Declining water levels in the aquifer and rising salinity of water extracted from the lens indicate a resource under stress (Brown and Harrington, 2001; Harrington and Brown, 2002). The average salinity of the town water supply on the 16 October 2001 was 2450 µS/cm @ 25^{o}C which is just below the accepted limit of 2700 µS/cm (~1500 mg/L TDS). Sampling of all production wells on that date showed the salinity of the water supply relied on the Southern borefield (EC of ~ 1380 µS/cm) to keep salinity below the accepted limit. The other extraction points ranged in salinity, measured as EC, from 2940 to 3680 µS/cm.

The trenches and production wells are all situated within a designated SA Water reserve of approximately 4 km^2. Although most of the area was originally cleared of native vegetation, controlled stock grazing and minimal agricultural activity within the reserve over the last 20 years has led to regrowth of much of the original vegetation. When compared to adjoining properties this return growth is easily delineated from aerial photography taken in 1997 (Fig. 1). The topography in the immediate area forms a small catchment enclosed by mainly remnant sand dune deposits that slope from an elevation of about 10 m in the north to north-east to about 2 m in the south-west. It is from this small catchment area that the lens derives rainfall recharge. Significant karst development in the form of dissolution features of more than 10 m in length are common, and are evident on the calcrete exposures in the lower topographic depressions. The low lying exposed karstic area is believed to be the main recharge zone for the lens.

The source of rainfall recharge to the lens is considered to be from direct precipitation and/or from surface run-off from the surrounding dunes. Recharge occurs at the lowest point in the catchment where karstic topography has developed. Therefore run-off events may contribute significantly to recharge.

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LOCALITY

Figure 1

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The lens lies within limestone, and calcareous sand and sandstone deposits. The combined thickness of these deposits ranges from approximately 15 m in the higher elevated north-east to about 7 m in the south west. The current maximum saturated thickness of the lens however ranges from zero at its perimeter to ~ 5 m in the south-west corner of the reserve. The depth to water for the aquifer ranges from ~ 9.5 m in the north-east to ~2.5 m in the south-west and generally mirrors topography. Groundwater extraction in the south-western portion of the reserve may also affect depth to groundwater levels.

A low-permeability clay aquitard (Reed, 1990) separates the calcareous sediment from an underlying highly saline (~35 000 mg/L equivalent to seawater concentration) Tertiary sand aquifer which has thickness of ~20 m beneath the reserve. Underlying both aquifers is hydrogeological basement consisting of undifferentiated granite.

RESULTS

Groundwater Hydraulics

Groundwater elevation contours for the water table aquifer in February 2002 are plotted on Figure 2. They show that a permanent cone of drawdown has developed in the south-western portion of the reserve with water levels permanently below sea level (eg. hydrograph for FOR04, Fig. 3). The hydrograph for well FOR04 shows a seasonal fluctuation of approximately 0.5 m which may indicate seasonal groundwater recharge and/or reduced pumping rates during the winter period. The hydrograph also shows a significant short term declining trend since the end of 1995. This is consistent with higher extraction rates since that time and below average rainfall since the end of 1992 (Brown and Harrington, 2001).

Groundwater Chemistry

In February 2002 a total of 17 wells were sampled for major ion concentrations, bromide, fluoride and nitrate concentrations (see Table 1). The location of each sampled well is shown on Figure 4. Field measurements for electrical conductivity (EC), pH and temperature were taken during the sampling program (Harrington and Brown, 2002).

Groundwater from the sampled wells can be sub-divided into three water types:

- Type 1: are those samples taken from wells that lie to the north-east of the main field (in pink).
- Type 2: are those samples taken from wells that lie south-west of Type 1 wells (blue), and,
- Type 3: is observation well FOR56 which is the only sampled well completed in the deeper confined sand aquifer (yellow).

Well FOR10 was not included in any of the types as the well is considered to be outside the area of the main freshwater lens.

The results of the major ion analysis of groundwaters sampled during the investigation are plotted on a trilinear Piper diagram (Fig. 5). Data from both Type 1 (in pink) and Type 2 (in blue) waters each show a distinct linear trend on the main trilinear plot.

Major cations from both Type 1 and Type 2 waters show a change from Ca as proportionally the main cation species to Na (+K) dominated. A similar trend is observable in the anion plot as the dominant species changes from HCO_3 ($+CO_3$) to Cl as the dominant anion. And while not evident from the plot, these linear trends are consistent with increasing concentration. Spatially, the change in groundwater chemistry and increasing concentration reflects increasing distance from the main recharge zone.

The Type 3 well, FOR56 has similar major ion composition to well FOR57, the north-eastern end member for Type 1 wells and well RIP013, the south-western end member of the Type 2 wells.

Nitrate concentrations of the groundwaters ranged from less than one to 26 mg/L. The highest value was obtained from RIP009 located outside the reserve and is possibly caused by livestock contamination. The recommended limit for safe drinking water for

Table 1. Summary of water chemistry analysis

Observation Well	Field EC µS/cm@25°C	Field pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^-	Cl^-	[1]SO_4^{2-}	Br^-	F^-	NO_3^-	[2]TDS	d^2H	$d^{18}O$	SIC	SID	CFC11	CFC12	CFC11	CFC12
			mg/L											mg/L	‰, SMOW				pptv		years	
FOR64	1240	7.47	113	18.9	116	3.6	0	253	246	26.8	0.86	0.29	21	651	-3.76	-23.5	0.4	0.31	109	263	1975	1979
FOR21	2040	7.41	157	31.8	197	5.7	0	404	415	42.1	1.6	0.25	9.81	1051	-4.25	-23.85	0.62	0.85	<25	108	1965	1969
FOR04	2570	6.79	147	37	316	8.6	0	365	615	51.8	2.21	0.51	8.83	1358	-4.3	-22	-0.09	-0.48				
RIP09	2770		134	45.5	371	11.5	0	335	641	73.7	2.5	0.57	26.3	1444	-4.54	-25			60	182	1971	1974
FOR27	3080	7.08	166	49.7	365	8.1	0	225	807	64.1	3.03	0.38	16.7	1572	-4.22	-25.5	0.02	-0.18	32	93	1967	1968
FOR23	3230	7.48	223	48.7	308	6.8	0	210	891	30.4	3.35	0.33	22.6	1613	-4.57	-24.5	0.52	0.69	90	238	1974	1977
FOR26	3190	7.24	259	46.4	269	6.5	0	280	836	23.6	3.31	0.25	14.4	1581	-5.18	-26.3	0.47	0.51	62	183	1971	1974
FOR20	3640	7.69	218	61	404	7.7	0	231	996	53.1	3.71	0.27	13.2	1855	-4.25	-24.4	0.73	1.22				
RIP10	3510		139	62.6	503	17	0	452	913	102	3.1	0.56	1.37	1963	-3.99	-22.9			<25	<60	<1965	<1965
FOR19	5150	7.32	364	71.1	497	8.2	0	236	1530	36.3	5.67	0.25	21.5	2625	-4.66	-26.1	0.56	0.71	89	247	1973	1977
FOR18	5070	7.44	249	86.3	631	12.5	0	278	1420	90.2	5.34	0.25	22.5	2628	-2.73	-24.4	0.6	1.05	78	195	1973	1974
FOR61	7490	7.02	298	124	1050	19.1	0	331	2260	172	8.36	0.29	20.7	4089	-4.4	-26.7	0.26	0.45	51	136	1970	1971
FOR31	11430		258	218	1900	45.1	16	478	3530	390	12.8	0.62	1.56	6596	-3.46	-21.8						
FOR57	21500		865	173	3810	75.4	0	190	7480	911	19.9	0.19	0.58	13409	-4.26	-24.2						
RIP13	50100		1100	1650	8670	109	0	736	18900	1890	68.8	0.23	1.42	32687	-3.83	-23.3			<25	<50	<1965	<1965
FOR56	48700		733	1300	10600	210	0	636	17300	2640	65.8	0.47	0.28	33101	-3.42	-20.4			<25	<35	<1965	<1965
FOR10	5270		96	112	821	30	29	423	1490	187	5.14	0.96	12.5	2977	-4.13	-24.8						

