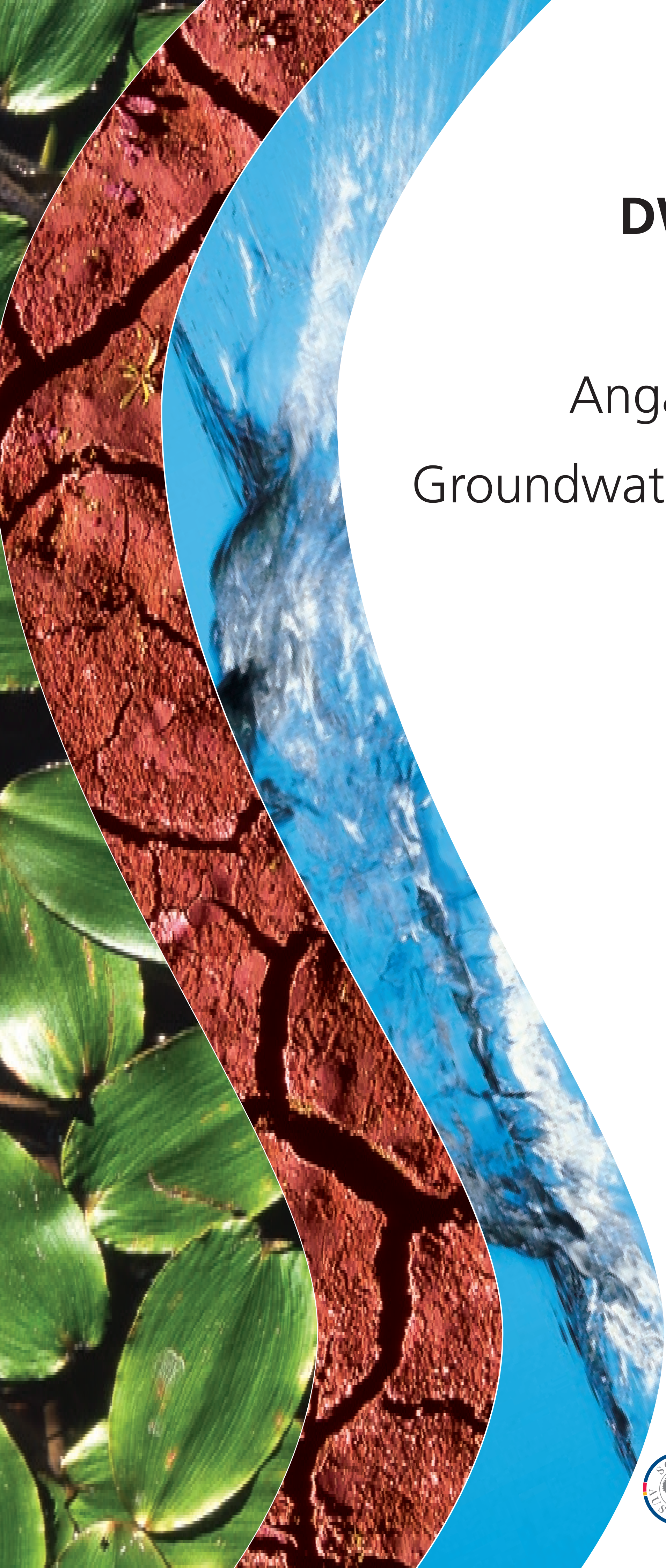

DWLBC REPORT

Angas Bremer PWA Groundwater status report 2007

2007/27

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Angas Bremer PWA
Groundwater Status Report 2007

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Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

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Report DWLBC 2007/27

Government of South Australia
Department of Water, Land and Biodiversity Conservation

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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1. INTRODUCTION

The Angas Bremer Prescribed Wells Area (Angas Bremer PWA) is located 16 km southeast of Strathalbyn and is bounded by the Mount Lofty Ranges (MLR) to the northwest and Lake Alexandrina to the south (Fig. 1). It occupies an area of ~250 km^2 and with the Angas Bremer Irrigation Management Zone (ABIMZ), extends to 344 km^2.

Groundwater resources have been extensively used for the irrigation of lucerne since the late 1950s. The area has undergone significant changes in land and water use since then. Currently, 75% of the total irrigated area is used for viticultural activities (Annual irrigation report 2004/05), and since 1990, groundwater extractions have been significantly reduced and have been substituted by River Murray water. The previously intensive groundwater development and the adverse impacts it had on the resource have resulted in a challenging environment for the irrigators and the management of groundwater resource.

In order to inform the development of the new water allocation plan (WAP) for the Angas Bremer PWA, analysis of groundwater level and salinity trends have been undertaken by the Department of Water, Land and Biodiversity Conservation (DWLBC).

The objectives of this report are to determine the long-term and short-term trends in groundwater condition, and to understand the drivers of these trends by undertaking a detailed assessment of groundwater monitoring data.

The agreed scope of work includes:

- Brief description of hydrogeology.
- Analysis of rainfall trends.
- Collation of groundwater use and allocation data, including available data on aquifer storage and recovery (ASR) activities.
- Collation of time-series information from groundwater level and salinity monitoring data for Quaternary and Murray Group Limestone (MGL) aquifers.
- Preparation of potentiometric surface contour maps for the winter 2006 and summer 2006–07.
- Preparation of salinity contour maps for 2006–07.
- Analysis of groundwater level and salinity trends.
- Estimation of a level of extraction that presents a low level of risk to the resource.

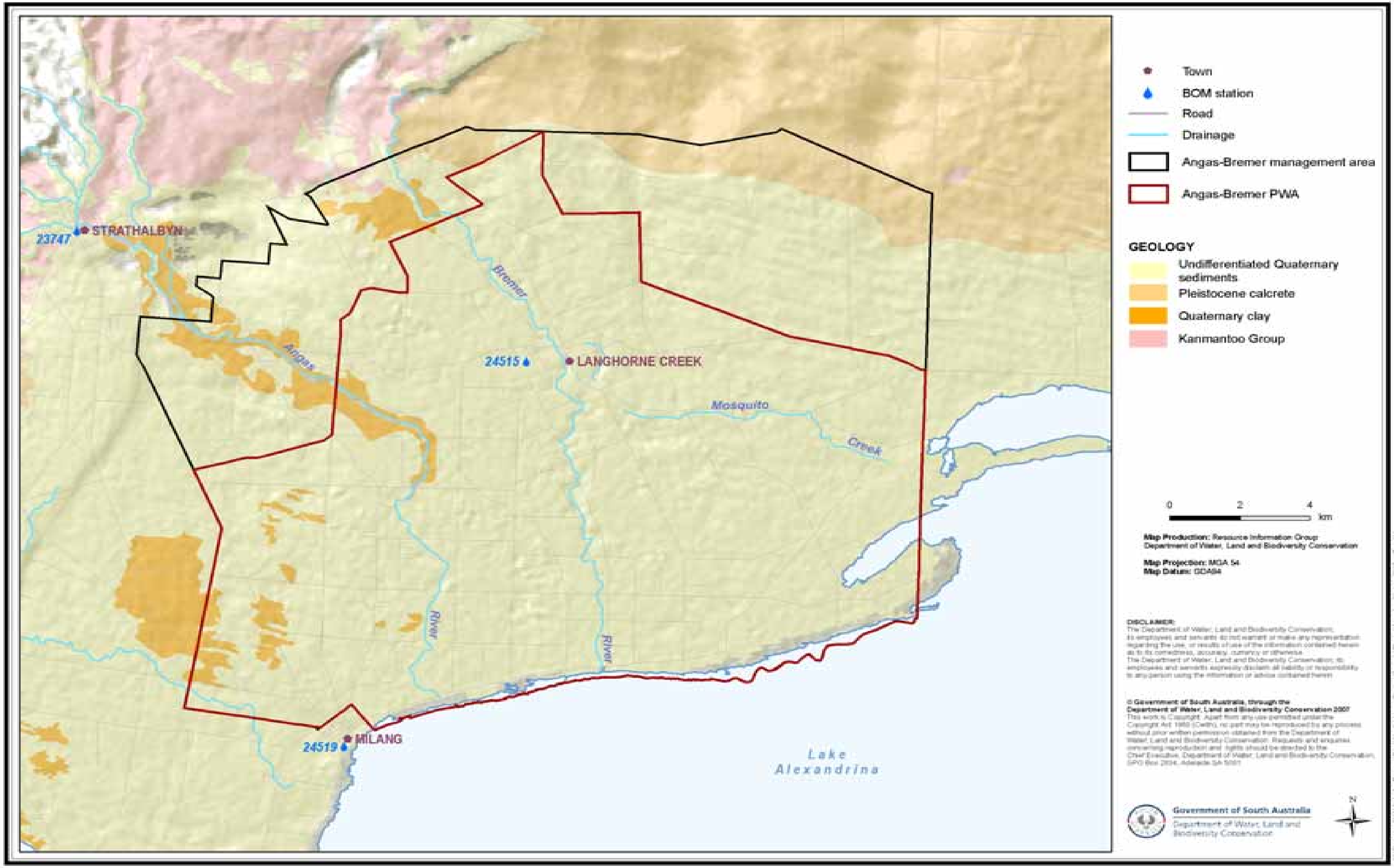


Figure 1 Angas Bremer PWA location map

2. HYDROGEOLOGY

The AB PWA occupies ~250 km^2 of the western margins of the Murray Basin, where Quaternary and Tertiary sediments are deposited over the Cambrian basement (Fig. 1).

Four aquifers are recognised within the area:

1. Unconfined/confined Quaternary aquifer.
2. Confined Tertiary Murray Group Limestone aquifer.
3. Confined Renmark Group aquifer.
4. Fractured Rock aquifer (Kanmantoo Group).

Table 1 presents a summary of the lithologies of these aquifers, and a simplified NW-SE cross section is presented in Figure 2. In addition, two confining layers occur - clayey members of the Quaternary sediments act as the confining layer to the Murray Group Limestone (MGL) aquifer, while the Renmark Group aquifer is confined by up to 5 m thick marls of the Ettrick Formation.

2.1 QUATERNARY AQUIFER

An aquifer system has developed within a 10–20 m thick sequence of Quaternary sediments, which consist mainly of clays, silt, sands and occasional gravels. In some areas, this aquifer system is unconfined, while in the others it is confined. In the northwest part of the AB PWA, the Quaternary sequence can be up to 35 m thick with the continuous gravel beds. In the central zone, it is represented mainly by clay, with minor discontinuous sand and gravel members (Waterhouse et al, 1978). To the south and southeast, the Quaternary sequence is thinner (~10 m) but consists of coarse material and is characterized by the absence of clay.

The Quaternary aquifer is generally highly saline with low yields and has limited use. Good quality groundwater is only found within narrow zones of rapid recharge, which occur along the Angas and Bremer Rivers during flooding events, and also laterally from the Mt Lofty Ranges (Australian Water Environments, 2000). Recharge from infiltration of rainfall is considered to be insignificant (Howles, 1995). The prevailing groundwater flow direction is from northwest to southeast.

Part of the Quaternary sequence forms a thin confining layer, which is considered to be effective in the north, but not very effective in the south (Howles, 1995).

2.2 MURRAY GROUP LIMESTONE AQUIFER

The confined MGL aquifer is up to 100 m thick and varies in composition from soft clayey limestone, hard sandy limestone to soft bryozoal layers. Irrigation supplies are generally obtained from the fossiliferous limestone member, which can be cavernous in some areas. Well yields vary from ~5 L/s in the north, to over 15 L/s to the south (Waterhouse et al, 1978). Occasionally, yields of up to 40 L/s can be obtained. A number of aquifer tests have determined that transmissivity varies from less than 100 m^2/day north of Langhorne Creek, to over 500 m^2/day in the south. Locally, values as high as 1500 m^2/day have been obtained in cavernous areas.

This aquifer is the main source of irrigation supplies, with suitable quality limited to relatively narrow zones parallel to the Angas and Bremer Rivers, where salinity ranges from 1500 to 3000 mg/L. Towards the margins of the basin, salinities can be as high as 10 000 mg/L.

The main source of recharge to the MGL aquifer is believed to be lateral recharge at the northwestern boundary with the MLR (Australian Water Environments, 2000). Some recharge occurs through vertical leakage from the overlying Quaternary aquifer, where the aquitard is absent or less effective. Similar to the Quaternary aquifer, the general groundwater flow is northwest to southeast.

Table 1 Stratigraphy and hydrostratigraphy of the Angas Bremer area

AGE	STRATIGRAPHY		HYDROGEOLOGY
	Unit	Lithology	Description
Quaternary	Various Quaternary sediments	Alluvial and lacustrine clays, sands, silts with occasional gravels	Unconfined / confined aquifer, salinities range up to 20 000 mg/L. Low yields (< 5 L/s) for stock water supply only.
		Clay, sands and silts	Confining layer
Tertiary	Murray Group	Fossiliferous limestone with sandy and marly interbeds	Confined aquifer, salinities range from ~1000 to 10 000 mg/L, yields 5–40 L/s. Main source of groundwater irrigation supplies.
	Ettrick Formation	Glauconitic, fossiliferous marl, calcareous clay and mudstone, silt and fine quartz sand	Confining layer
	Renmark Group	Sandstone, carbonaceous sand, silt, clay and lignite	Confined aquifer, not used extensively for irrigation due to low yields and discontinuous nature.
Cambrian	Kanmantoo Group	Metamorphosed sandstone, siltstone, greywacke	Poor aquifer, generally with high salinities and low yields.

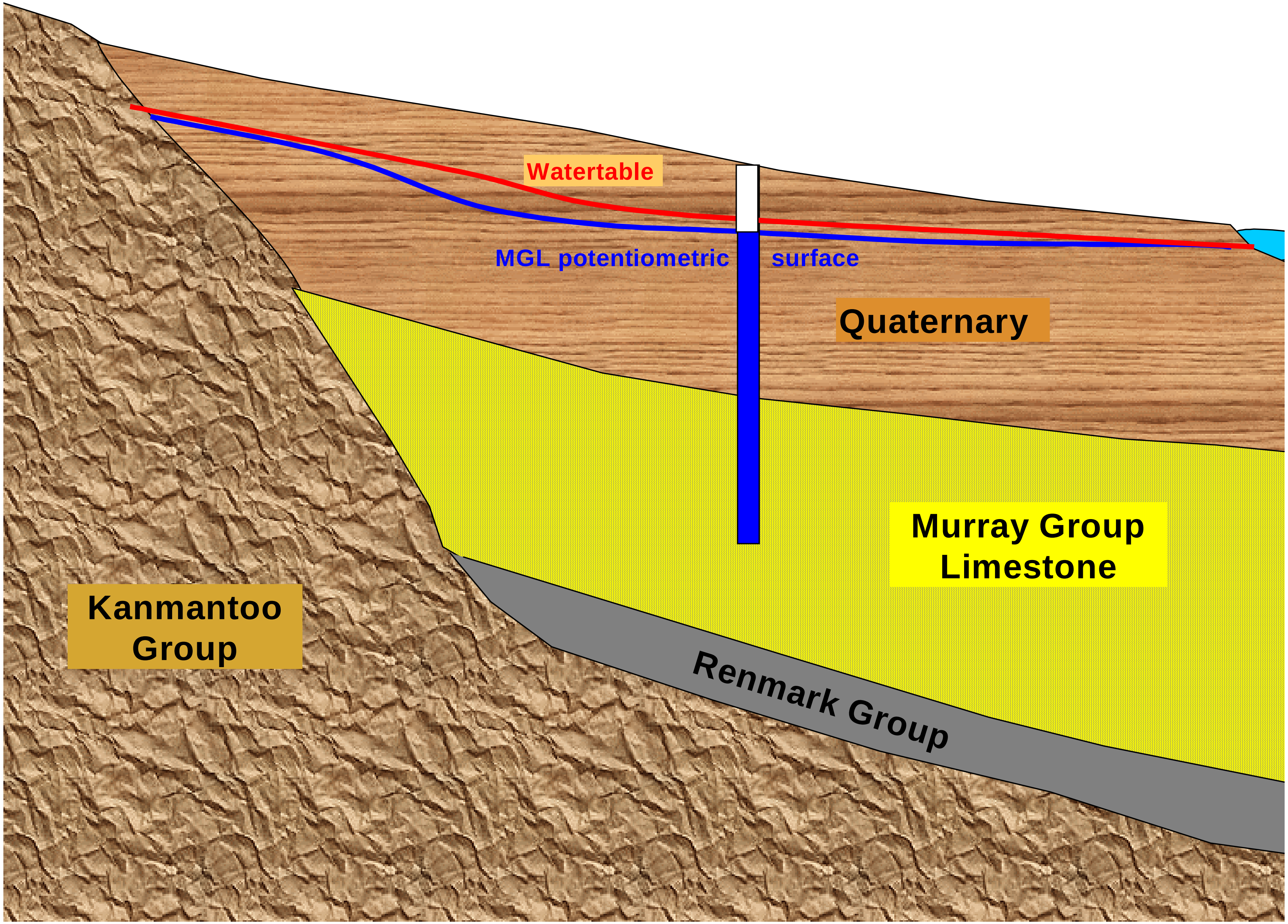


Figure 2 **Simplified geological cross section**

3. MONITORING NETWORK

A groundwater monitoring network in the Angas Bremer PWA was established in the late 1960s in response to falling groundwater levels and rising salinity. Currently there are 86 observation wells monitoring three aquifers, as detailed in Table 2. Monitoring well locations are shown in Figure 3.

Table 2 Current observation wells in the Angas Bremer PWA

Aquifer monitored	Symbol (SA Geodata)	Number of monitoring wells
Quaternary Aquifer	Q	39
Murray Group Limestone Aquifer	Ty	37
Renmark Group Aquifer	Tr	5

Water levels were monitored monthly until 2005, but since then have been monitored on a three monthly basis. Salinity monitoring has been irregular. Since 2001, salinity sampling has been conducted every two years, with the latest monitoring round conducted during the summer of 2006–07.

All water level and salinity results are available from the DWLBC 'OBSWELL' web site, under the network name of ANGBRM. The web address is;

https://info.pir.sa.gov.au/obswell/new/obsWell/MainMenu/menu

The shallow observation well monitoring network established by the Angas Bremer Water Management Committee (ABWMC) was incorporated into the 'OBSWELL' database in the early 2000s. After completion of annual irrigation reports, the monitoring data is uploaded into 'OBSWELL'. The monitoring results for the shallow network were not available for generating the potentiometric surface contour maps for 2006–07, which were based on the regional monitoring data.

The Angas Bremer Water Management Committee (AB WMC) had data loggers installed in 11 wells completed in the MGL confined aquifer, and also in 12 wells completed in the Quaternary aquifer. The AB WMC is custodian of the data, which has not yet been incorporated in the corporate database, but would be beneficial to any future groundwater assessments.

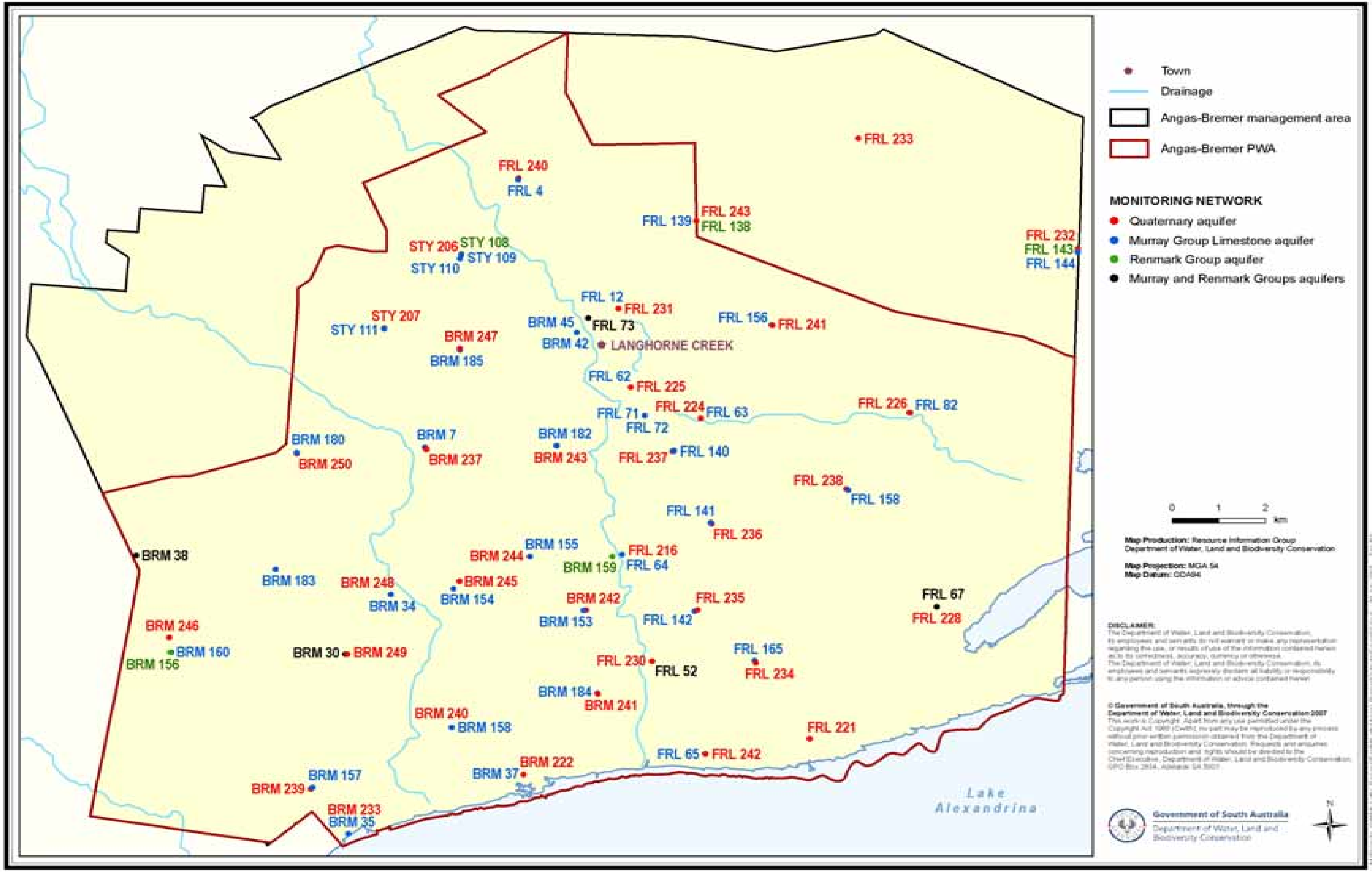


Figure 3 Angas Bremer PWA monitoring wells location map

4. DRIVERS OF GROUNDWATER TRENDS

To be able to determine the long-term and short-term trends in the condition of the groundwater resource, it is imperative to define and understand the drivers of these trends. This is achieved by undertaking an assessment of groundwater monitoring data and the relationships with rainfall patterns, groundwater use, and ASR activities.

4.1 RAINFALL TRENDS

The Angas Bremer PWA lies in the rain shadow of the Mt Lofty Ranges and has a relatively low annual rainfall of ~400 mm (Table 2). Rainfall is winter dominant and occurs mainly between April and October, with the average monthly rainfall for the past 55 years (1950–2005) given in Table 3 (BoM 2007).

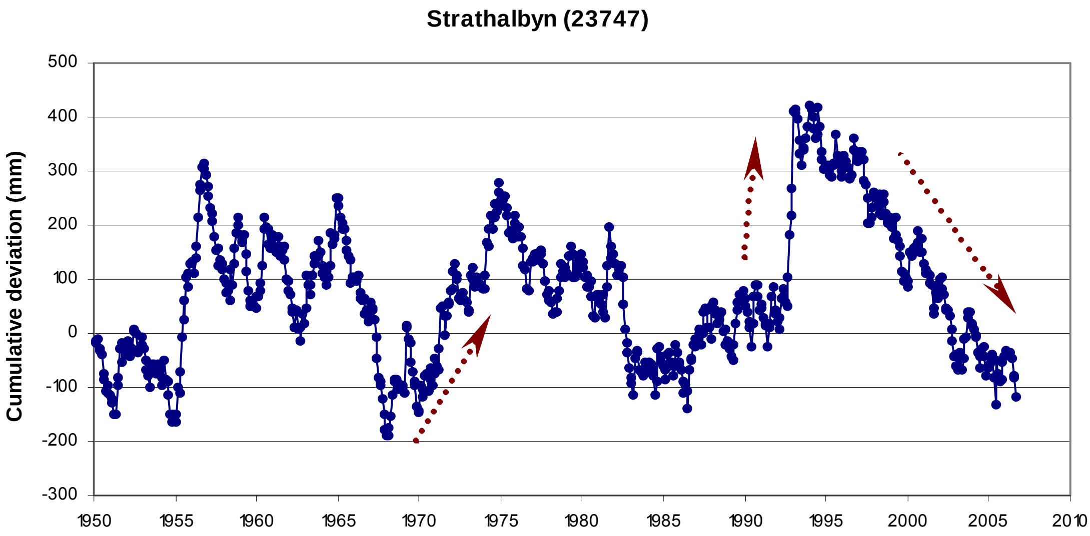
Table 3 Average monthly and annual rainfall (mm)

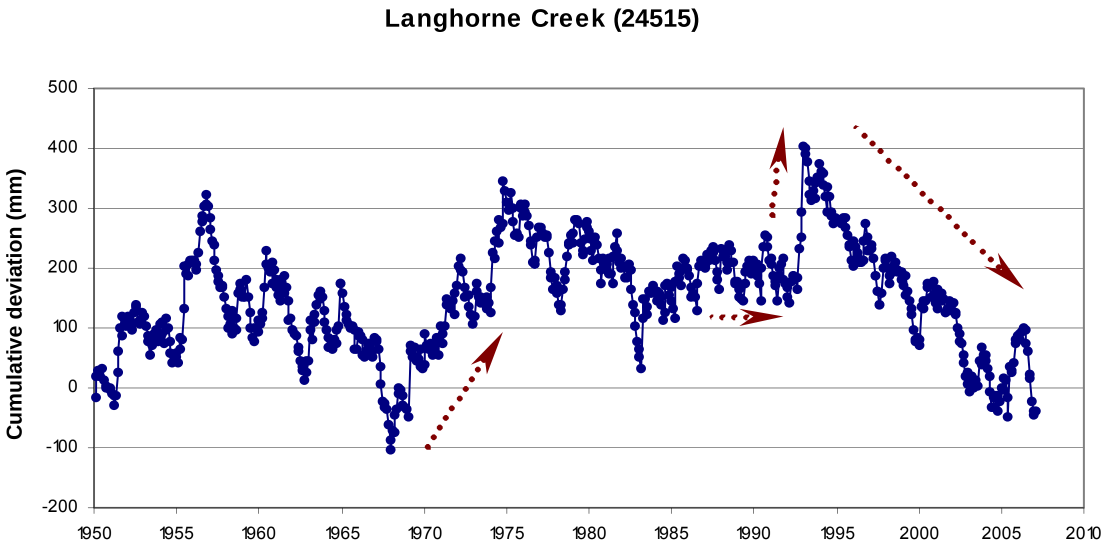
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Langhorne Creek 24515	19	21	19	33	40	42	42	44	38	39	26	24	**387**
Milang PO 24519	19	20	19	34	45	49	52	48	39	38	25	21	**408**
Strathalbyn 23747	19	23	22	40	53	54	61	64	50	46	29	27	**490**

The cumulative rainfall deviations for Langhorne Creek, Milang (Post Office) and Strathalbyn rainfall stations has been calculated based on a monthly basis and are presented in Figure 4. An upward trend indicates greater than average rainfall, average rainfall is represented by a horizontal trend, while a downward trend indicates below average rainfall.

The Langhorne Creek and Strathalbyn rainfall stations show very similar general trends with above average rainfall from 1968 until 1975 and two extremely wet periods in 1956 and 1992–93. These extremely wet periods were followed by below average rainfall, particularly since 1993. The Milang rainfall station shows that above average rainfall started in 1968 and continued until 1992, when entered a below average period which continued towards the end of 1997. Since 1997 the rainfall trend has been average.

In other regions, rainfall trends have an influence on water levels in unconfined aquifers that are recharged directly from rainfall. Rainfall patterns may also have an indirect influence on confined aquifers that are not recharged from rainfall. This is because a wet or dry year may influence pumping regimes that have a direct effect on pressure levels.





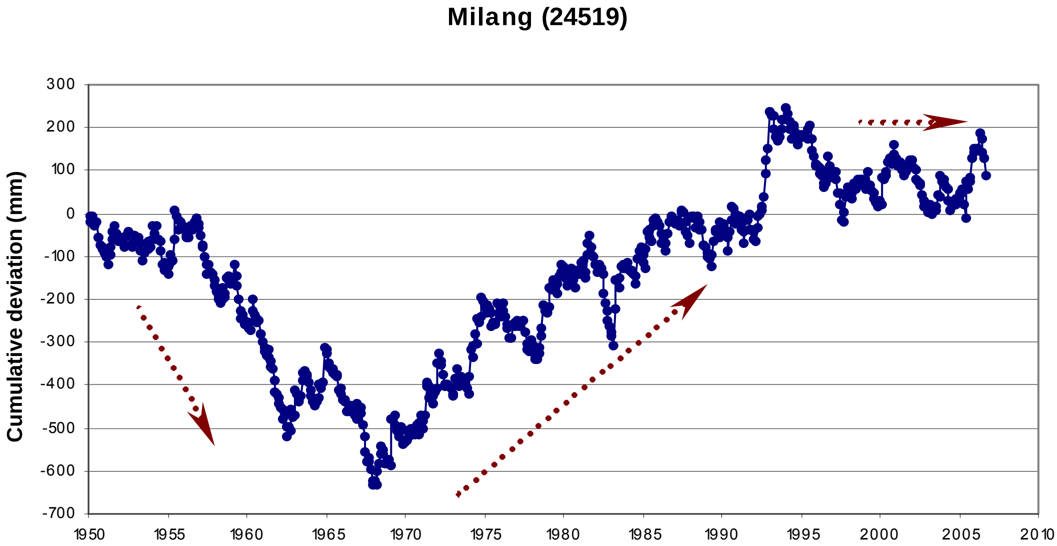


Figure 4 Cumulative rainfall deviation

4.2 GROUNDWATER AND SURFACE WATER USE

Groundwater from the confined MGL aquifer has been a major source of irrigation water supplies since the early stages of irrigation development in the 1950s. Groundwater extraction reached a peak of 26 600 ML in 1980–81 and has been steadily declining throughout the 1980s (Fig. 5). This trend continued through the 1990s, when groundwater use was well below 6000 ML/yr, with the exception of 1994–95 when it reached 7000 ML. Since then, annual groundwater extraction has decreased to ~2000 ML, however there has been a significant rise in use of surface water through River Murray diversions from Lake Alexandrina (Fig. 5). This rise coincides with accelerated vineyard development, especially since 1995. The use of surface water had been increasing steadily from 5000–15 000 ML in 1998–99 and is currently averaging ~15 000 ML/yr.

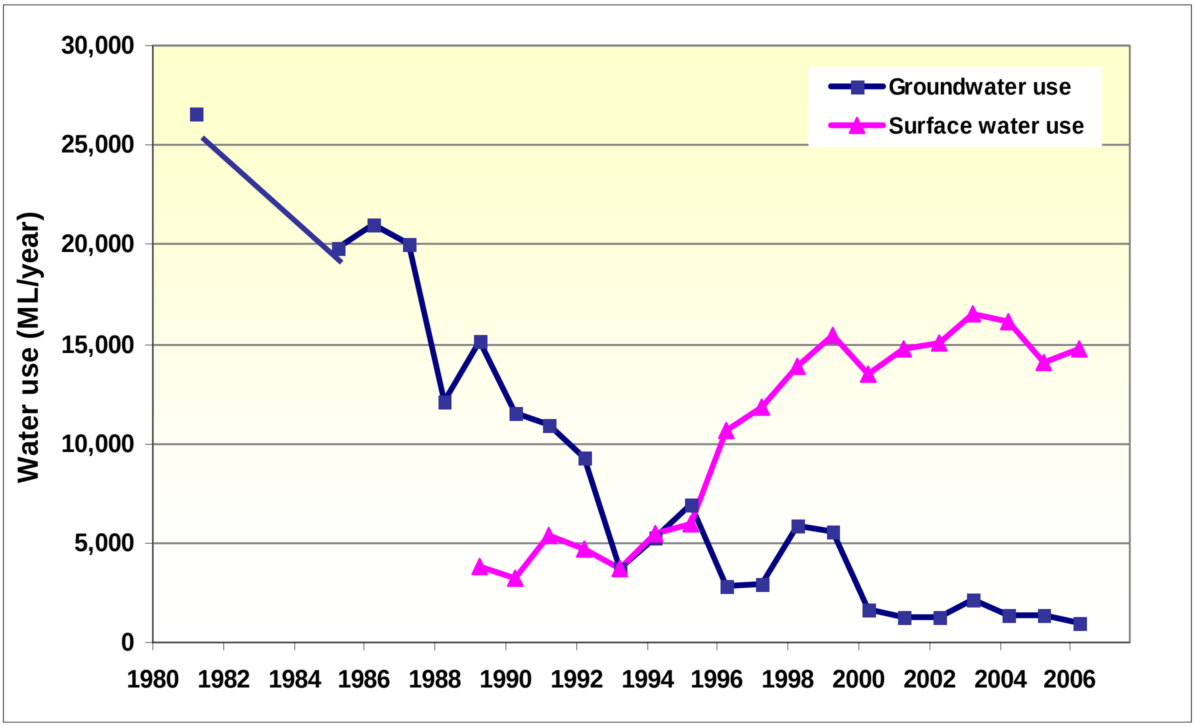


Figure 5 Groundwater and River Murray water use in the Angas Bremer PWA

High groundwater extractions in the 1970s and early 1980s induced lateral inflow of saline groundwater, as well as downward leakage from the Quaternary aquifer in those areas where the aquitard is more permeable or absent (Australian Water Environments, 2000). This lead to a dramatic reduction in groundwater allocations. However the very low groundwater extractions recorded in the 2000s are significantly lower than groundwater allocations, which amount to ~6500 ML/yr (Fig 6), which was the estimated sustainable yield of the MGL aquifer adopted for the first Water Allocation Plan (Howles, 1995).