1. Total inorganic sulphur as sulphate
2. Sum of major ions less half bicarbonate

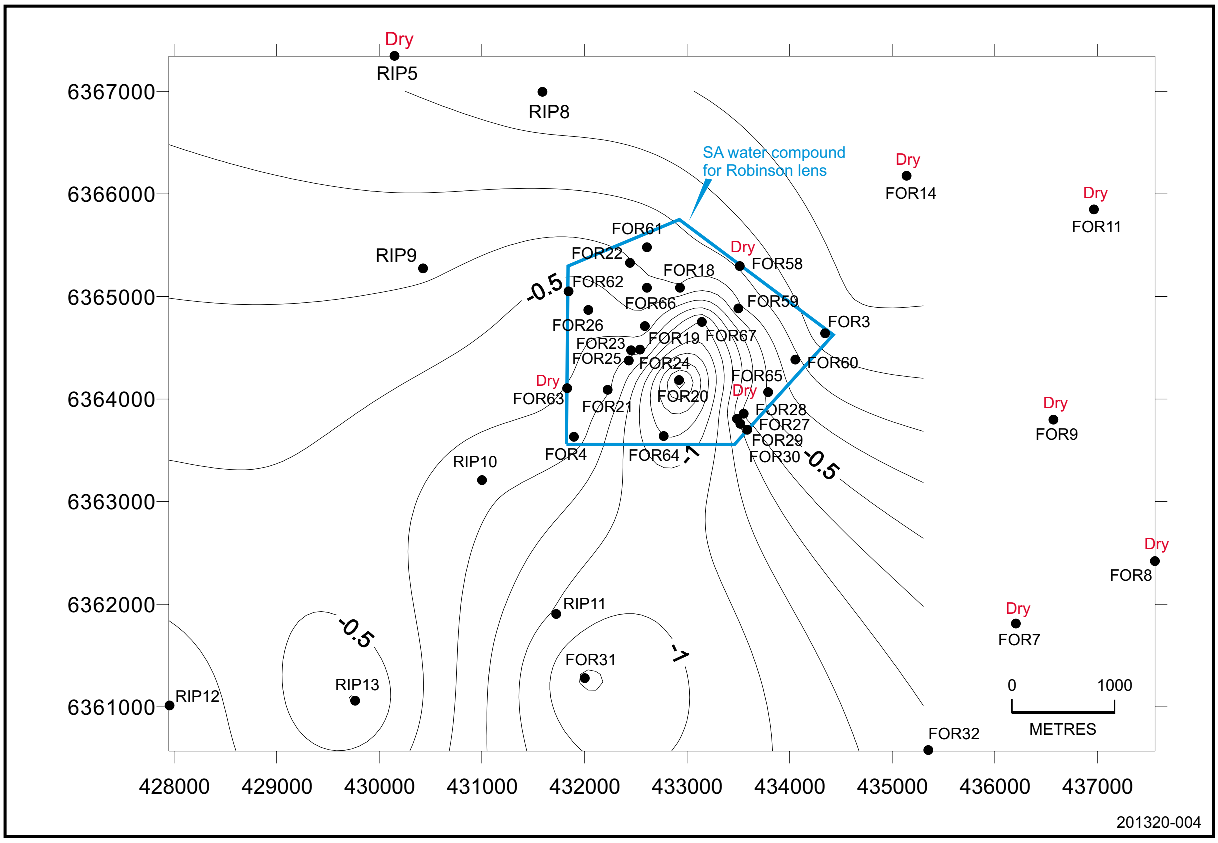

Figure 2 Watertable contour map, February 2002

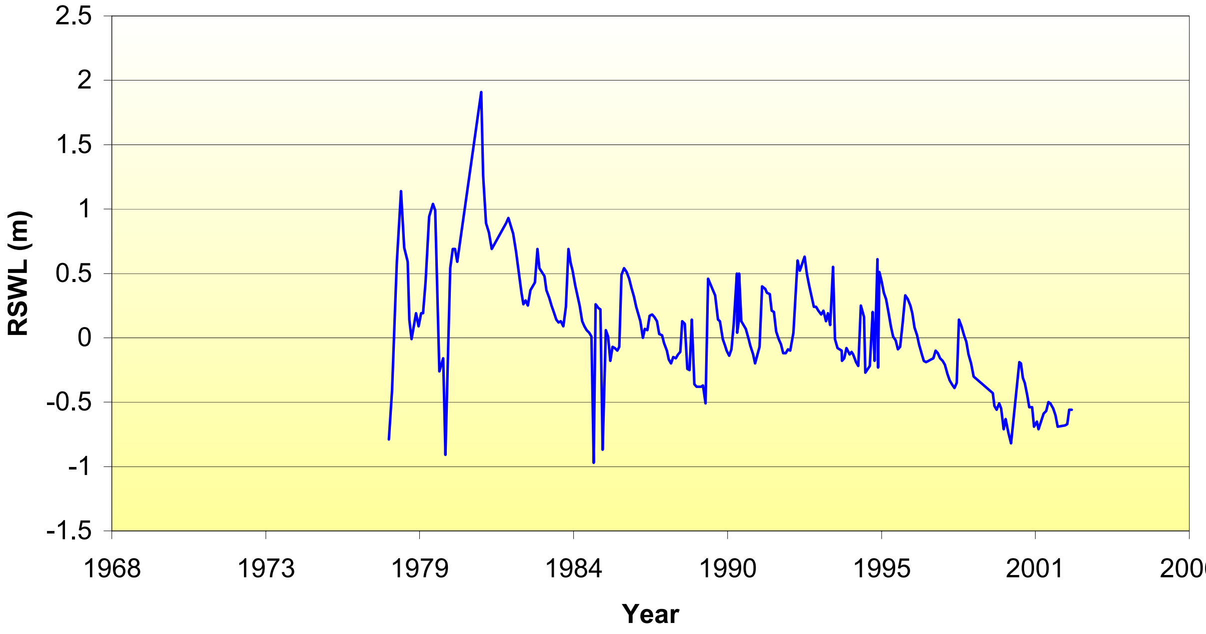

Figure 3 Observation well hydrograph for FOR 04

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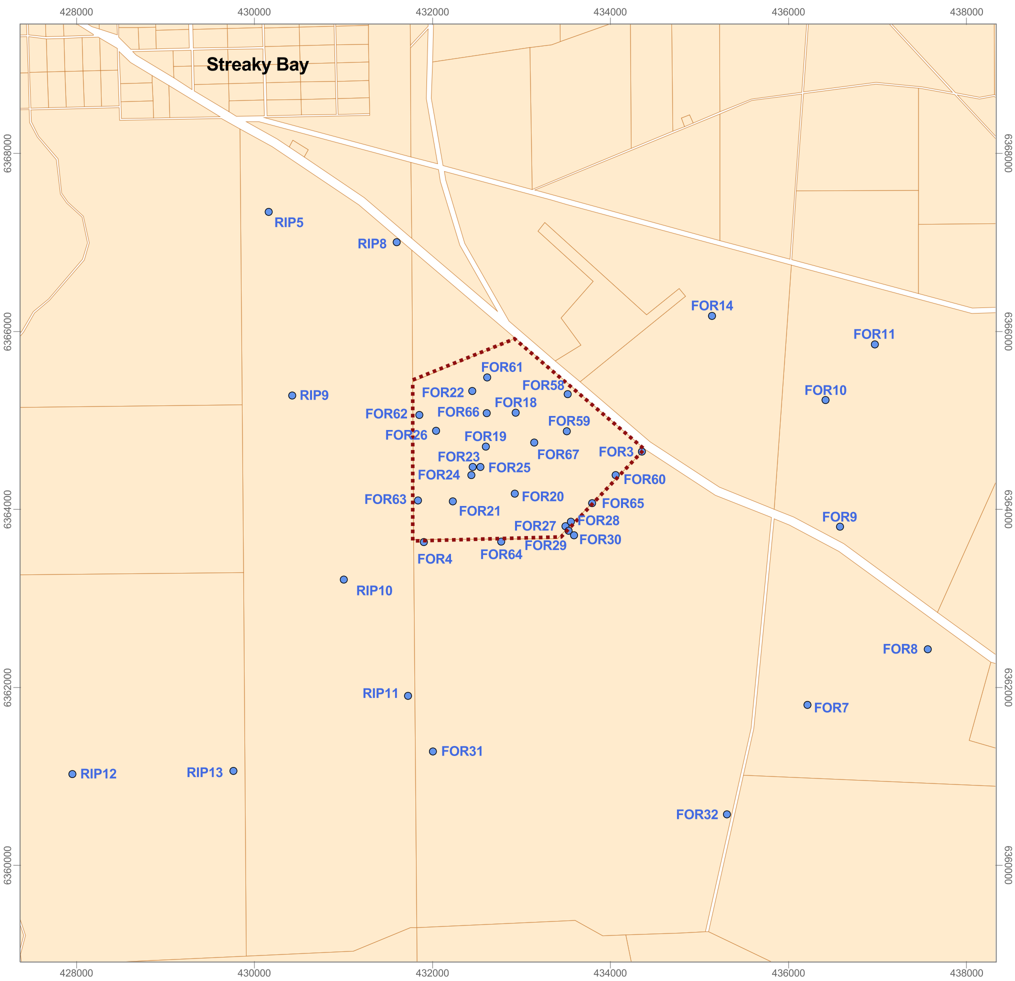