Several sources were used to compile groundwater use data. Groundwater extraction volumes in 1982, 1985 and 1986 were determined by land and water use surveys, while annual volumes between 1986 and 1992–93 were obtained from annual irrigation reports. Since 1992, the majority of irrigation wells have been metered. The DWLBC Licensing Administration Group provided annual groundwater allocations and extractions since 1992–93 as shown in Fig. 6, along with the annual volumes compiled from annual irrigation reports. The total annual groundwater extractions from both sources are similar except in 1998 and 1999, when annual report extractions are significantly lower. This is attributed to significant underreporting by irrigators in the area.

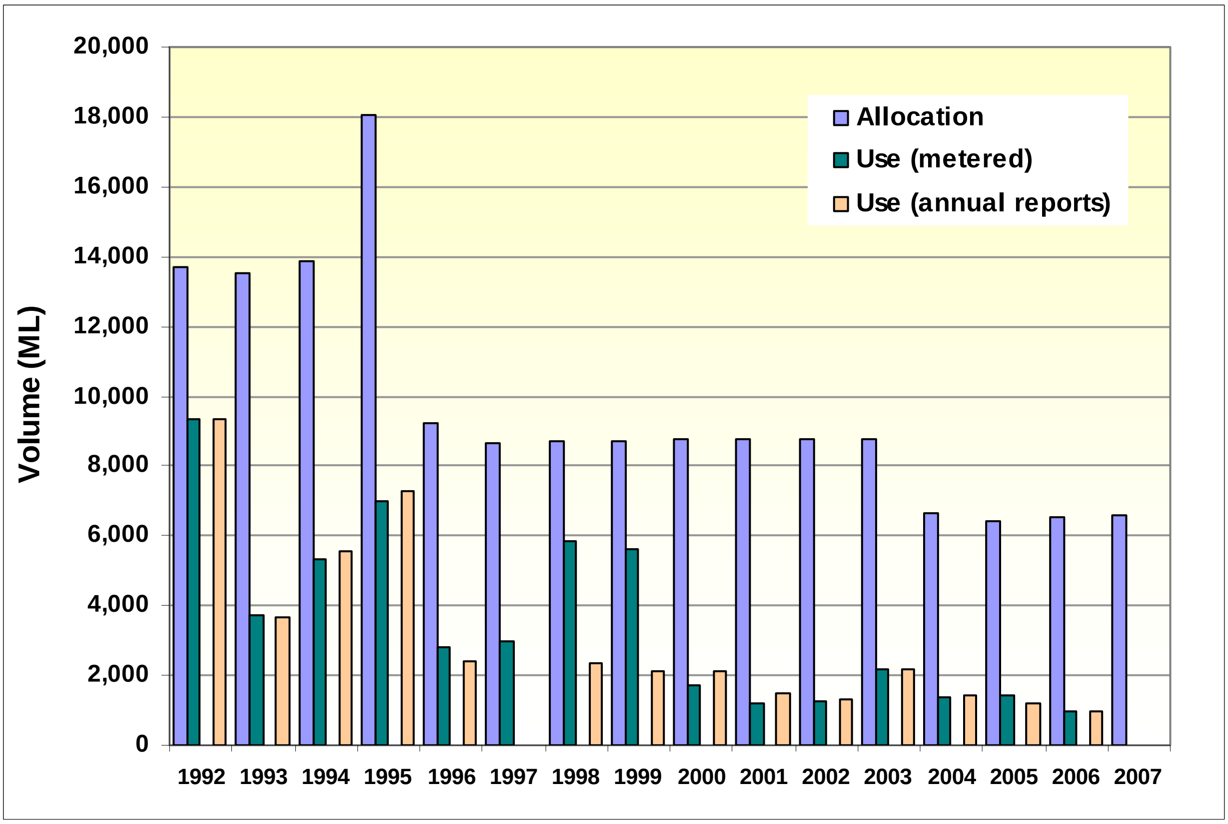


Figure 6 Annual groundwater allocation and use in the Angas Bremer PWA

The majority of groundwater extractions and allocations are concentrated in areas of low salinity along the Angas and Bremer Rivers (Fig. 7). The 2004–05 irrigation season was the most recent for which for which groundwater use metered data is believed to be complete and was supplied by Licensing Administration Group for each well. Groundwater allocations were however, supplied as total volume per licence, which is often associated with more than one well (sometimes up to five), and it is difficult to accurately represent spatial distribution of allocations. Because of this, allocations for 2004–05 are compared with the usage data for the same period, and where there was more than one well associated with a licence, allocation volumes were arbitrarily assigned to those wells where there was a record of usage. Wells with zero recorded usage were not plotted in Figure 7. This method potentially carries a certain level of error, but is nevertheless, the best possible at present.

The 2500 mg/L salinity contour was then used to categorise the level of current groundwater use and allocation within two zones, Angas (A) and Bremer (B). The summarised groundwater allocation and use volumes in 2004–05 for each zone are presented in Table 4. In Zone A, use was 644 ML or ~30% of the allocation for that year, while in zone B, irrigators used only 556 ML or 20% of their entitlements. In the reminder of the AB PWA, licensed irrigators used a total of 211 ML or 12% of the total allocation.

Table 4 Groundwater use and allocation for 2004–05

Zone	**2004–05 use** (ML)	**2004–05 allocation** (ML)
Angas - Zone A	644	2185
Bremer - Zone B	556	2767
Area outside Zones A & B	211	1662
Total	**1411**	**6614**

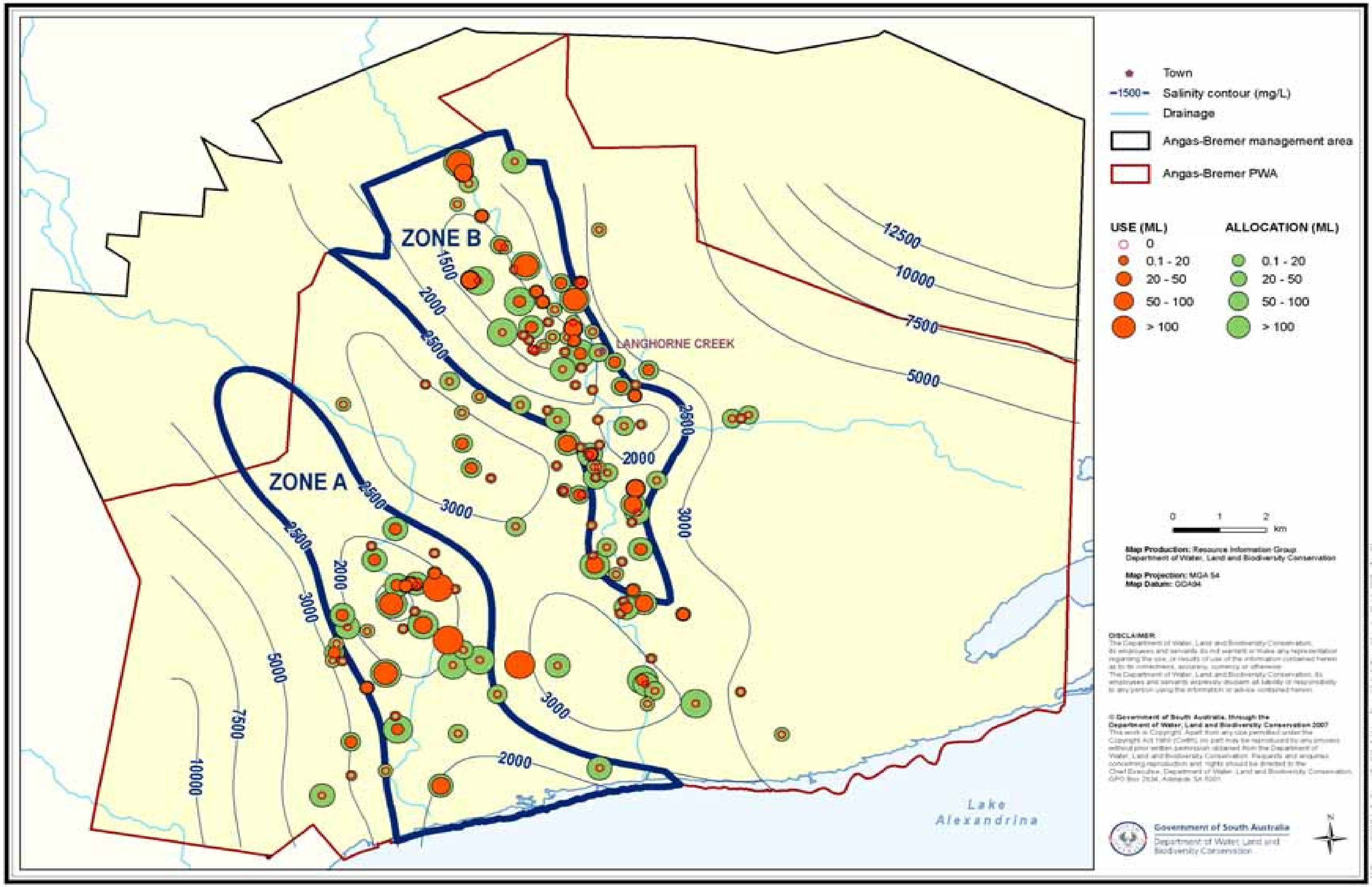


Figure 7 Distribution of groundwater allocations and use – 2004–05 irrigation season

4.3 AQUIFER STORAGE AND RECOVERY

Aquifer Storage and Recovery (ASR) started in the area in the early 1980s. The amount of surface water injected into the confined MGL aquifer every year varies significantly, depending on the availability of surface water with salinities less than 1500 mg/L (Fig. 8). The volumes of recharged water have been recorded since 1984 and are obtained from 1984–95 (Howles, pers. comm.) and 1996–2006 (Allnutt, pers. comm.).

Most recharge occurs along the Bremer River, with fewer sites located adjacent to the Angas River and Mosquito Creek (Fig.1). The recharge volumes peaked in 1992 following extremely high late spring rainfall, which resulted in very high streamflows.

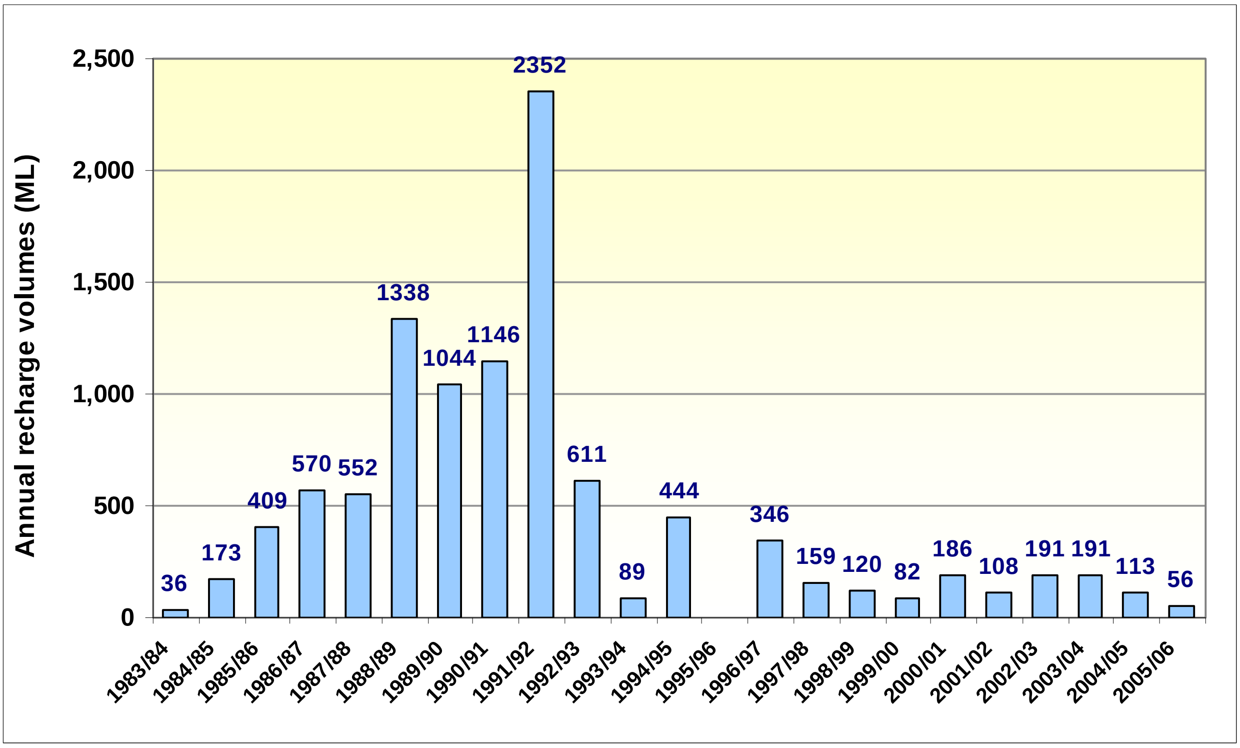


Figure 8 Annual recharge volumes in the Angas Bremer PWA

5. WATER LEVEL TREND ANALYSIS

The time series water level data for currently monitored wells has been used to generate winter and summer potentiometric surface maps (pre- and post-irrigation season), and analysed to identify long and short-term water level trends relative to changes in groundwater extractions and climate changes.

5.1 MURRAY GROUP LIMESTONE AQUIFER

Extensive annual groundwater extractions of up to 21 000 ML during the 1970s and 1980s created seasonal drawdowns of 5 m during the summer irrigation season (Australian Water Environments, 2000), which later recovered during winter. Over a period of about 25 years, some localised areas experienced a decline of up to 5 m in the winter pre-irrigation water level with a cone of depression developing within the MGL confined aquifer. This prevented throughflow of groundwater from north to south. Figure 9 presents a typical MGL water level hydrograph from BRM 7.