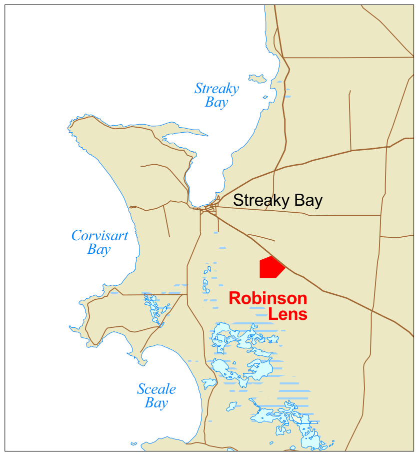

Water reserve

FOR8 Observation well and number

0 1 2 3 Kilometres

Datum GDA94 - Map Projection MGA Zone 53

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OBSERVATION WELLS

Figure 4

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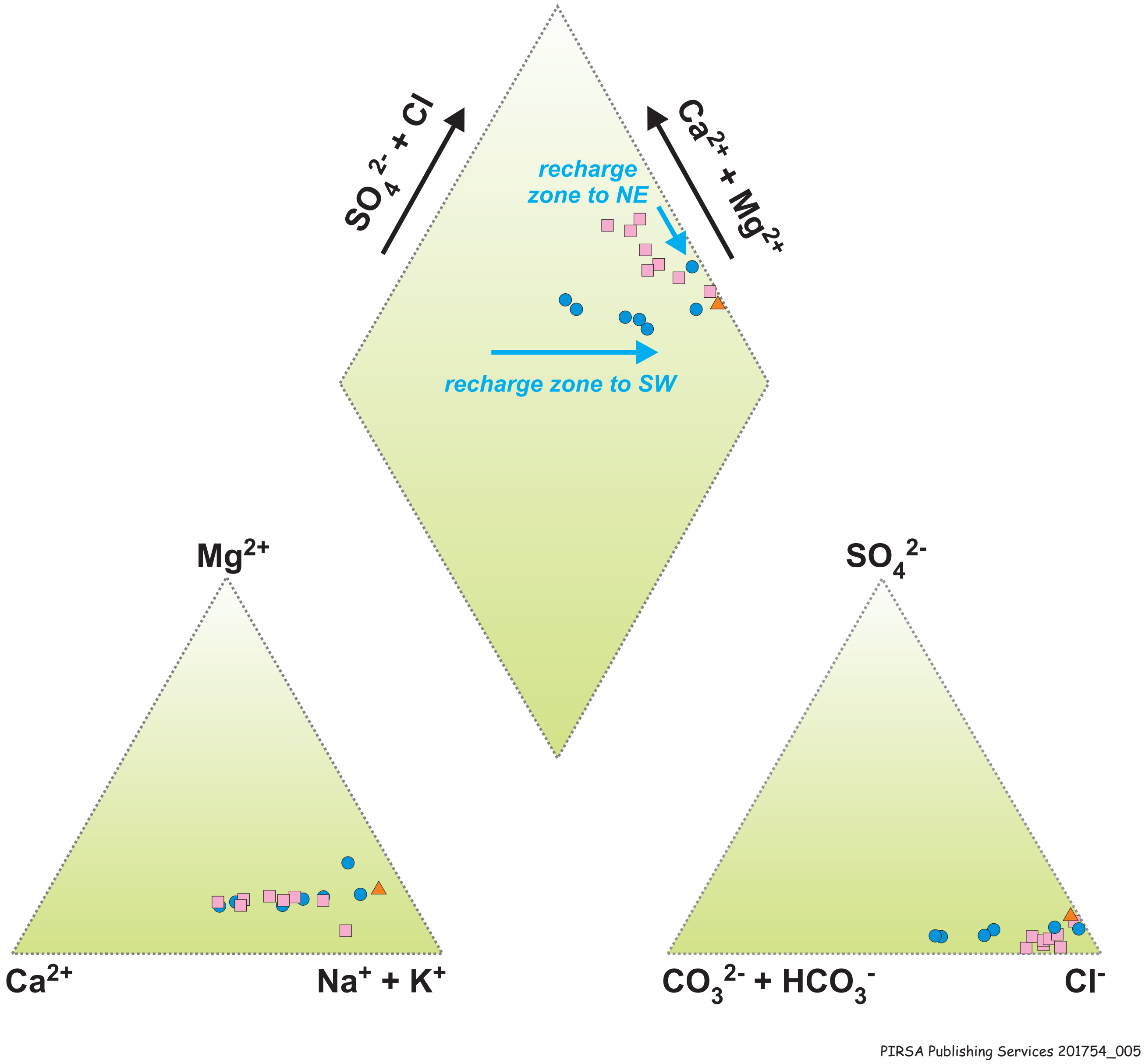

Figure 5 Piper diagram plot

Nitrate is ~40 mg/L, which is clearly higher than any measured concentrations at Robinson Lens. Therefore nitrate was not considered significant enough to warrant identification of sources.

Fluoride concentrations ranged from 0.19 to 0.96 mg/L, which are also well below the recommended limit for safe drinking water of 1.5 mg/L.

Bromide, sampled for the purposes of hydrochemical interpretation, ranged from ~1 to 70 mg/L.

Stable Isotopes

Stable isotope compositions of groundwater samples (Table 1) exhibit an approximate linear trend on a conventional δ^2H-$\delta^{18}O$ plot (Fig. 6), reflecting the strong control that evaporation has on these groundwaters. However, the degree of evaporative enrichment of the groundwater compositions is not necessarily correlated with salinity (indicated by chloride concentrations; Fig. 7). This suggests that the recharge mechanism for the fresh samples may be distinct from that of the more saline samples (discussed further below).

Unfortunately the nearest location where measurements of rainfall isotope compositions have been made is Adelaide, which has much higher mean annual rainfall than the Streaky Bay area and is often influenced by different rainfall-producing air masses. Thus comparison of Robinson Lens groundwater compositions with Adelaide rainfall compositions would not provide reliable insight to the recharge processes.

The stable isotope signatures of the most saline groundwater samples are more negative than seawater, therefore demonstrate that these waters were derived from rainfall rather than seawater, albeit the salinities are approaching that of sea water (ie. 35 000 mg/L).

Chlorofluorocarbons

CFC-11 and CFC-12 concentrations of groundwater samples from eleven of the observation wells are presented in Table 1. These concentrations have been converted into groundwater ages in terms of the year in which the samples were isolated from the atmosphere in recharge. Recharge dates range between < 1965 and 1977 and demonstrate a general trend of groundwater becoming older as sampling depth below the water table increases (Fig. 8). It should be noted that the two samples with a recharge date of 1965 are actually older than 37 years, but their true age cannot be estimated reliably as concentrations were below the limit of detection. The two samples from the centre of the freshwater lens (FOR 21 and FOR 64) and the next two nearest samples (FOR 23 and FOR 26) plot along an almost linear trend in Figure 8 (red points), corresponding to an average recharge rate of 11.3 mm/yr for this part of the basin (assuming a mean aquifer porosity of 20%). The seven other samples yield recharge rates of between 0.9 and 16.1 mm/yr, with a mean value of 8.3 mm/yr.

The spatial distribution of groundwater ages determined from CFC-12 concentrations is shown in Figure 9. The map (Fig. 9) clearly shows that the youngest groundwaters occur near the Southern borefield (FOR 64) and immediately to the north of Trench 1 (FOR 23). This trend may reflect the distribution of enhanced recharge or, more likely, mining of the youngest freshwater via the production well activity over the last 25 years.

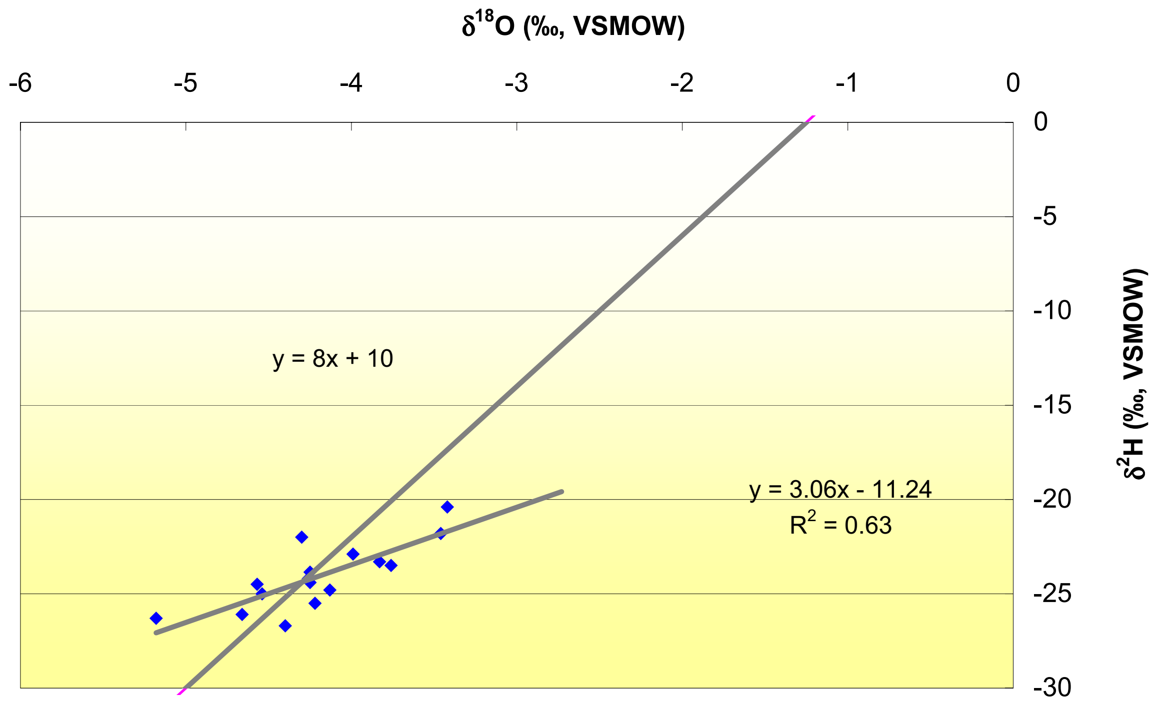

Figure 6 Deuterium vs Oxygen-18 plot

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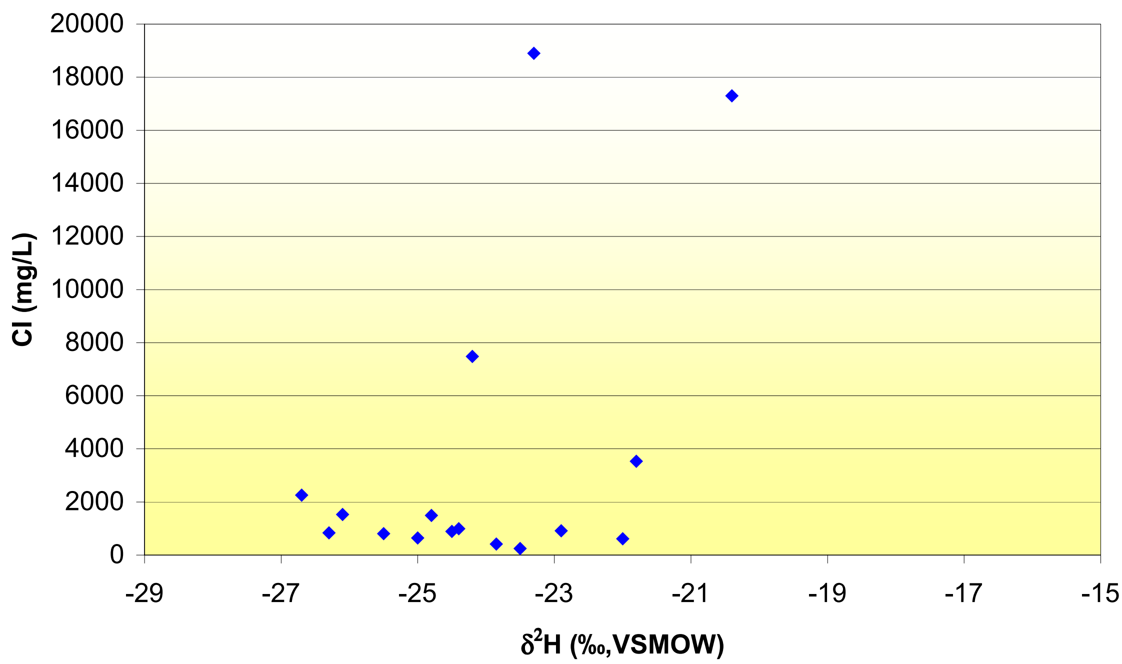


Figure 7 Chloride against Deuterium excess plot

201754_007

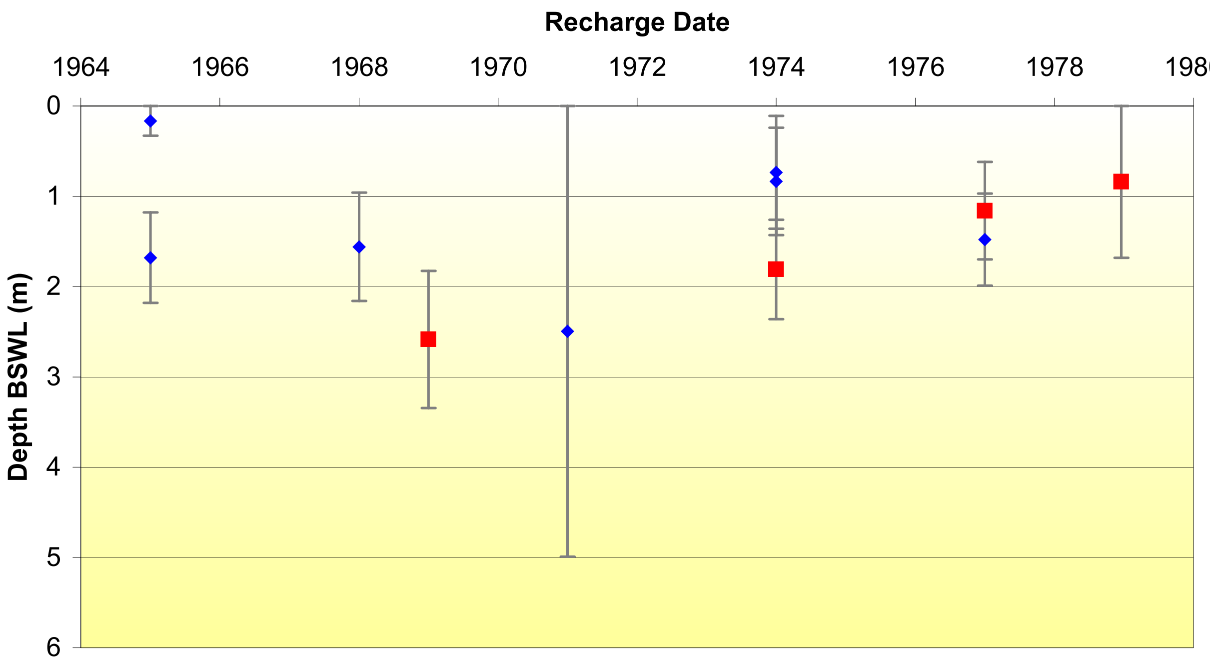
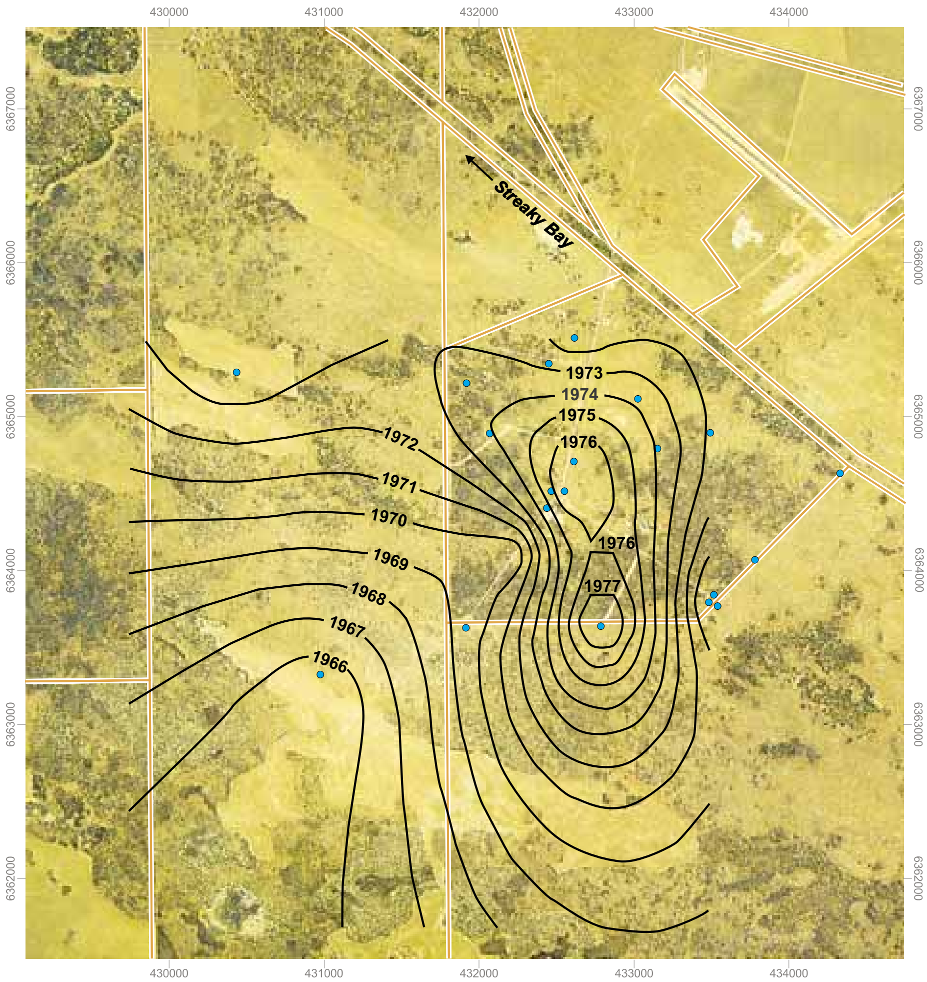
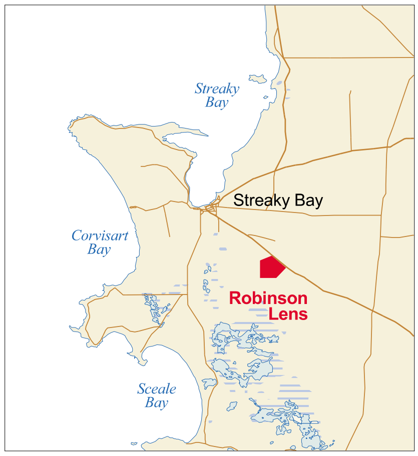