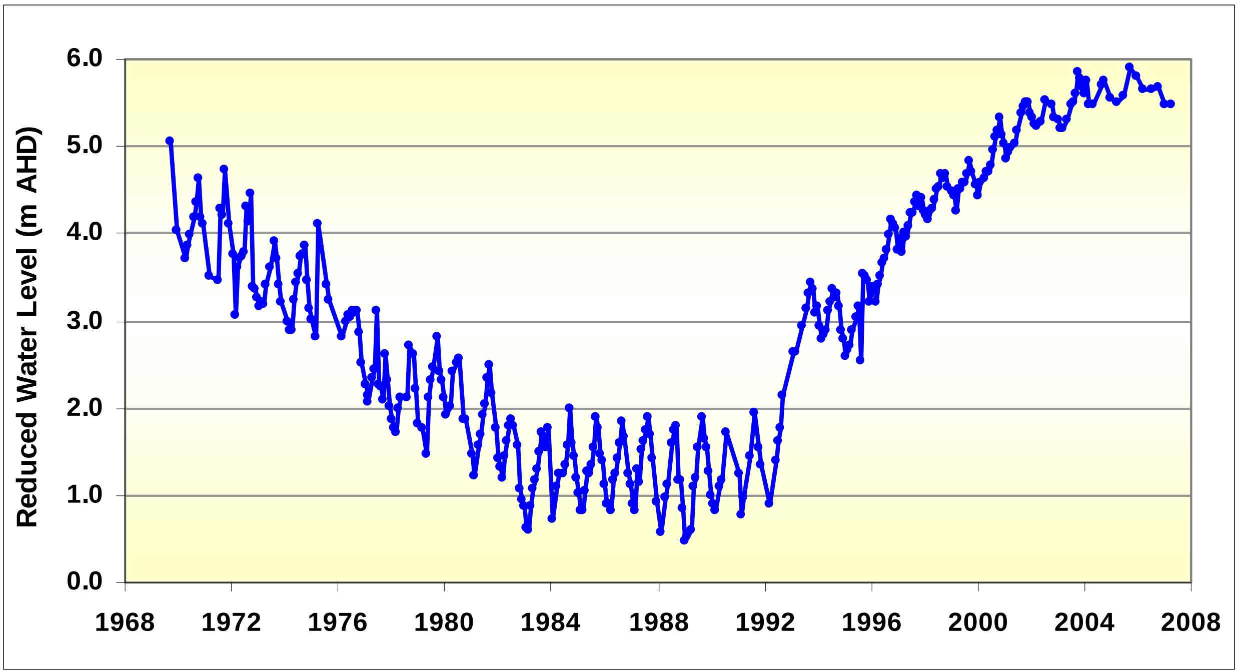


Figure 9 Water level hydrograph for BRM 7

Since then, a number of factors had a significant restorative effect on groundwater levels, such as the implementation of ASR and in particular, large reductions in groundwater extraction. The exceptionally large volume of surface water injected into the aquifer (over 2300 ML) during the 1992 floods, caused water levels to rise sharply (Fig. 9). They have continued to rise over the past decade, with the exception of the period 1993-95 when rainfall was below average and consumption rose to over 7000 ML/yr.

Considering the groundwater flow rate of 5 m/yr (AWE, 2000), the observed recovery in water levels could not be due to increased lateral flow from the northwest, but is almost certainly the result of the continuous decrease in groundwater extraction.

Potentiometric surface maps for the confined MGL aquifer have been generated for the pre-irrigation (October 2006) and post-irrigation (April 2007) periods for the 2006–07 irrigation season (Fig. 10). The groundwater flow direction is also shown.

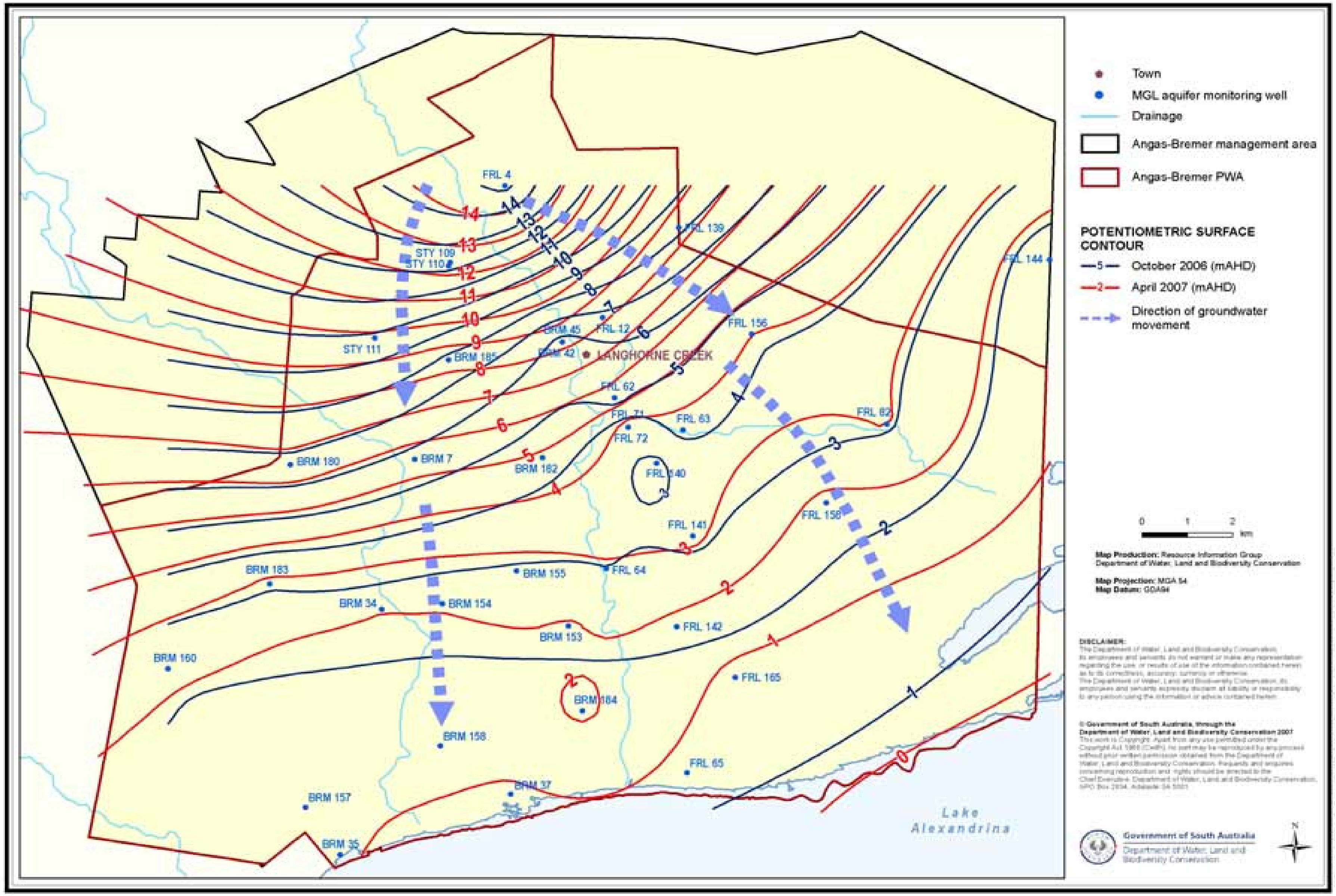


Figure 10 MGL aquifer potentiometric surface maps, October 2006 and April 2007

The general groundwater flow direction is towards Lake Alexandrina in a southeasterly direction. There is a typical northerly shift of the 1–4 m contours for April 2007 caused by groundwater extractions during the irrigation period. The somewhat extreme shift in the 4 m contour between the Bremer River and Mosquito Creek is caused exclusively by the water level in observation well FRL 71. Observation wells FRL 71 and FRL 72 have a dual completion at depths of 70 and 46 m respectively and monitor different aquifer intervals. It is unclear if the wells are completed in different intervals of the same aquifer (MGL) or two different aquifers, the MGL and Renmark Group aquifers.

Three groups of distinctive groundwater level trends are evident:

1. Wells located in Hundred of **Bremer** generally show:
   - A general decline until ~1984.
   - Stable trends from 1984–92.
   - A sharp rise in 1993 after the wet spring of 1992.
   - A decline in 1993–95.
   - Continuous rise between 1995–2005, at a slower rate.
   - Since 2005, a small decline or stable.
2. Wells located in Hundred of **Freeling** show:
   - Stable trend, with large seasonal fluctuations until 1989 (FRL12, 63, 64).
   - Rising trend since 1989, with a leap in 1993 after late spring floods.
   - Stable or rising trends since 1994.
3. Wells located in Hundred of **Strathalbyn** show:
   - Continuous declining trend until 1992.
   - An rise in 1992–93 as seen across the whole area.
   - Rising trend since 1993, which stabilised in recent years.

Groundwater level trends were determined by calculating the average rate of change in water levels, which are plotted in Figure 11. It shows regional distribution of water level trends before 1993 in blue, as well as trends after the significant rise in 1993 until 2007 in red. An average increase in water levels since 1993 is 0.15 m/yr, compared to an average of 0.04 m/yr before 1993. Eleven out of 31 wells used to determine trends before 1993 displayed a falling trend averaging 0.11 m/yr, and are predominantly located northwest of Langhorne Creek.

Figure 12 displays the difference between pre-development water levels as recorded in 1950 (Waterhouse et al, 1978) and those measured in October 2006. Although there has been a significant recovery in water levels, the 2006 level in zones of high groundwater use is still about 2 m lower than in 1950, and up to 3.5 m lower immediately west of Langhorne Creek. Around the margins of the Angas Bremer PWA, levels have recovered to 1950 levels, however these are high salinity zones with very low or no groundwater extraction.

Hydrographs of representative wells monitoring water levels in the confined MGL aquifer are presented in Appendix A. Only three wells with long term monitoring data since 1969, BRM 4, FRL 4 and FRL 12, are still being monitored.

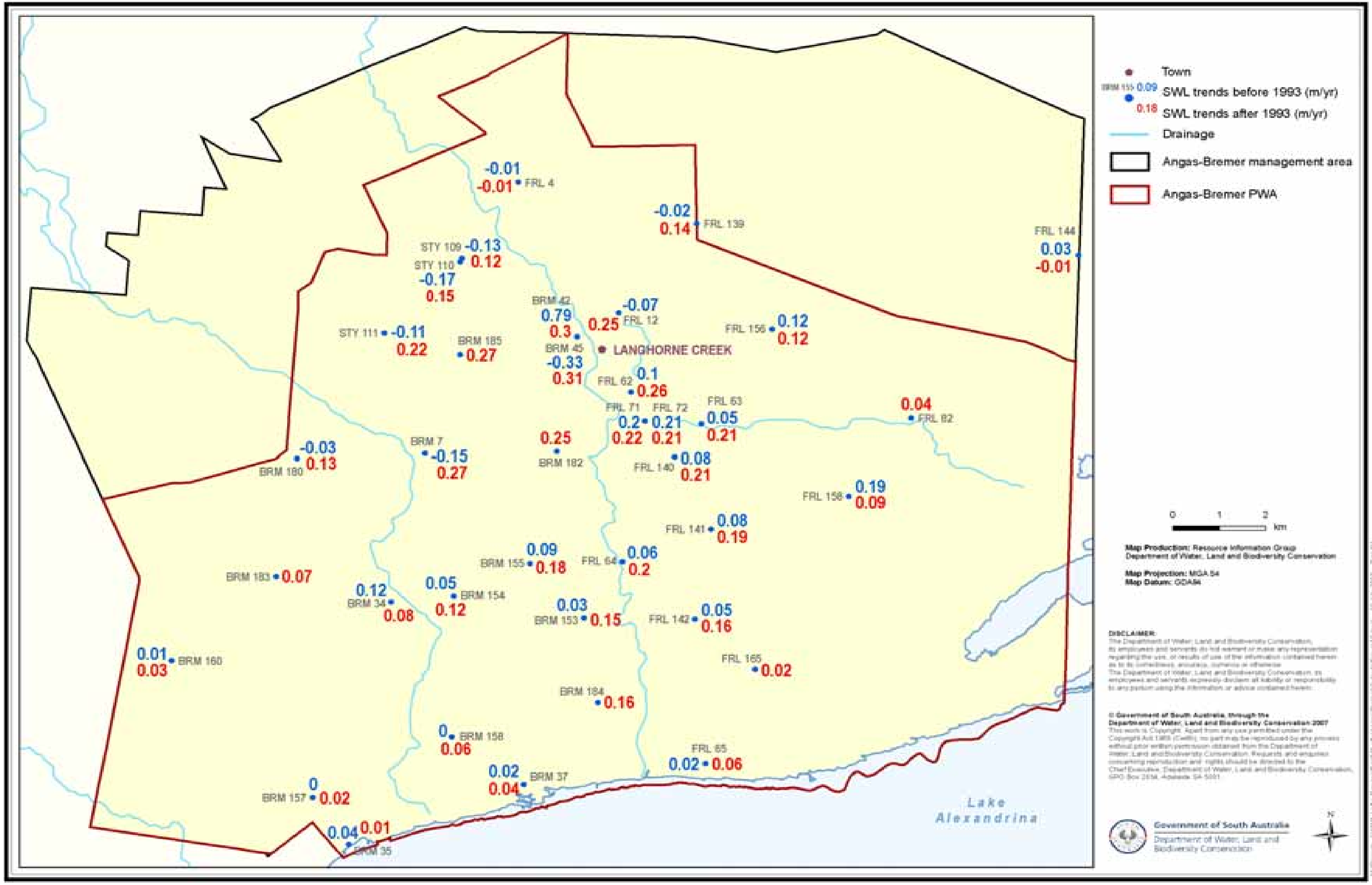


Figure 11 MGL aquifer water level trends

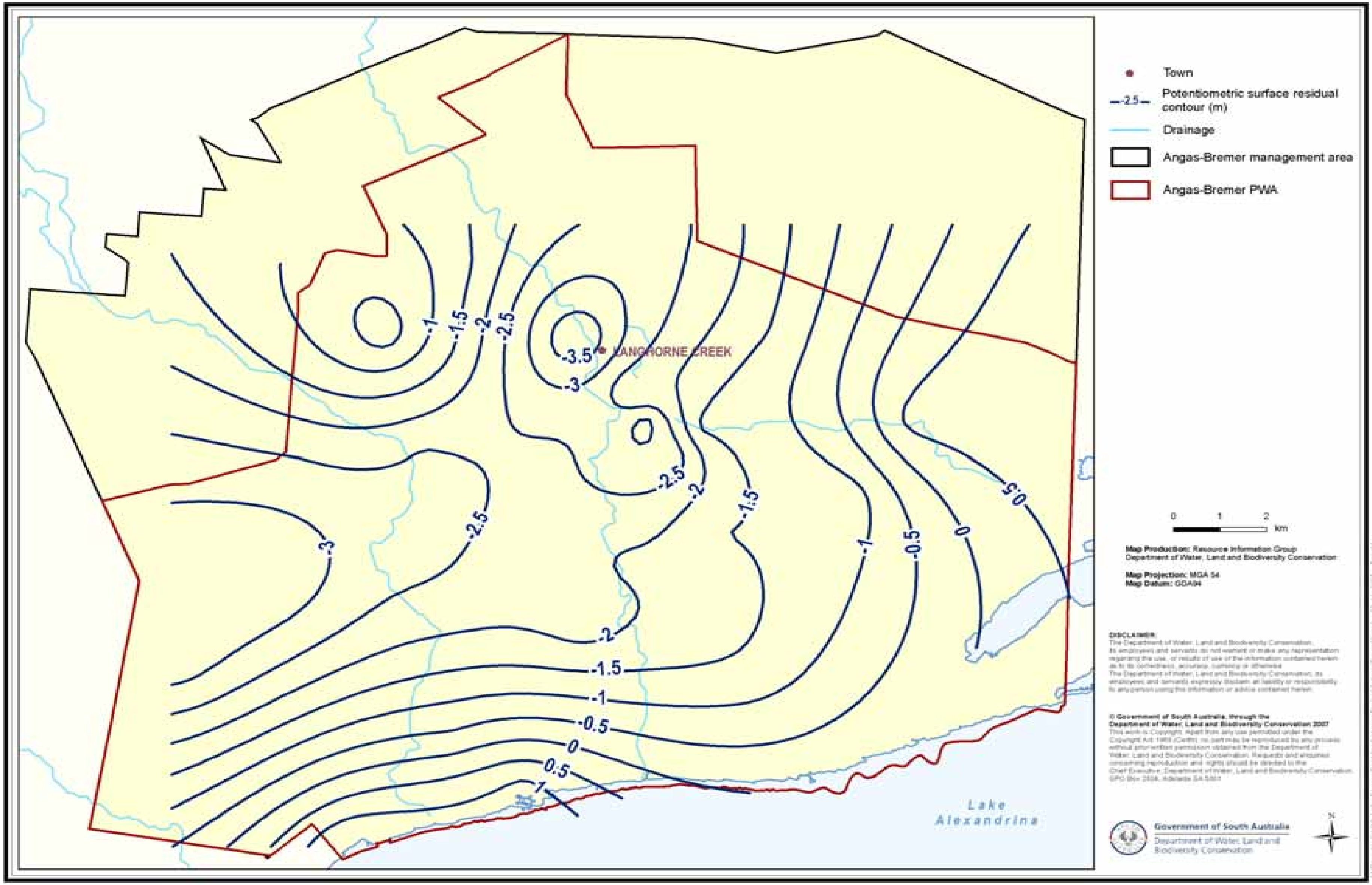


Figure 12 MGL aquifer potentiometric surface residual map for 2006 and 1950

5.2 QUATERNARY AQUIFER

Very limited long-term monitoring data is available for the Quaternary aquifer, with the earliest records starting in 1976. Potentiometric surface contour maps for the Quaternary aquifer are generated for pre-irrigation (October 2006) and post-irrigation (April 2007) periods (Fig. 13).