Figure 8 Recharge date against depth

201754_008





- Selected observation wells
- Spatial contours of CFC ages

0 1 2 Kilometres

Datum GDA94 - Map Projection MGA Zone 53

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SPATIAL DISTRIBUTION OF CFC AGES
(February 2002)

Figure 9

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DISCUSSION

Detailed analysis of chemical and isotopic data in conjunction with results presented in earlier reports (Brown and Harrington, 2001: Harrington and Brown, 2002) has enabled a new conceptual model to be developed for the hydrogeology of the Robinson Lens.

Evolution of Groundwater Chemistry

The main processes that can contribute salts or alter the major ion compositions of groundwater are:

- accession of salts in rainfall,
- concentration by evapotranspiration of recharge water,
- water rock interaction (dissolution/precipitation, cation exchange), and,
- mixing (between two or more water types).

From plots of TDS concentration against Cl/total anion concentration as a molar ratio the mechanisms for the chemical evolution of the groundwater lens become clearer (Fig. 10). Lower Cl/total anion molar ratios are indicative of fresher groundwaters, in this case influenced by higher bicarbonate concentrations. It is most likely that the origin of the salts in these relatively fresh groundwaters is therefore from water and rock interaction; ie. the dissolution of calcium carbonate. However the more saline waters are dominated by chloride, indicating that the chemical composition of these waters is probably dominated by the concentration of rainfall salts.

Groundwaters reach saturation with respect to calcite ($CaCO_3$) resulting in precipitation of HCO_3 at relatively low concentrations. The much greater concentrations attained during the evapotranspiration process effectively mask the effects of water rock interaction.

In terms of spatial hydrochemical processes, as the low concentration water, which exhibits the greatest contribution of salts from water rock interaction (in the lens recharge zone), moves outward, concentrations increase as the fresher water mixes with the more highly concentrated surrounding groundwater. The high salinity groundwater near the boundary of the lens probably reflects significant alteration of rainwater by evaporation. These two processes form two end members of the water chemistry spectrum of the lens; the low concentration Ca-HCO_3 dominated waters in the recharge zone and the high salt concentration Na-Cl waters form the perimeter of the lens.

The data presented in Figure 10 are grouped as one of the previously identified three water types (pink symbols for Type 1, blue for Type 2 and yellow for Type 3, the confined aquifer). Well FOR57, the farthest sample point in the north-east has the highest TDS concentration and the highest Cl/major anion ratio for the Type 1 wells. TDS and Cl/major anion ratios decrease concurrently in a south-westerly direction in the Type 1 wells towards the central part of the Lens. The opposite trend occurs in the Type 2 waters: TDS increases from low concentrations and low molar ratios to high TDS and high molar ratios south westward away from the centre of the lens. The diagram therefore shows the third main process that can influence groundwater chemistry, that of mixing between the two end members.

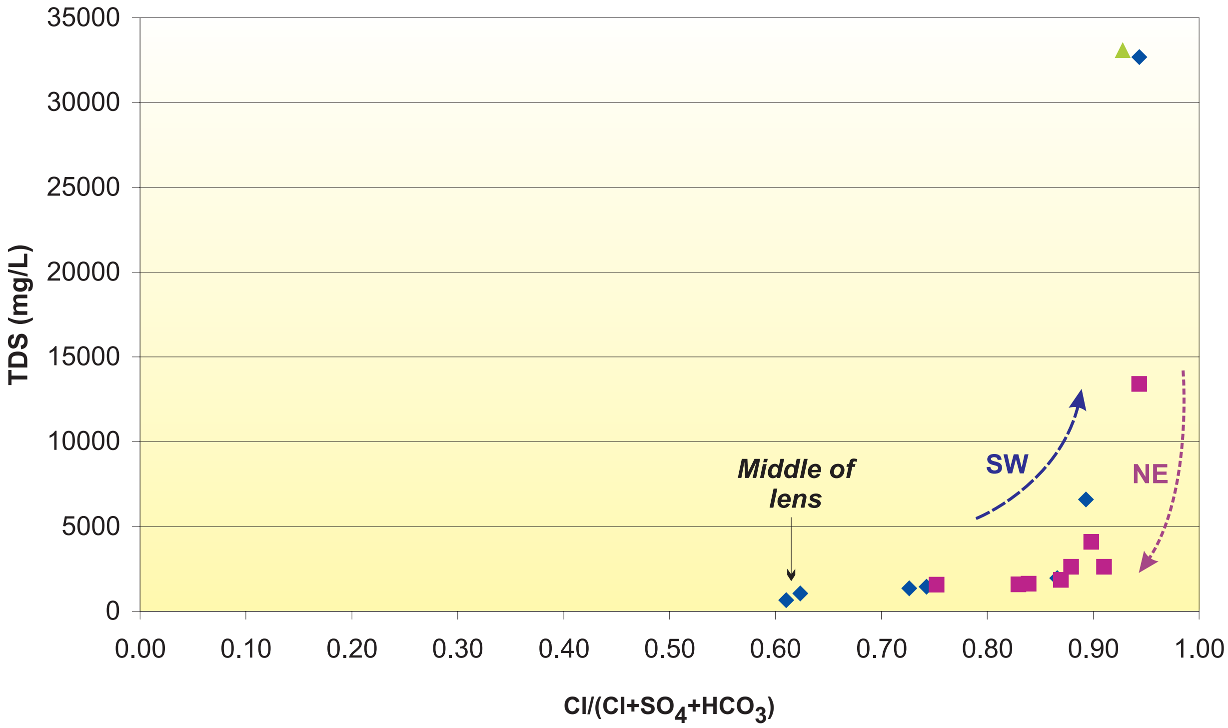

Figure 10 TDS against Cl/sum of anions plot

201754_010

Plots of major ions/Cl molar ratios against Cl concentrations can also help identify hydrochemical processes influencing groundwater chemistry (Fig. 11 (a-g)). The data is again divided into the three water groups. Each plot also shows the sea water ion/Cl dilution line. Bromide to chloride molar ratios form an almost linear trend when plotted against the extraction (Fig. 11(f)) and are close to the seawater ratio (1.57×10^{-3}) which suggests little input of chloride to the system from any water rock interaction process. Therefore chloride is considered to be behaving conservatively within the groundwater system.

The data points generally form a curved line on all respective ion/Cl versus Cl concentration plots. This trend is most apparent for calcium, bicarbonate and sulphate. Curved trends in these plots are most indicative of mixing of waters between different "end member" ion/Cl compositions and, to a lesser extent, water rock interactions.

With the exception of groundwaters from well FOR4 for calcite, and wells FOR4 and FOR21 for dolomite, all the remaining waters are saturated with respect to these minerals. Sulphate/Cl ratios in Type 1 and Type 2 waters are below that of equivalent seawater concentrations but none of the waters are saturated with respect to gypsum ($CaSO_4$). It is unlikely therefore that the below seawater ratios are a result of precipitation of gypsum. Similarly, potassium is also depleted with respect to seawater ratios, particularly in the Type 2 waters. It is possible that meteoric water entering the groundwater system does not have the same chemical composition as the standard sea water concentrations.

Origin of freshwater lens

Water table contour maps produced prior to the introduction of pumping (pre-1937) suggest groundwater flow was generally from the north-east to the south-west in the vicinity of the present well field (Segnet and Dridan, 1938). The maps however were created using only a limited number of data points and covered all of the Robinson Basin. With so few data points it was not possible to delineate the extent and shape of the freshwater lens within the Basin, even though it was known to exist. Based on this information Segnet and Dridan, (1938) suggested recharge to the freshwater lens was from highland areas to the north-east of the present wellfield and that the freshwater lens formed a thin layer that sat immediately on top of the highly saline water.

Segnet and Dridan (1938) did not however identify the low permeability aquitard that acts as a barrier separating the freshwater lens from the underlying high salinity groundwater. While hydraulic continuity is inferred from their map it is misleading because the calcareous sediments are not saturated in most of the areas to the north-east and east of the lens.

As a result of this study using an integrated hydraulic and hydrochemical approach a new conceptual hydrogeological model for the origin and evolution of the freshwater lens in the Robinson Basin prior to the implementation of extraction can be presented (Fig. 12). This hypothesis explains why the lens is located where it is and how it has responded to the effects of extraction.

Recharge to the lens probably occurs in a relatively small area, most likely where karstic topography has developed in the areas of lowest relief in the sub-catchment. $Ca\text{-}HCO_3$ waters of low concentration dominate this zone and are typical of recharge waters found in other parts of the world. The groundwater flow direction prior to the introduction of