In general, groundwater flow is towards Lake Alexandrina, in a north to south and northwest to southeast direction. In the vicinity of the observation wells FRL 224, 225 and 237, a mound is formed in the Quaternary aquifer, causing groundwater to flow radially away from it.

Temporal analysis of hydrographs of all currently monitored wells (App. B) shows that prior to 1992, the majority of wells displayed a seasonal variation, which demonstrates a connection with the underlying MGL aquifer. After the relatively large rise in 1993, two typical trends emerged:

- Rising trend in the majority of wells in the PWA.
- Falling trend near Langhorne Creek - BRM 243 and FRL 224, 225, 226, and 237.

Groundwater level trends show a rise in the majority of wells averaging 0.12 m/yr. Figure 14 shows a minimum rise of water level of 0.02 m/yr (BRM 239) with a maximum of 0.3 m/yr (BRM 247). The main drivers of the water level rises are recharge related to river flows and flooding, increased irrigation drainage (from River Murray water) and a reduction in groundwater extractions. Wells located between the Angas and Bremer Rivers show the highest rate of rise, up to 0.35 m/yr (BRM 247). Rising water levels of between 0.02–0.06 m/yr in wells located close to the lake where the watertable is shallow, indicate a potential for waterlogging and salinisation to occur.

Falling trends near Langhorne Creek are due to dissipation of the watertable mound beneath the Bremer River (Fig. 13) caused by lack of recharge from streamflow. These falling trends average 0.07 m/yr, with FRL 237 declining at the highest rate of 0.19 m/yr.

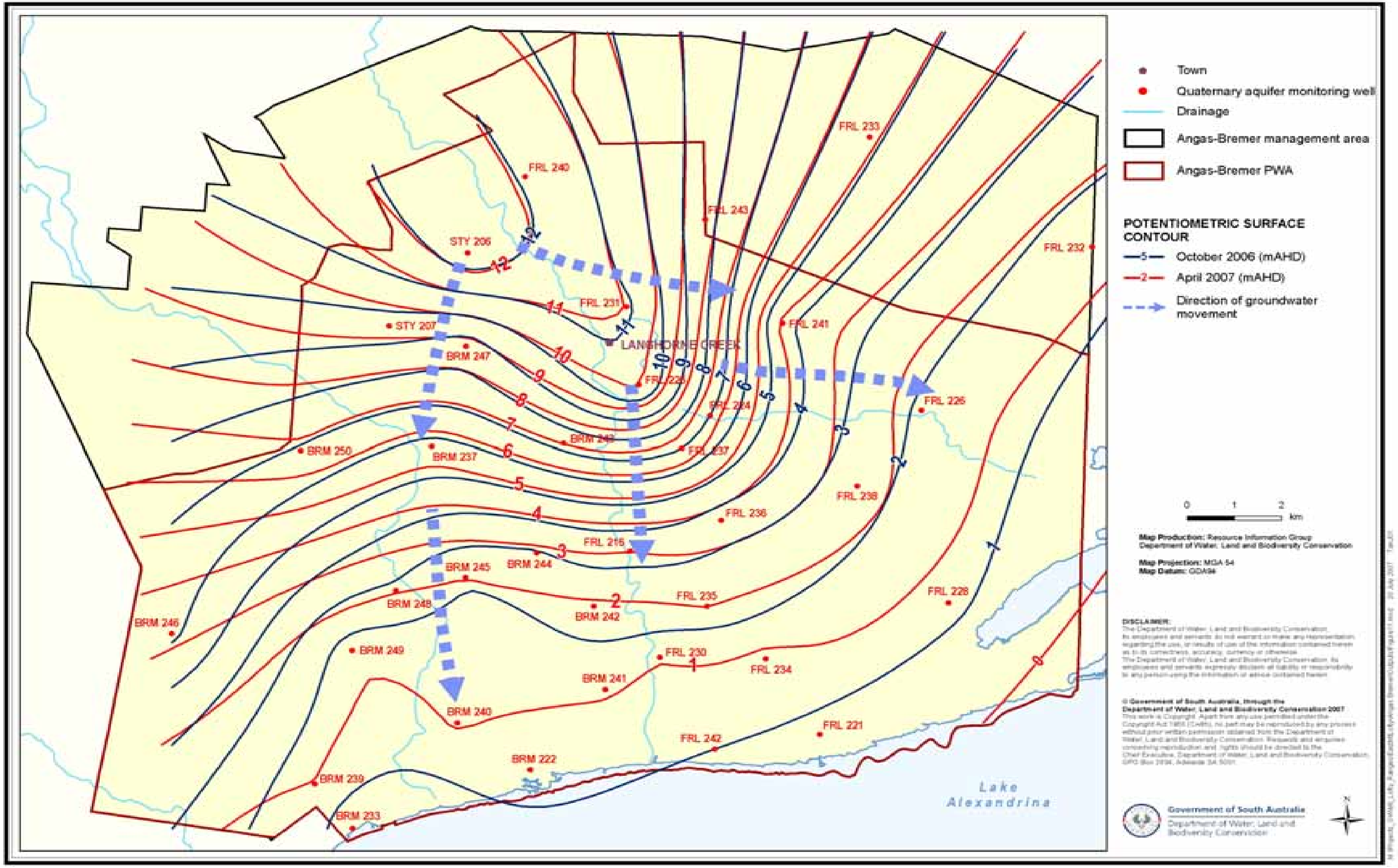


Figure 13 Quaternary potentiometric surface contour maps, October 2006 and April 2007

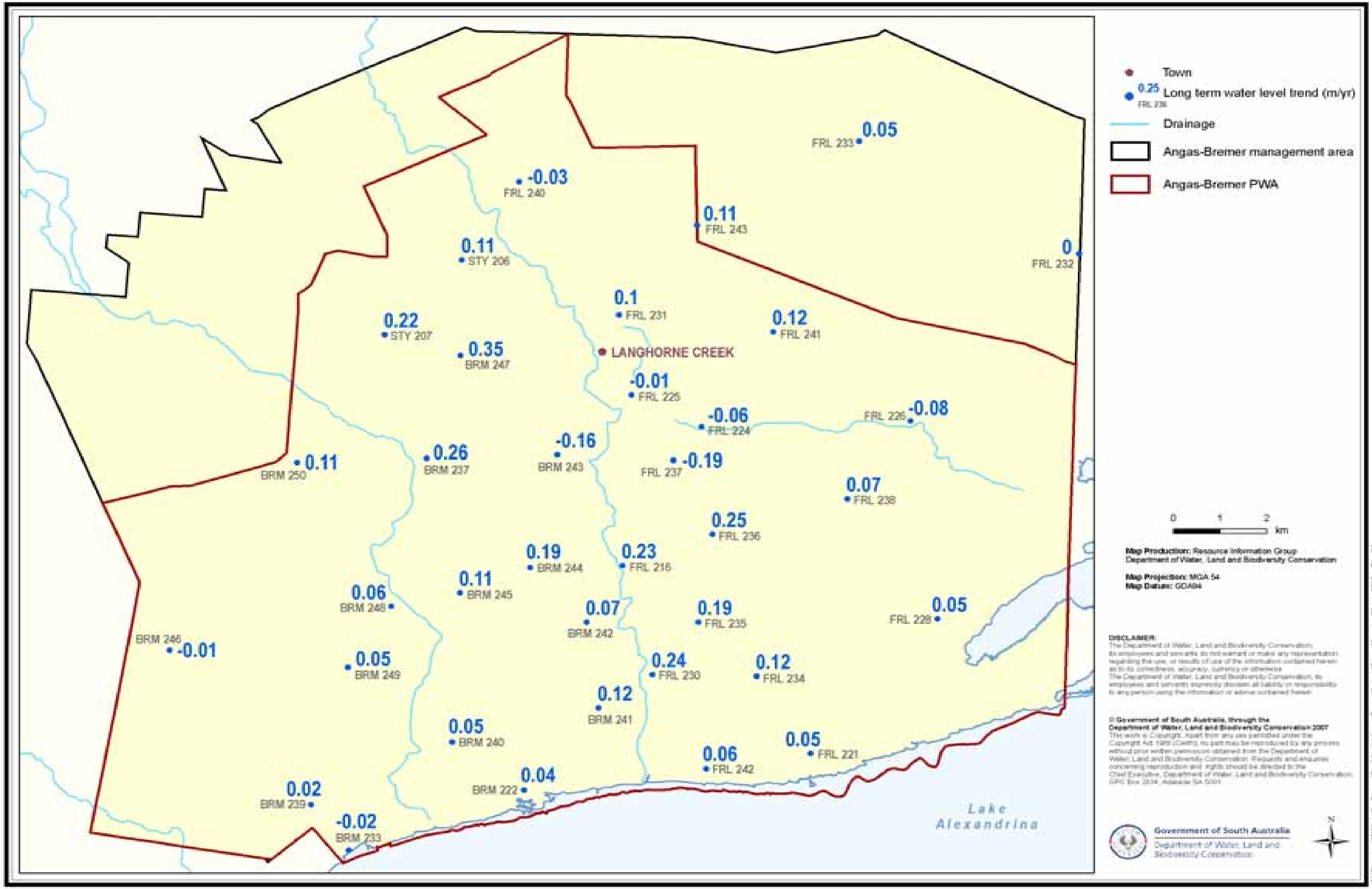


Figure 14 Quaternary aquifer water level trends

6. SALINITY TREND ANALYSIS

Salinity in the Angas Bremer PWA has not been monitored on a regular basis. The first salinity monitoring was attempted in the late 1960s. Between the mid 1970s and 1985 when a major increase in salinity probably occurred, there was no coordinated monitoring. From 1985 until the mid 1990s, salinity was monitored two to three times a year. Monitoring then ceased completely until 2001, when it resumed again with a two yearly monitoring frequency.

Time series data for currently monitored wells was used to generate salinity maps and identify salinity trends.

6.1 MURRAY GROUP LIMESTONE AQUIFER

The latest salinity sampling was conducted during the summer of 2007. Salinity results from 37 wells were used to create a salinity contour map (Fig. 15).

Observation wells FRL 71 and 72 are recharge wells and their recent salinity data was not used for the 2007 salinity map (Howles, pers. comm.). The original salinity recorded during drilling was used instead. The last two readings for BRM 184 (2005 & 2007) are abnormally low at ~200 mg/L, and these records were also not included. The most recent recorded salinities were used from observation well FRL 65 (May 2005), and from BRM 156 and 183 (January 2006).

There are a number of other issues, which influence the presentation of the salinity distribution and affect the interpretation of the data:

- Insufficient number of wells which currently monitor salinity.
- The spatial distribution of monitoring wells is inappropriate, and more wells are required in areas of concentrated use.
- The monitoring frequency is inadequate, as sampling is currently conducted every two years. It is a particularly sensitive issue, since all transfers are based on the salinity distribution and allocation reductions are relative to salinity increases over time.
- The quality of collected data needs to be verified, as some of the most recent salinity results display dubious values.
- Water quality in some monitoring wells is probably affected by ASR schemes, but the extent of this influence is not known.

Based on the best possible information available, it is evident that zones of high extraction coincide with areas of lowest salinity along the Angas and Bremer Rivers. The 1500 mg/L contour delineates very small zones of good quality water around well BRM 34, and northwest of Langhorne Creek. There has not been a significant change in salinity distribution, or a shift in the 2000 mg/L contour line in comparison with the map produced by Australian Water Environments (2000), which is based on 1996 data.

From analysis of a relatively limited number of samples, a rising trend still persists over most of the Angas Bremer PWA (Fig.16). This is of particular concern in areas of concentrated groundwater use. The salinity trends for representative MGL observation wells are presented in Appendix A.

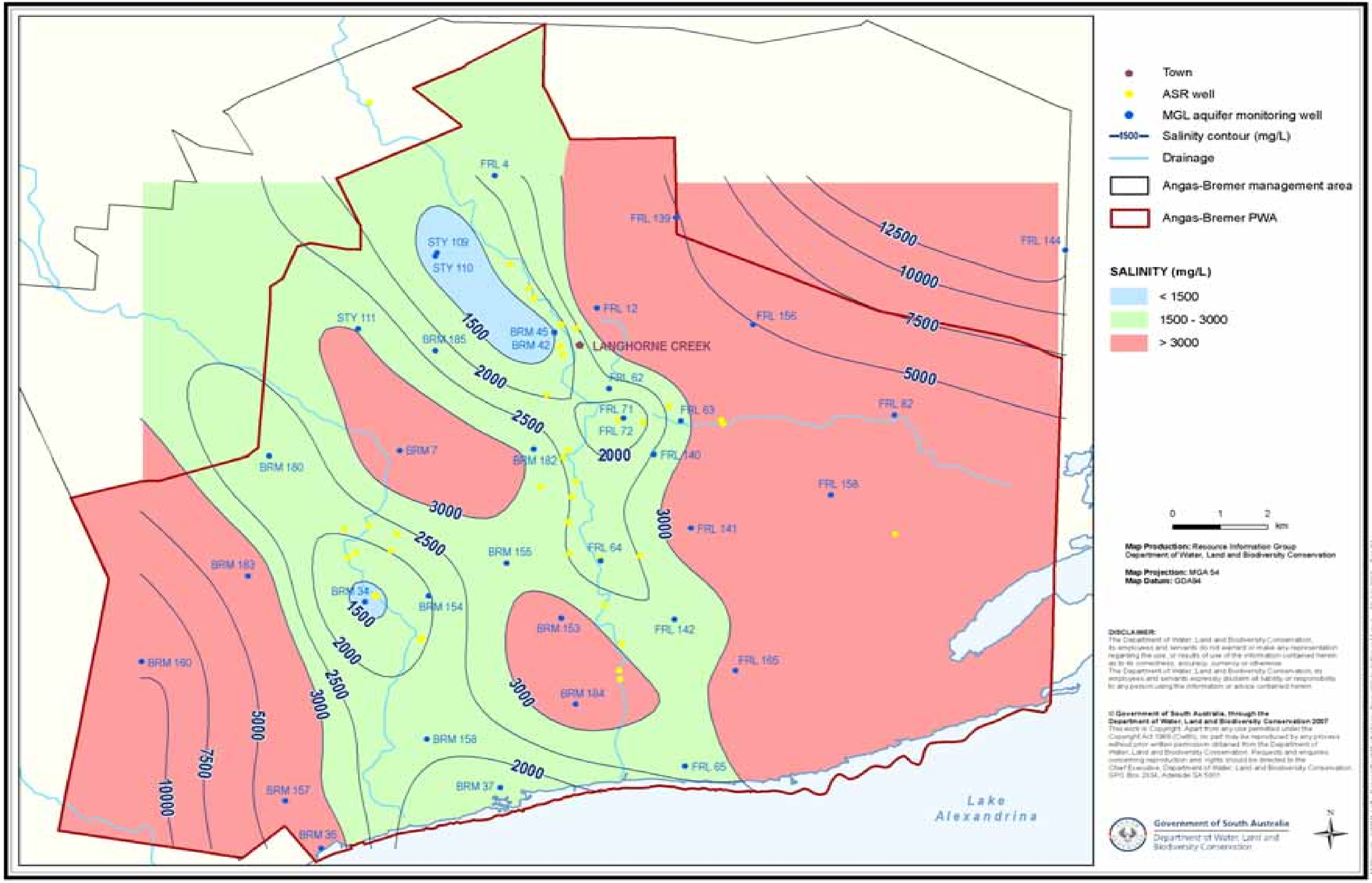


Figure 15 MGL aquifer salinity map, April 2007

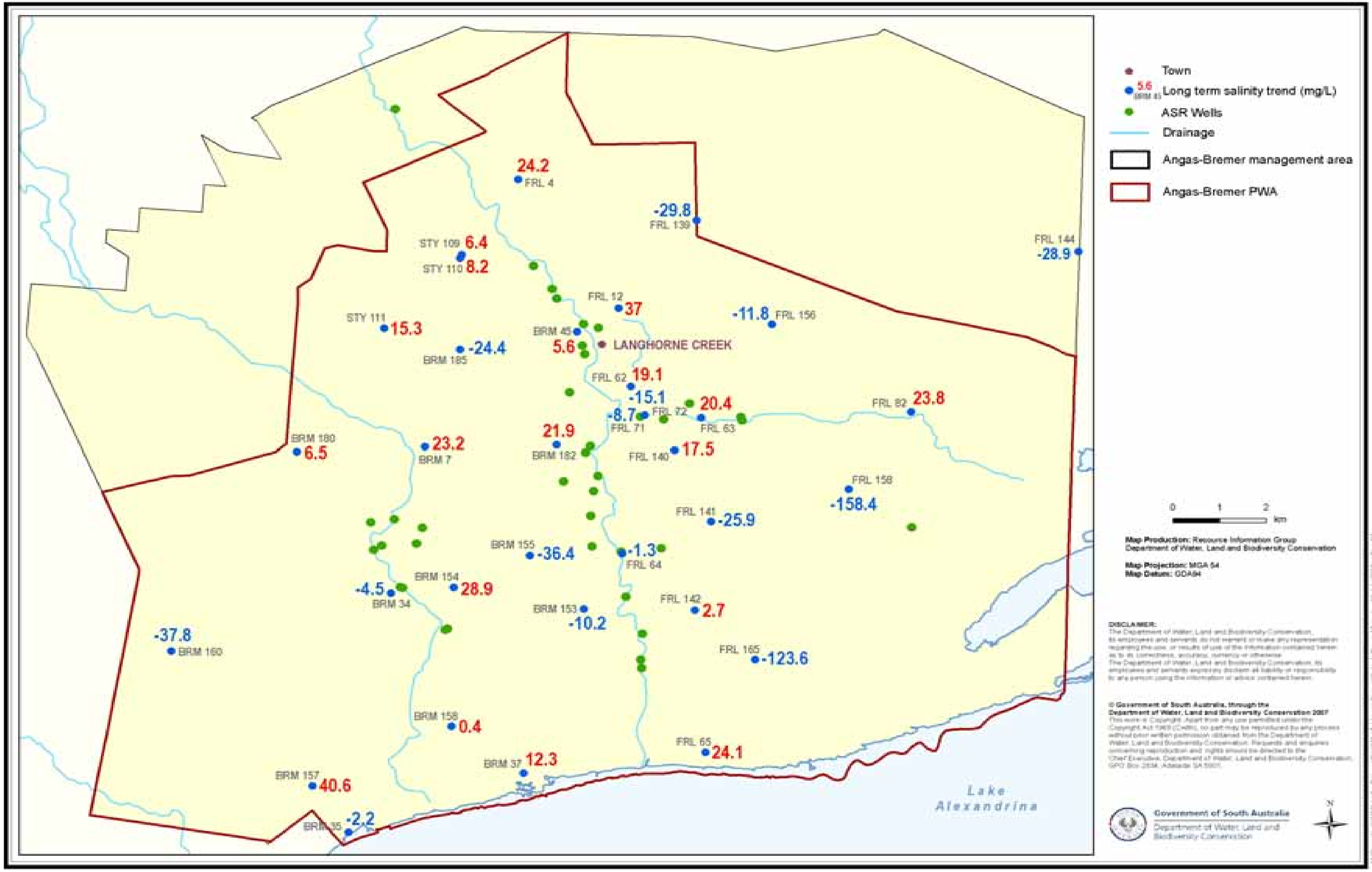


Figure 16 MGL aquifer salinity trends

The increase in salinity shown in Figure 16 varies between a relatively insignificant 1 mg/L/yr, to a disturbing 40 mg/L/yr. On average, salinity increases are ~18 mg/L/yr over the period 1985–2006. It is important to note that salinity increases after the 1992 flood average 20 mg/L/yr when extractions have been generally below 2000 ML/yr, whereas before the flood when extractions were much higher (over 15 000 ML/yr), the average rise was 19 mg/L/yr. The major reduction in extractions since 1992 has resulted in a significant recovery in water levels, but has had no impact on the rate of salinity increase in the limestone aquifer.

A few observation wells (BRM 34, BRM 153, FRL 64, FRL 71 and FRL 72), display a decrease in salinity due to injection of low salinity surface water through ASR, and are not representative of the regional groundwater salinity. Other wells displaying large decreases in salinity, such as FRL 165 and FRL 158, are in zones of high salinity in excess of 3000 mg/L with no significant groundwater use.

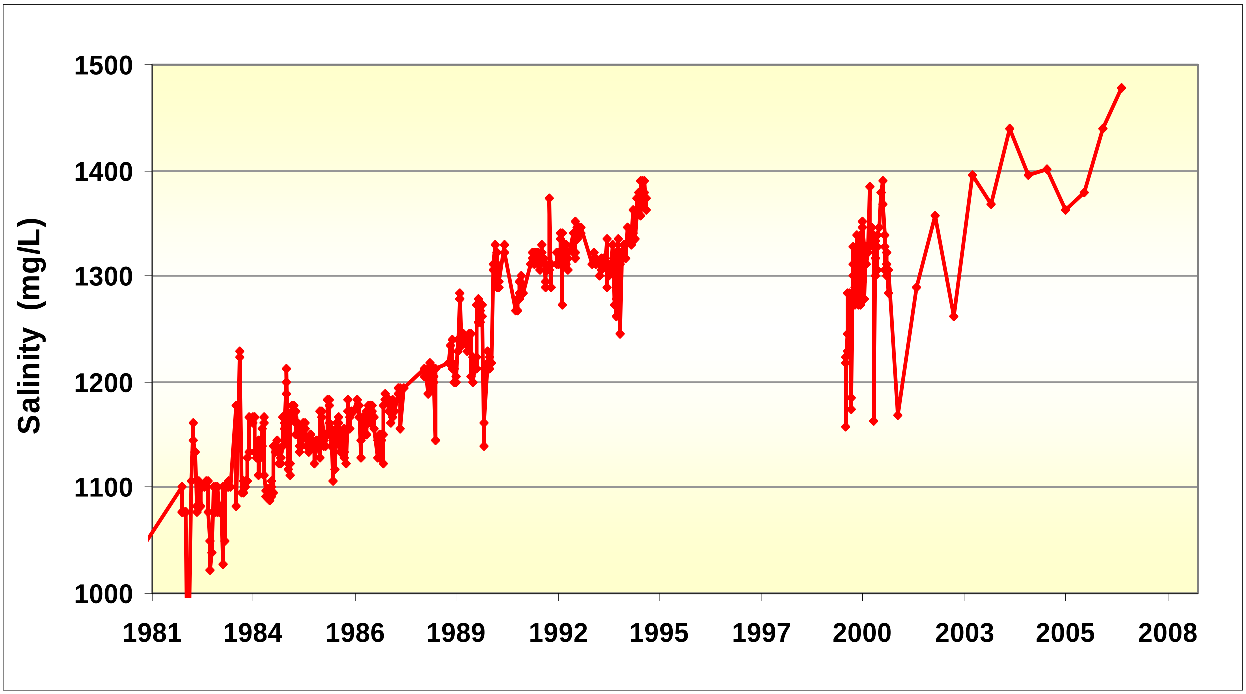


Figure 17 Salinity trends in Langhorne Creek town supply well

Figure 17 shows the salinity trend for the Langhorne Creek town supply well (STY 114) which has arguably the best salinity record in the area. It clearly displays a continuous rising trend from 1980 until 1994 (with a small decline coinciding with the 1992 flood). After a break in monitoring, readings from 1999 until 2007 also show a rising trend.

6.2 QUATERNARY AQUIFER

Salinity sampling in the Quaternary aquifer has been conducted sporadically since 1976 with insufficient spatial coverage. With no sampling conducted between 1996 and 2001, the data on which the assessment of salinity movements is based is extremely limited.

Historically, zones of low salinity persisted along the course of both rivers (Fig.18). Rapid recharge to the Quaternary aquifer occurs during flooding periods, resulting in significant improvements in quality, especially after the floods in 1992–93 (App. B).

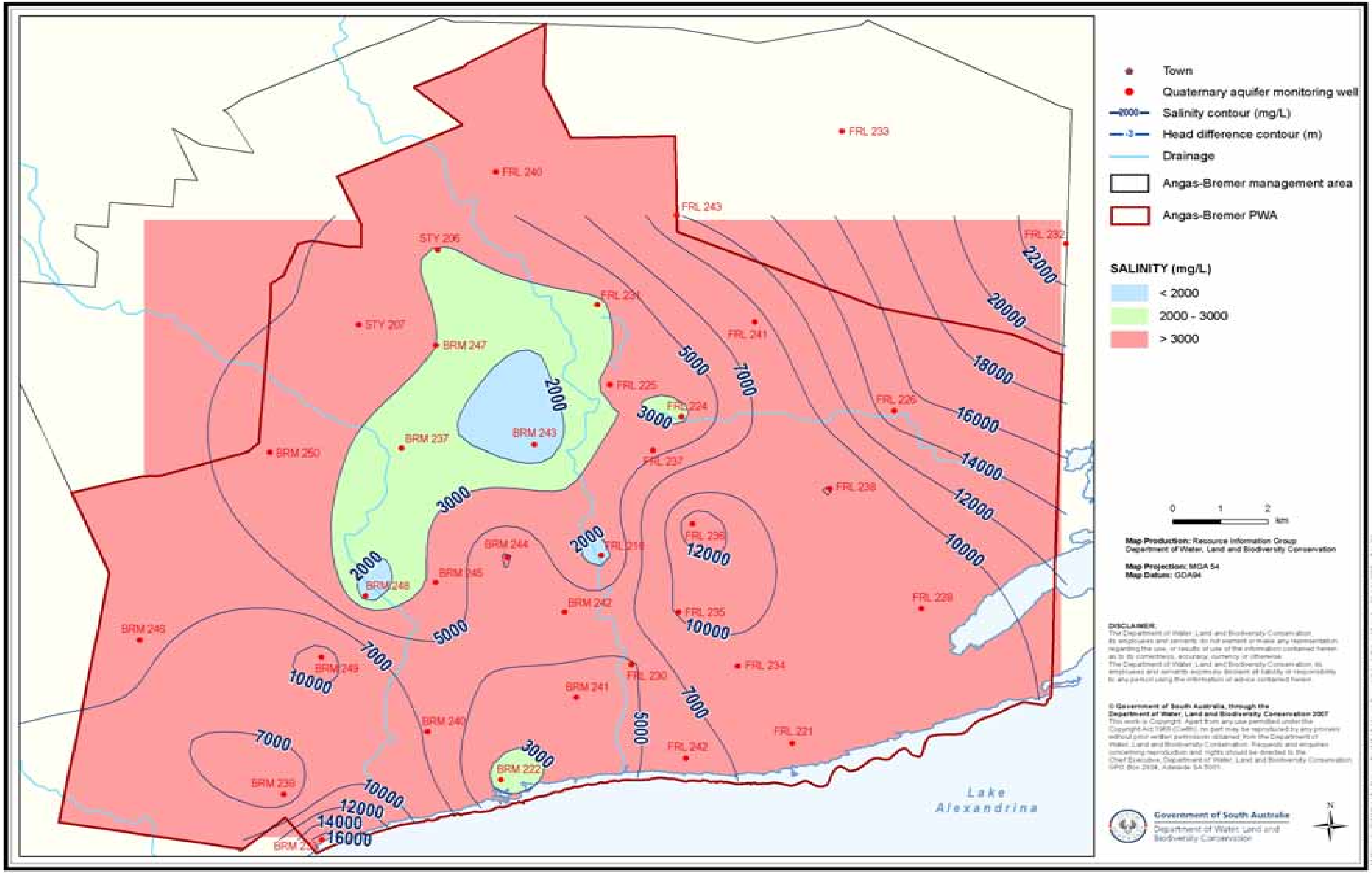


Figure 18 Quaternary aquifer salinity contour map, April 2007

7. SUSTAINABILITY ISSUES

When considering the long term viability of the groundwater resource, a number of sustainability issues should be considered. These include the current rising salinity trends and long term recharge fluxes.

7.1 SALINITY TRENDS

Historically, the two processes causing the continuous increase in salinity averaging 40 mg/L/yr (Waterhouse et al, 1978) that lead to the dramatic reduction in allocations in the 1980s, were:

- downward leakage from the Quaternary aquifer into the MGL aquifer due to head difference, particularly during the irrigation season,
- laterally induced inflow from areas of high salinity within the confined MGL aquifer.

Another possible cause of salinity increase in the MGL aquifer is leaking wells that allow downward flow of saline Quaternary groundwater into the MGL aquifer.

7.1.1 HEAD DIFFERENCE

The head difference between the MGL and Quaternary aquifers was calculated by subtracting heads in the Quaternary from those in the underlying MGL aquifer. A negative difference indicates a potential for downward leakage from the Quaternary aquifer into the MGL aquifer.

Figure 19 displays the head difference both for December 1976 and April 2007. In 1976, it indicates that the highest potential for downward leakage from the Quaternary to the MGL aquifer is in the Langhorne Creek area, with a maximum head difference of 14 m in 1976 when extractions were over 20 000 ML/yr. The downward red arrows indicate downward leakage occurring over almost all of the Angas Bremer PWA.

A maximum head difference of 4 m still exists in 2007 (Fig. 19), despite the significant recovery in MGL water levels since 1993. The downward leakage is still occurring within the zero head difference contour (red arrows). Given the salinity of the Quaternary aquifer as shown in Figure 18, it is not surprising that much of the observed salinity increases in the MGL aquifer is within this zero head difference contour (Fig.19). Australian Water Environments (2000) also concludes that downward leakage from the unconfined aquifer can be expected in the future, and that a gradual rise in salinity will occur in the long term.

Currently, areas of upward leakage occur outside the margins of the zero head difference contour as shown by the blue arrows. A zone east from Mosquito Creek (see Fig. 1) currently has a positive head difference of 1 m, which coincides with an area where an improvement in salinity in the MGL aquifer is recorded due to the cessation of downward leakage from the more saline Quaternary aquifer.

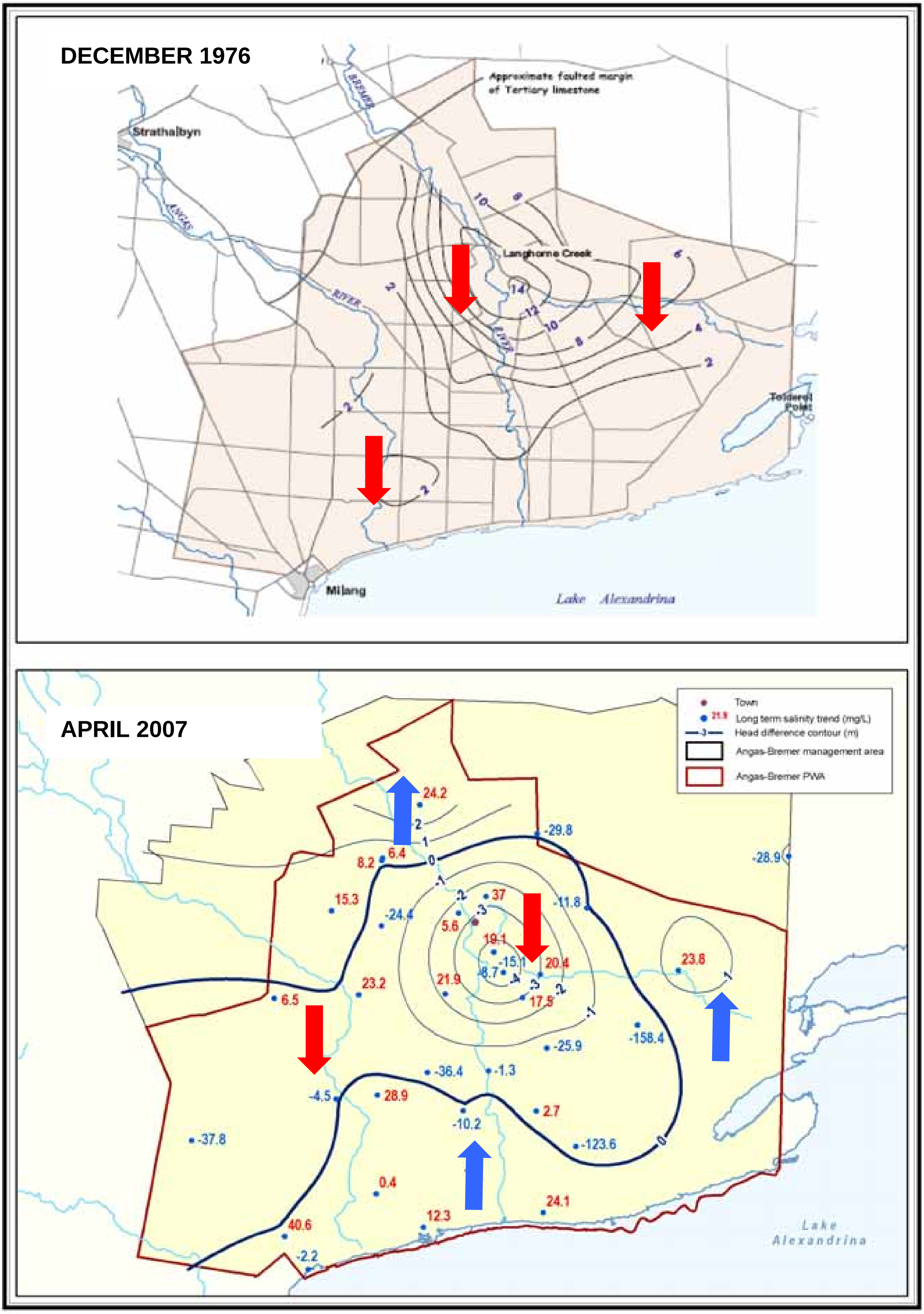


Figure 19 Comparison of head difference between Quaternary and MGL aquifers

7.1.2 LATERAL INFLOW OF SALINE GROUNDWATER

Figure 20 displays the potentiometric surface contours during the summer of 1977 and the direction of groundwater movement which brought more saline groundwater into areas of concentrated pumping which caused cones of depression in the potentiometric surface. It also shows that in summer 2007, the cones of depression have disappeared and that throughflow from the northwest to the lake has resumed with no reversal of flow from the south, and no lateral inflow from east or west.