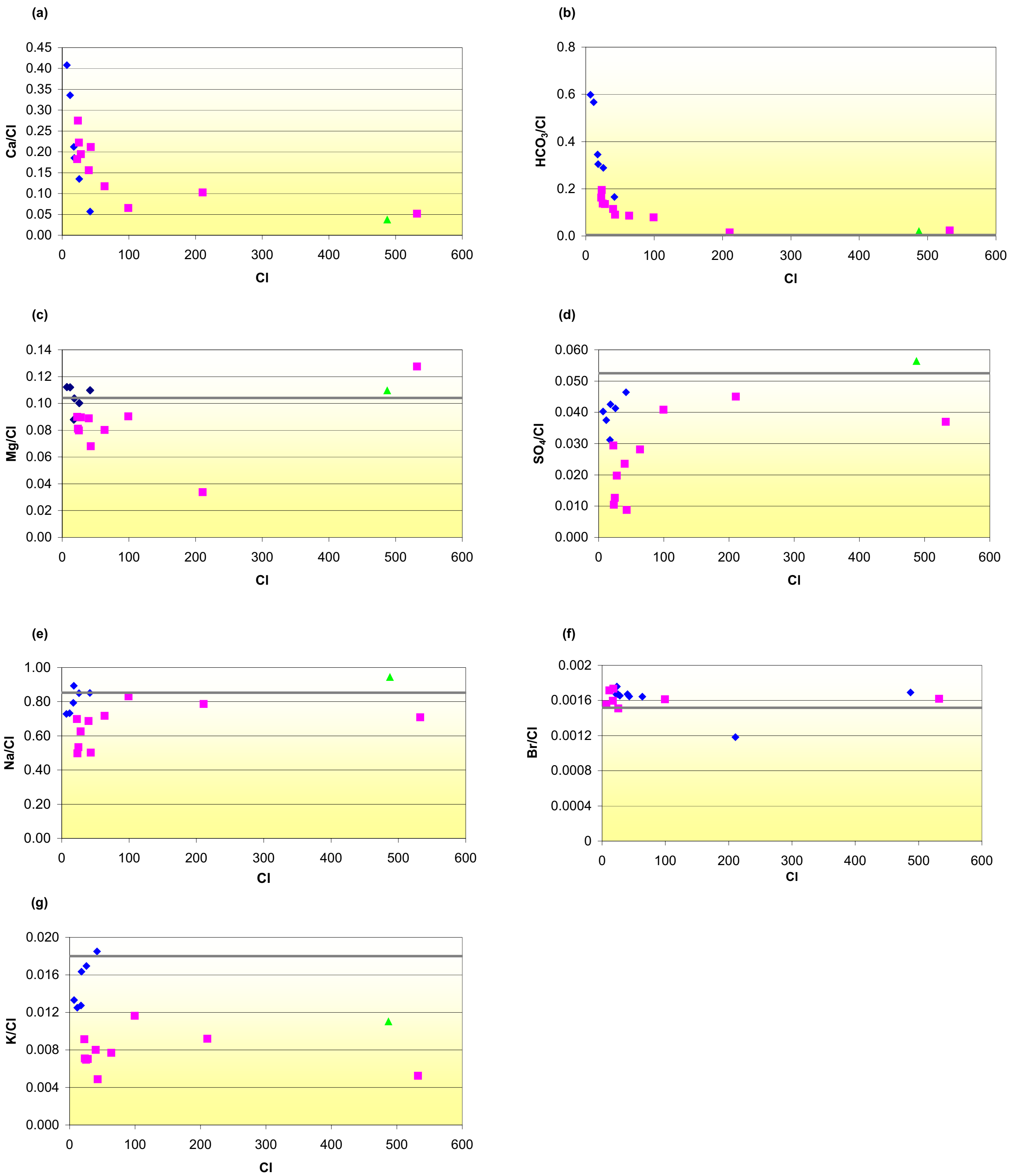

Figure 11 Major ion/Cl against Cl plots

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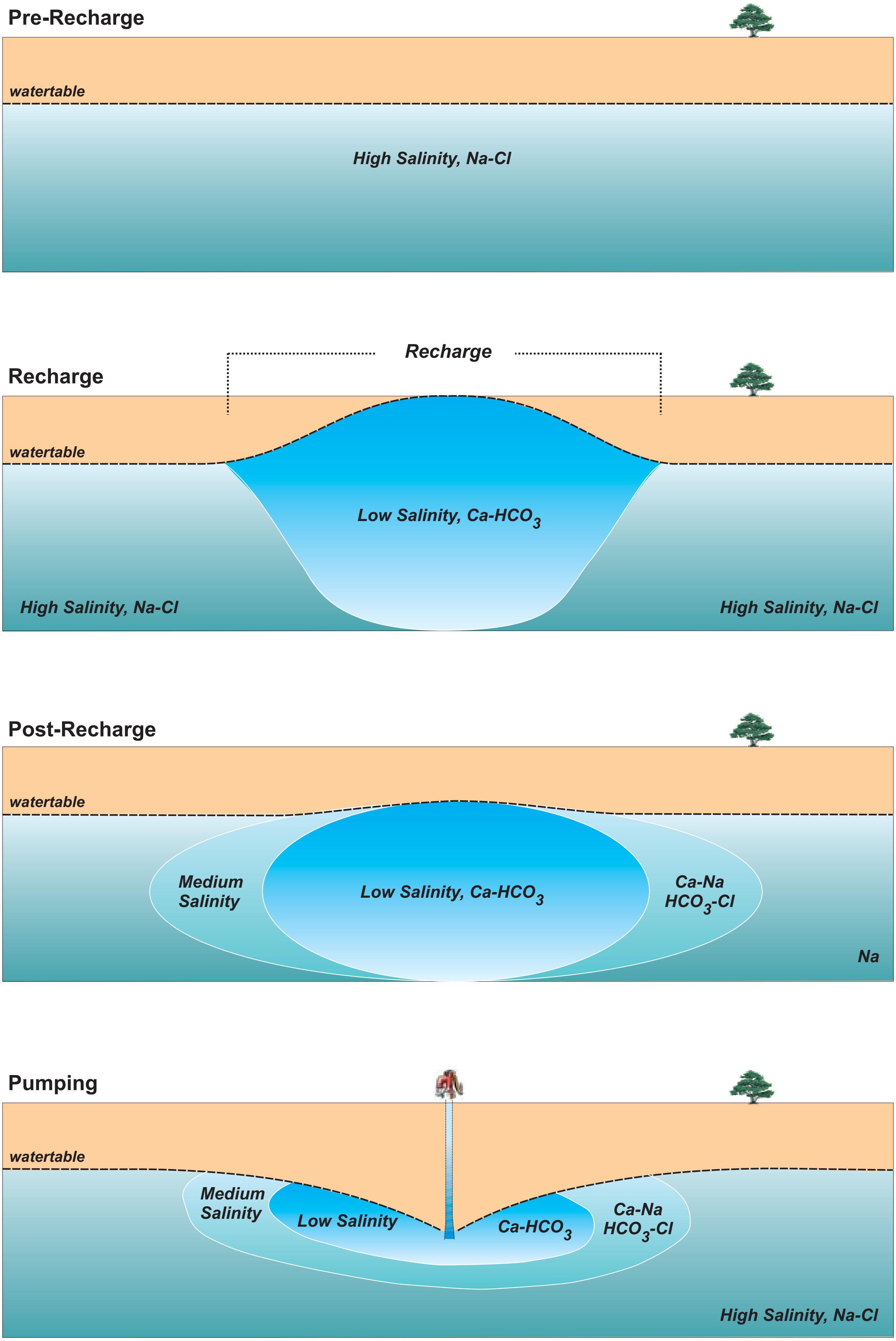

Figure 12 Conceptual groundwater model for the freshwater lens.

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pumping would have been radially outward away from the recharge zone. These waters sit on top of the more saline Na-Cl dominated waters but are also separated by an aquitard. Since the introduction of pumping, a permanent drawdown cone has developed. This has resulted in a reversal in head gradient and a contraction in the size of the lens. Subsequent sampling of waters shows mixing between these two end members.

This new conceptual model particularly recognises the importance of the following in the evolution of the lens:

- the enclosed nature of the sub-catchment and its elevation,
- the sub-surface geology that isolates the lens from underlying highly saline water and does not allow for the lateral inflow of more saline water from aquifers to the east and north-east,
- the karst topography developed in the low lying areas of the sub-basin which forms a natural recharge zone for the lens, and,
- the impact pumping has had on the hydraulics of the freshwater lens and on the chemistry of the lens as it has contracted in size.

Lens Dynamics

An observation well network was established in the late 1970s approximately 40 years after extraction from the lens began. Therefore it is not possible to determine the full impact of pumping on water levels in the immediate vicinity of the production wellfields. However data from Trench 1, all though limited (FOR01, Fig. 13), shows a long term decline in water level and also a rising salinity trend. Extrapolation of trendlines for both water level and salinity indicates that the water level will fall below the base of the trench in by approximately 2009 and the EC will be ~ 3500 μS/cm (pump water level would be less). There are a number of simplistic assumptions in these estimates and hence are only a first estimate of the long term trend.

The observation well data from 1978 shows a permanent cone of depression has developed in the central part of the lens primarily as a result of the high extraction volumes and recent below average rainfall (Fig. 2).

As previously discussed, the reliability of the groundwater salinity data taken from most observation wells prior to this study is questionable. However samples taken from the production wells (eg. Trench 1) should be satisfactory as both trenches have been in continuous use and obtained while pumping was occurring from each trench. The salinity-time graph for Trench 1 (Fig. 13) shows a disturbing but not unexpected long-term salinity increase of more than 80 μS/cm/year.

The shape of the groundwater lens with EC < 2500 μS/cm (Fig. 14) is poorly correlated with spatial distributions of different vegetation, soil or geology types. There is a reasonable correlation between topography and the shape of the lens (Fig. 15). However, the present shape of the lens probably reflects the pumping regime as much as the recharge distribution. The shape of the CFC recharge date distribution (Fig. 9) may also be reflecting various pumping regimes from the production wells over the last 25 years.

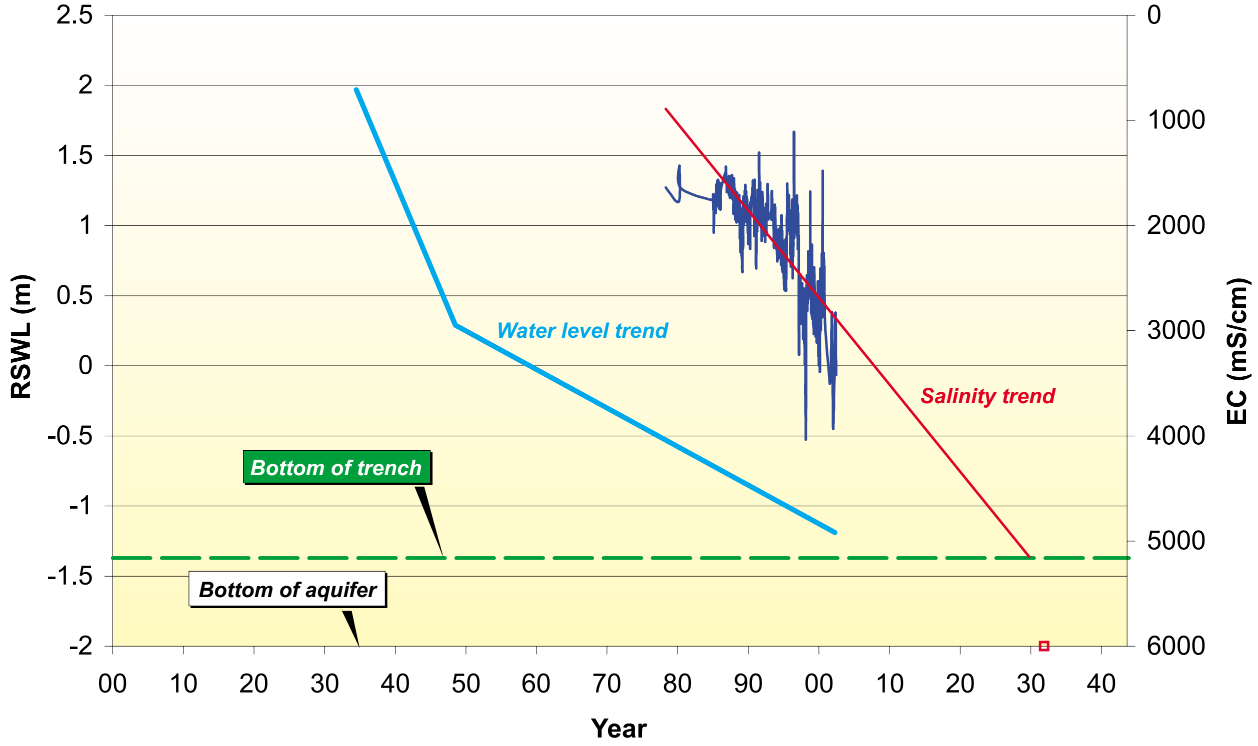

Figure 13 Observation well hydrograph for FOR01

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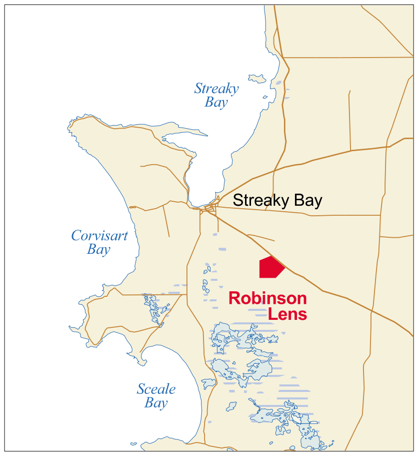