However, Figure 20 also delineates areas of higher salinity upgradient of low salinity areas where extractions are concentrated. Drawdowns due to pumping will draw this higher salinity groundwater into the low salinity zones. Increasing extraction rates will accelerate this process. Even if pumping were to cease, this higher salinity groundwater would still slowly displace the better quality water as it moves downgradient at a rate of several metres per year.

7.1.3 LEAKING WELLS

Australian Water Environments (2003) surveyed a number of wells to evaluate the nature and magnitude of corrosion, and to estimate volumes of inter-aquifer leakage. Geophysical logging, inspection by downhole camera and metering of water flow upward or downward within the well casing were carried out. In order to estimate the impacts of leaking wells, the following assumptions were made:

- a total of 300 abandoned wells and an unconfined salinity of 3000 mg/L,
- 50% of wells not leaking, 40% leaking at 0.1 L/min and 10% leaking at 1.5 L/min.

This worst case scenario was calculated to add 90 tonnes of salt per year to the MGL aquifer. Assuming that this salt mixes only in the top 10 m of the aquifer, the resultant salinity increase would be 0.3 mg/L/yr, which is significantly lower than the observed 20 mg/L/yr.

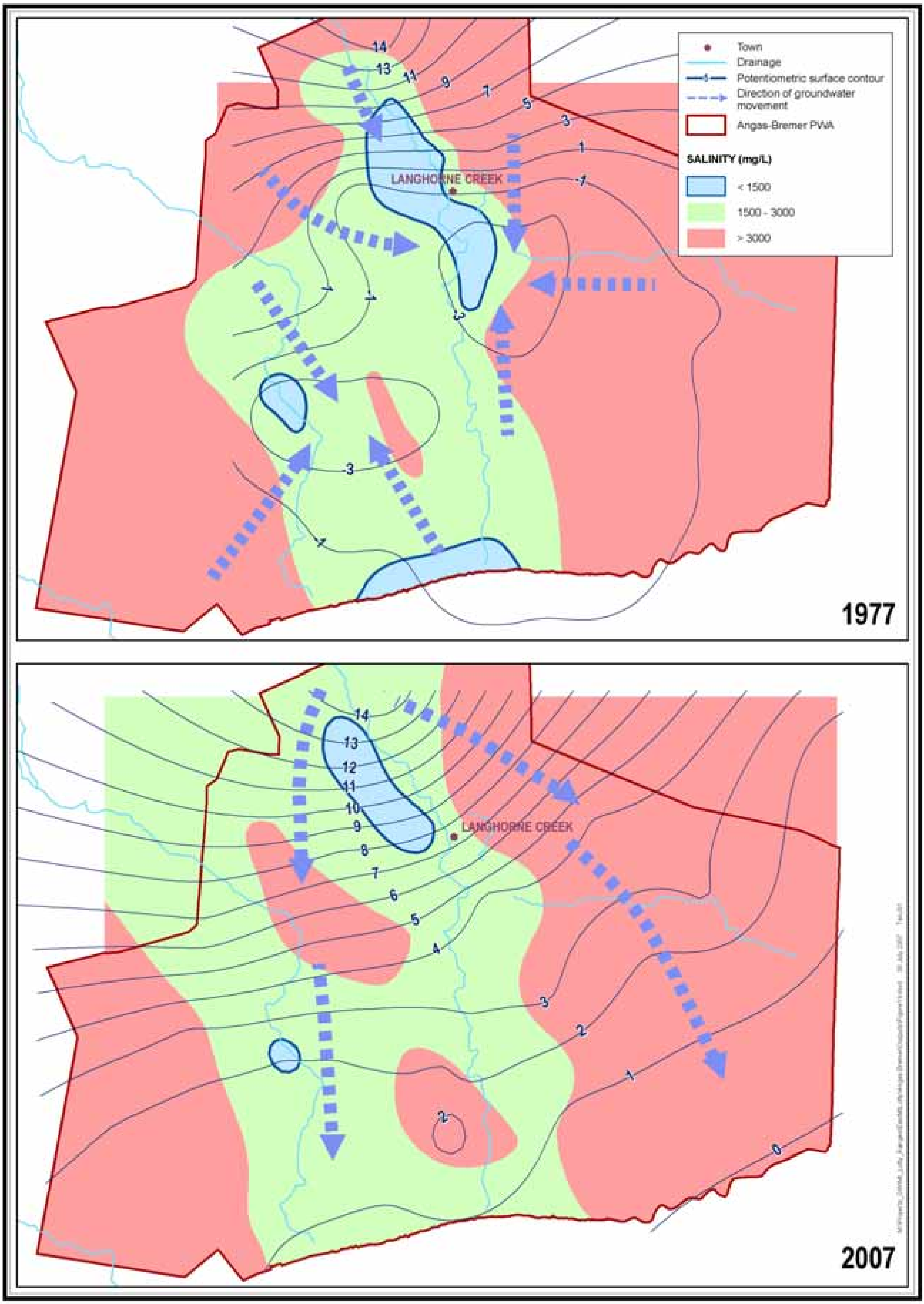


Figure 20 Comparison of groundwater flow directions – 1977 and 2007

7.2 RECHARGE

Between 5000 and 8000 years ago, South Australia and much of the rest of the world, experienced a much wetter climate than has existed over the last hundred years or so (Bowler, 1971). Sea levels were also higher, and the areas flooded in 1956 around the lakes were probably permanently inundated. There would have been significantly greater volumes of runoff flowing out of the Ranges onto the plains of the Murray Basin, which would have recharged the MGL aquifer forming the areas of low salinity. The area inundated by the 1992 floods was less than one third of the total area that has undergone flooding at some time in the past, based on radiometric data collected by airborne geophysics. This process of ancient recharge is supported by the carbon-14 estimate of the uncorrected age of the MGL groundwater of about 4000–8000 years (Cresswell and Herczeg, 2004).

Cresswell and Herczeg (2004) also deduced that current groundwater flow from the Ranges is not a significant contributor to recharge in the MGL aquifer, and that slow downward leakage from the Quaternary aquifer across the aquitard recharges the MGL aquifer over a time scale that varies spatially from a few hundred to a few thousand years.

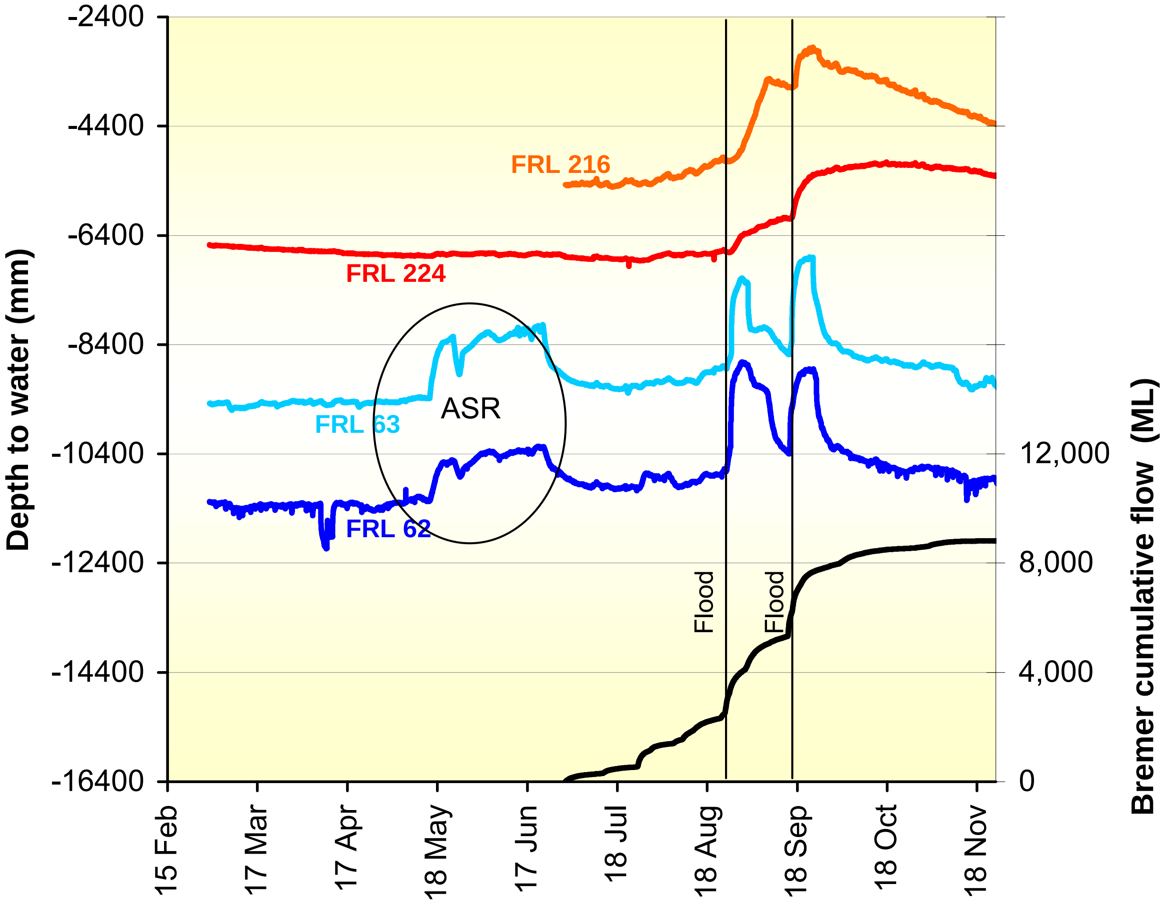


Figure 21 Groundwater level response to 2003 floods

Figure 21 displays the response to two flood events in 2003 in both the confined MGL aquifer (FRL 62 and 63 in blue), and the Quaternary aquifer (FRL 216 and 224 in red) as measured by the AB WMC data loggers. The confined aquifer response is instantaneous and is due to hydrostatic loading caused by the extra weight of the floodwaters pressing down on the aquifer. The unconfined response is more gradual, reflecting a slower response to infiltrating surface water.

The rapid decline in confined pressure levels as the floods pass also suggests that no water has recharged the aquifer, when compared with the prolonged response to injection for ASR in May and June. Australian Water Environments (2003) reports that the 1992–93 flood event had "little impact on water levels, and hence appears not to have contributed significantly to adding water to the confined aquifer." If this is the case for the second largest recorded flood in the AB PWA, then the contribution during average or dry years would be even smaller.

These data supports the thesis that there is virtually no current recharge of low salinity water to the confined aquifer, and that even the relatively low current extraction levels still exceed recharge by a considerable degree. The increases in salinity described previously are the manifestation of the depletion of the reserves of fresh groundwater that were recharged 4000–8000 years ago, and also the downward leakage from the saline Quaternary aquifer. Figure 22 shows the gradual decline in the area of low salinity groundwater between 1950 and 2007.

Options to maintain the low salinity groundwater resource include injection of low salinity water such as lake water when the quality is suitable, or imported water from outside the PWA. Injection of what is likely to be dwindling supplies of surface water from the Angas and Bremer Rivers can also be continued, when flows occur. The role of the aquifer will then change from being a source of water supply, to a long term water storage for drought proofing purposes. Desalination of brackish water from either the MGL or Quaternary aquifer is also a possibility.

Figure 22 Depletion of area of low salinity groundwater – 1950, 1977 and 2007

8. DATA LIMITATIONS

Since 1969, when a monitoring network was first established in the Angas Bremer PWA in response to falling groundwater levels and increasing salinity, water levels were monitored at monthly intervals until 2005. Since then, a three monthly water level monitoring regime has been introduced due to resource constraints. This timing does not necessarily capture recovery peaks and drawdown troughs, and may need to be readjusted according to climatic conditions each year. The AB WMC has data loggers installed in 23 wells in the Quaternary and MGL aquifers, however this data has not yet been incorporated in the DWLBC database.

Salinities have been monitored at irregular intervals until 2001, when a decision was made to conduct salinity sampling every two years. The long periods of interrupted monitoring before 2001 has made analysis of salinity trends quite difficult. Although there are currently 86 wells used to monitor salinity in the three aquifers, it is particularly important to have more salinity monitoring wells in areas of concentrated pumping. Monitoring salinity in active irrigation wells in a coordinated manner has proved to be a very efficient method in other prescribed wells areas. The current two yearly salinity monitoring is inadequate for obtaining a good understanding of salinity changes, since all allocation transfers are based on aquifer salinity patterns.

It is imperative to have a good understanding of aquifer and aquitard geometry and the level of interconnection between different aquifers. Significant work has been carried out to identify the extent and thickness of the Quaternary and MGL aquifers. However, there is not a good understanding of the spatial limits and thickness of the aquitard between the Quaternary and MGL aquifers, even though it has major influence over connectivity between the Quaternary and MGL aquifers.

The potential impact of leaky wells on groundwater salinity, particularly under pumping conditions, is not known with certainty

ASR affects groundwater levels and salinity, but the extend of this influence is not known due to incomplete spatial coverage of ASR wells. Annual injection volumes obtained from annual irrigation reports do not reflect the actual total volumes injected because not all irrigators submit reports, and those that are submitted are sometimes incomplete.

9. CONCLUSIONS

The major drivers of changes in the groundwater system are the intensity of groundwater use, and the amount of recharge entering the aquifers. An assessment of groundwater monitoring trends and groundwater use and allocation data has reached the following conclusions:

- Since 1993, the significant reduction in groundwater extractions has resulted in large recovery of pressure levels in the MGL aquifer, with an average rise of 0.15 m/yr. A similar trend has been observed in the Quaternary aquifer.
- The potentiometric surface map for 2006–07 does not show a cone of depression during the irrigation season at the current level of groundwater extraction, and groundwater throughflow has been resumed.
- Despite the large recovery in MGL pressure levels, salinity levels are continuing to increase at an average rate of ~20 mg/L/yr since 1993. Some wells display a decrease in salinity, which is due mainly to ASR activity and is not representative of regional trends. The increases in salinity are driven by lateral inflow of more saline groundwater from upgradient of extraction areas, and downward leakage from the Quaternary aquifer.
- There is virtually no current recharge of low salinity water to the confined aquifer, and the relatively low current extraction levels (~1000 ML/yr) are depleting of the reserves of fresh groundwater that were recharged 4000–8000 years ago. The rate of depletion will increase if extractions also increase.
- About 85% of the total current extraction in the Angas Bremer PWA comes from two low salinity zones located along the Angas and Bremer Rivers. This extraction represents only 24% of the total allocation in these zones.
- The only way to maintain the low salinity groundwater resource for the long term, is to inject good quality water from other sources, and continue to recharge surface water. The role of the aquifer will then change from being a source of water supply, to a long term water storage for drought proofing purposes.
- The current groundwater monitoring program needs to be improved in order to accurately assess groundwater trends and provide appropriate advice for ongoing adaptive management of the resource.