Selected observation well

Electrical conductivity (μS/cm@25°C)

0 1 2 Kilometres

Datum GDA94 - Map Projection MGA Zone 53

Government of South Australia

The Department of Water, Land and Biodiversity Conservation

Dynamic behaviour of a stressed, semi-arid groundwater basin, Streaky Bay

SALINITY CONTOUR MAP

(February 2002)

Figure 14

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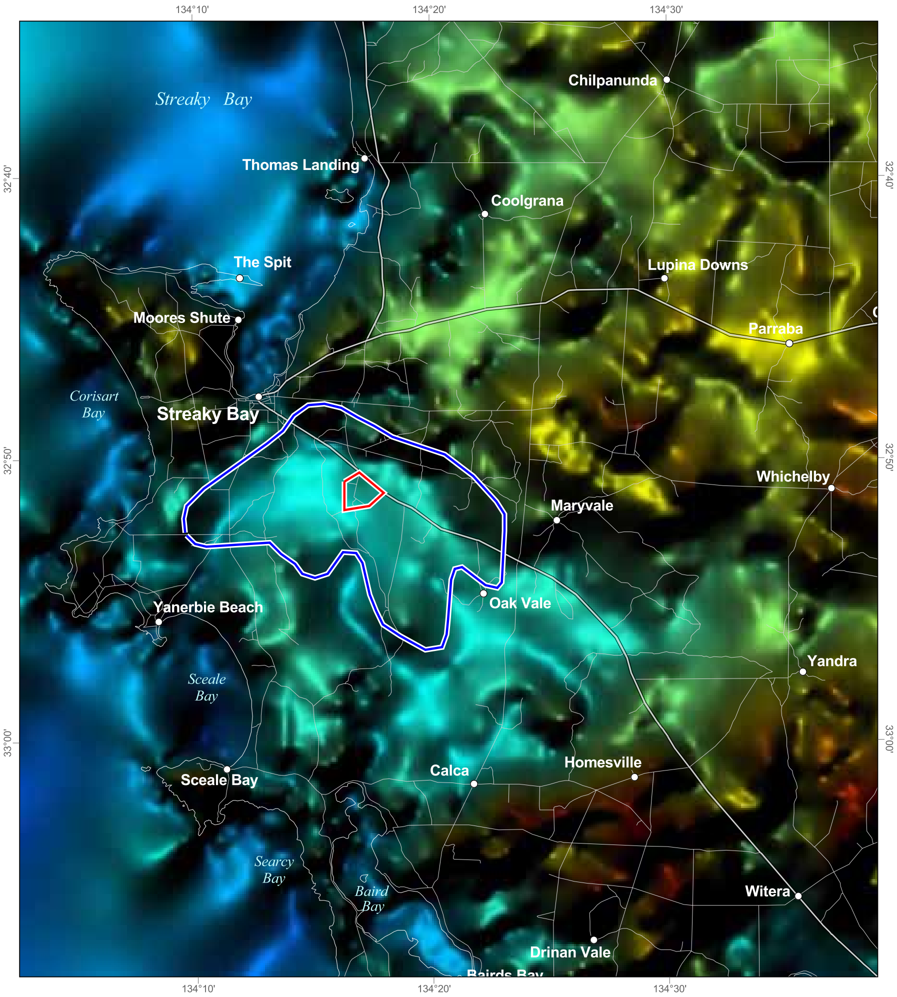

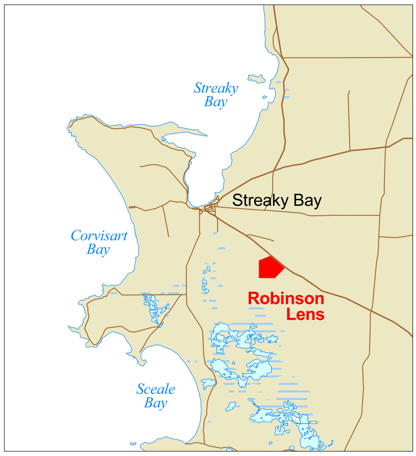

Water reserve

Approximate extent of sub-catchment

0 5 10 15 Kilometres

Datum GDA94 – Map Projection Equidistant Conic

Government of South Australia

The Department of Water, Land and Biodiversity Conservation

Dynamic behaviour of a stressed, semi-arid groundwater basin, Streaky Bay

REGIONAL TOPOGRAPHIC SURFACE

Figure 15

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Long term outlook for the Robinson Lens

The groundwater hydrographs, chemical trends and distributions of CFC ages and EC all suggest that the dynamics of the Robinson Lens are completely controlled by occasional, episodic recharge events and subsequent continuous pumping of the fresh groundwater resource.

Without a significant recharge event, the maximum lifetime of the existing freshwater resource (2777900 m^2 of groundwater with EC < 2500 μS/cm) at the current rate of annual extraction (~ 250 ML/yr) is ~ 10 years (assuming a saturated aquifer thickness of 3 m for the area underling the lens).

The real length of time that this fresh groundwater lens can continue to be pumped at 250 ML/yr is likely to be much less than 10 years because of mixing with the surrounding saline groundwater. Such processes could be modelled using a numerical code such as MODFLOW to provide a more realistic estimate of the lifetime of the resource, however there is currently insufficient aquifer data available for reliable calibration of this type of model.

An alternative mechanism for managing the freshwater lens to ensure long-term sustainability is to decrease current extraction rates to match the mean annual recharge flux for the lens. The mean recharge rate determined from CFC-12 ages and sampling depth information for samples collected within and near the 2500 μS/cm boundary was 11.3 mm/yr (see above). This value equates to a mean recharge flux of approximately 31 ML/yr or just 12.5% of current annual extraction volumes.

CONCLUSIONS

Unlike previous studies into the Robinson Basin freshwater lens, this investigation included the use hydrochemical data and environmental tracers. This information proved vital and, in conjunction with the hydraulic data enabled a conceptual model depicting the genesis of the lens and the impact pumping has had on the system. This report includes the results of the third and final phase of an investigation into the state of the Robinson Basin freshwater lens from which the following conclusions are summarised below:

- The freshwater lens in the Robinson Basin has been supplying reticulated groundwater to the residents of Streaky Bay since 1938. As the township has grown an ever increasing demand has been placed on a limited water resource. Results from the investigation show the lens can not meet the current water demand requirements of the township. It can be concluded that the condition of the lens has been greatly reduced over the sixty or so years that it has been used for a town water supply. Declining water level trends and increasing groundwater salinity show an aquifer under severe stress. The long-term forecast for the aquifer is not good. A maximum of 10 years of effective life, at the current rate of extraction is predicted, but collapse of the system is likely to occur much earlier.

- Relationships between major ion concentrations suggest a dominance of Ca-HCO_3 waters with low concentrations in the main recharge zone are a result of water rock interaction predominantly controlled by the dissolution of Ca-carbonate. The chemistry of the water changes to Na-Cl waters at high concentrations as water has moved outward and away from the main recharge area. The Na-Cl waters are probably a result of the evapotranspiration of localised meteoric water. This is supported by stable water isotopes, which show the highly saline groundwater that surrounds the lens is not connate seawater. These Ca-HCO_3 and Na-Cl waters are two end members that are increasingly mixed as the groundwater moves away from the main recharge zone to the outer edges of the lens.

- The main controlling factors that have resulted in the formation of the lens are considered to be the shape of the sub-catchment, the sub-surface geology and the karst topography of the recharge zone.

- CFC-12 groundwater ages were used to obtain estimated recharge rates of 11.3 mm/yr in the main recharge zone. In surrounding areas the estimated recharge rate ranged between 0.9 and 16.1 mm/yr.

RECOMMENDATIONS

From the results of this investigation it is recommended that the annual permissible extraction volume from the freshwater lens be reassessed as a priority. The new extraction volume should take into consideration degradation that has occurred to the resource as a result of long-term over extraction and that the average annual recharge rate be used as the basis for future sustainability calculations.

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