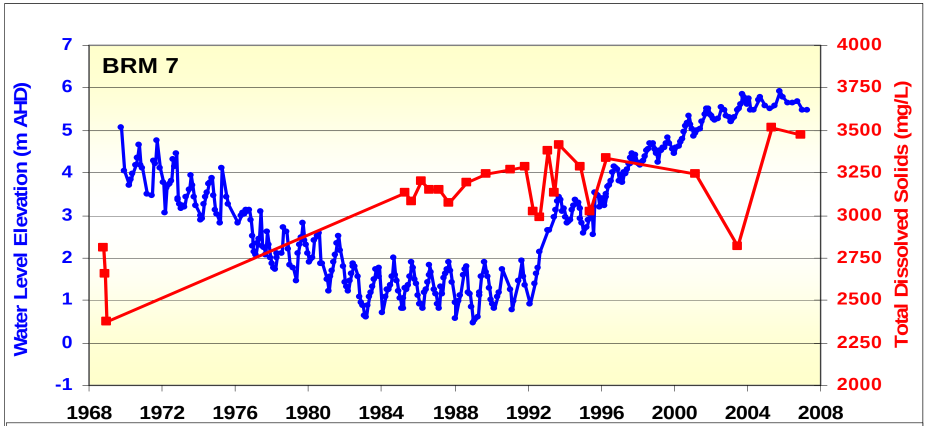
10. RECOMMENDATIONS

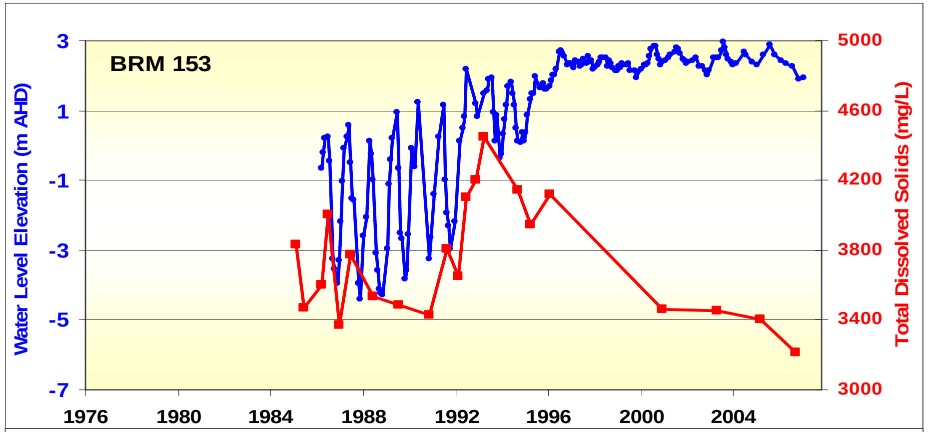
In order to manage groundwater resources successfully, the following actions are recommended:

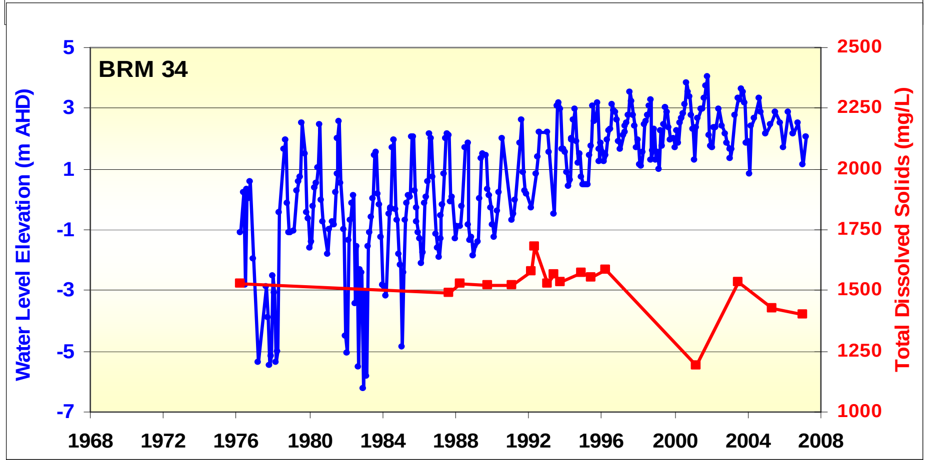
- Two management zones should be created over the areas of low salinity groundwater defined in this report. Given the current slow degradation of the resource, the total long term extraction rate within these zones should not increase significantly above 1000 ML/yr. The potential change in role of the aquifer from supply to storage, should also be discussed. Further monitoring and the development of an appropriate groundwater model in the future may assist in formulating management options, such as recharging imported or lake water, and extracting saline or brackish groundwater for desalinisation.
- A comprehensive monitoring network review is needed with particular consideration of the density and spatial distribution of wells, as well as frequency and quality of data collected. The status of the monitoring network has to be reviewed at regular intervals, with recommendations on required well maintenance and network upgrades.
- Monitoring status reports should be produced on a regular basis every two years to inform possible adjustments in allocations.
- Salinity monitoring needs to be conducted at least annually, but ideally twice a year (before and after each irrigation season), to establish if salinity fluctuations occur within an irrigation season caused by downward leakage. A groundwater sample should also be collected annually from each licensed well.
- The hydrostratigraphy of the area needs to be reviewed, in particular the identification of the aquitard between the Quaternary and MGL aquifers from geological or drillers' bore logs, and whether the upper Tertiary unit should form one aquifer with the Quaternary or Tertiary sediments, ie. STY 109 & 206 and FRL 71 & 72.
- The potential for resource degradation through leaking wells should be investigated in areas where saline groundwater in the Quaternary aquifer has a higher head than the MGL aquifer, with recommendations for further work. More extensive salinity monitoring would assist in identification of leaking wells.

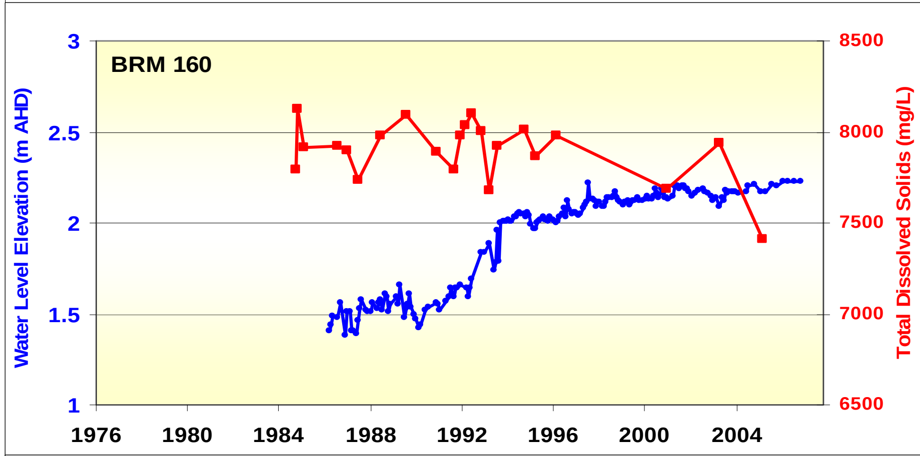
APPENDICES

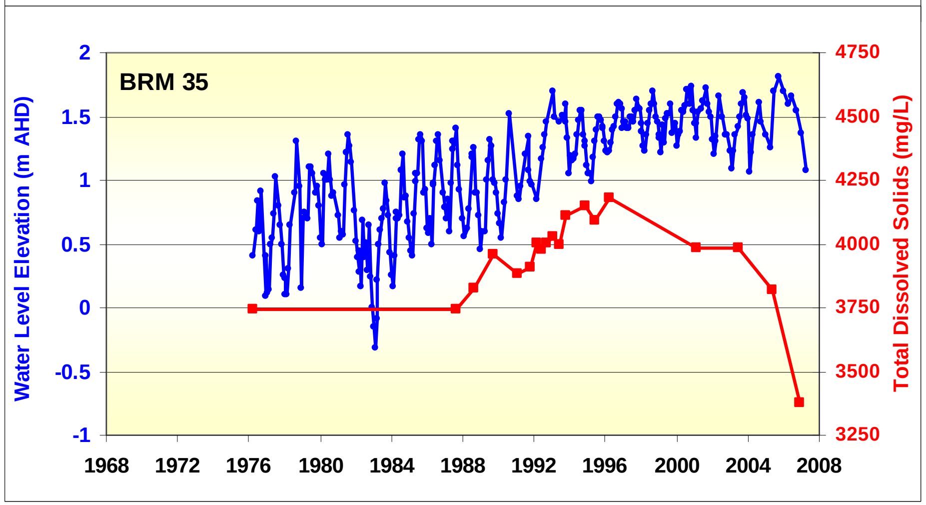
APPENDIX A. SELECTED MGL HYDROGRAPHS OF WATER LEVEL AND SALINITY

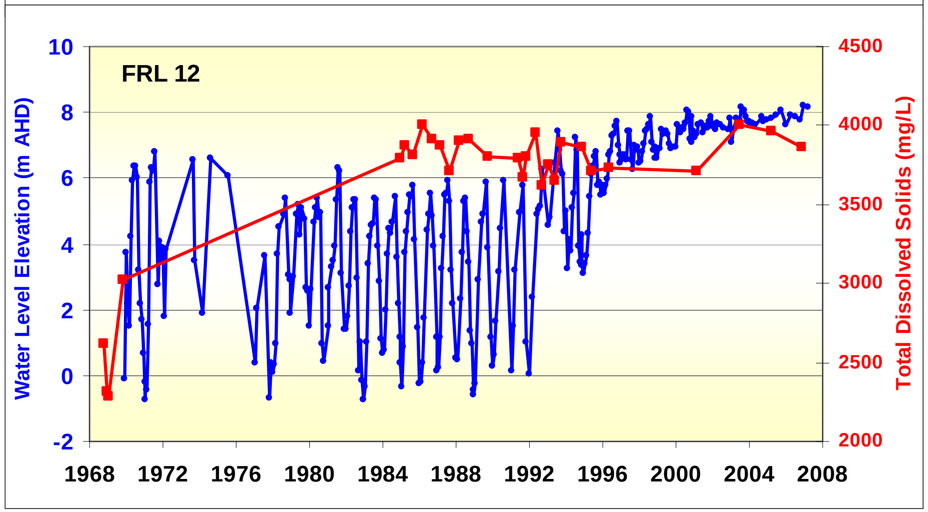

BRM 7
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
7
6
5
4
3
2
1
0
-1
4000
3750
3500
3250
3000
2750
2500
2250
2000
1968 1972 1976 1980 1984 1988 1992 1996 2000 2004 2008

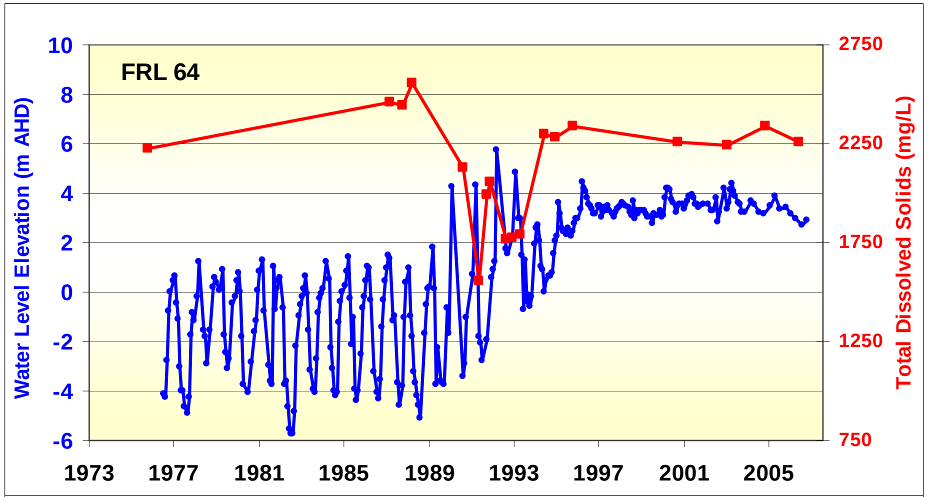

BRM 153
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
3
1
-1
-3
-5
-7
5000
4600
4200
3800
3400
3000
1976 1980 1984 1988 1992 1996 2000 2004

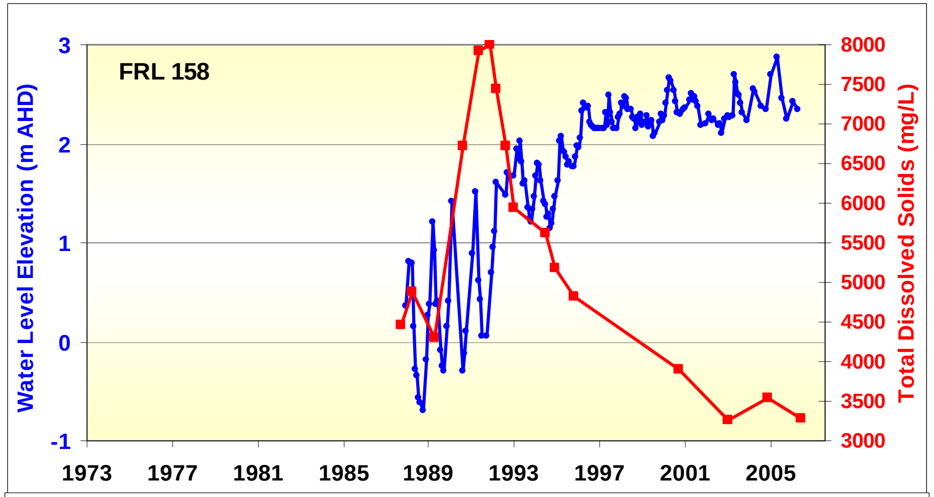

BRM 34
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
5
3
1
-1
-3
-5
-7
2500
2250
2000
1750
1500
1250
1000
1968 1972 1976 1980 1984 1988 1992 1996 2000 2004 2008

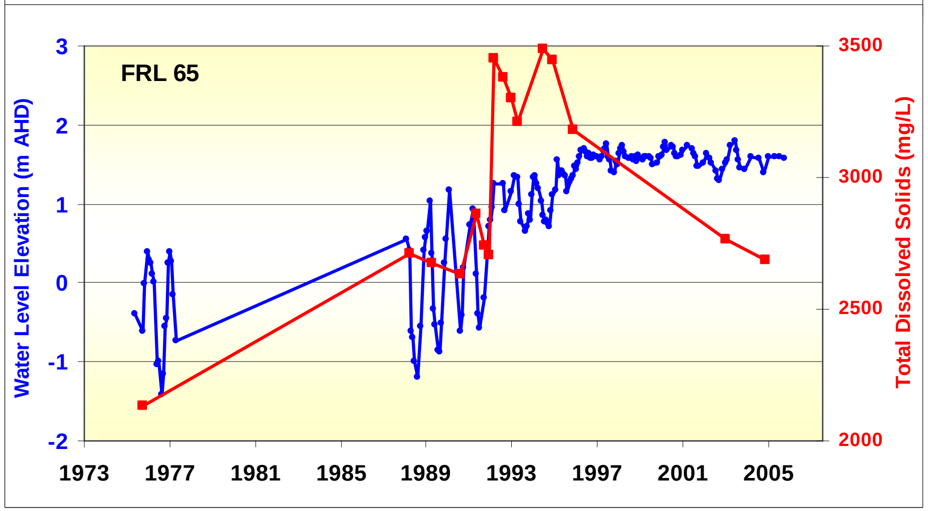

BRM 160
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
3
2.5
2
1.5
1
8500
8000
7500
7000
6500
1976 1980 1984 1988 1992 1996 2000 2004

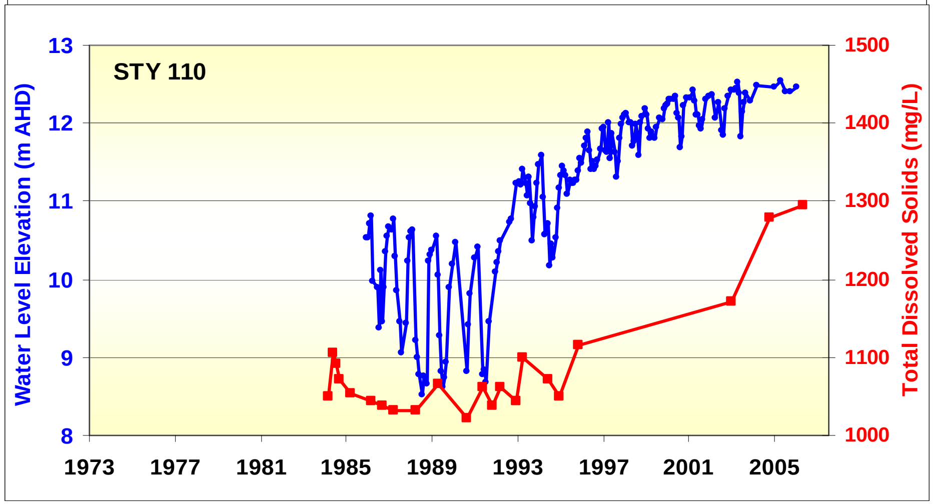

BRM 35
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
2
1.5
1
0.5
0
-0.5
-1
4750
4500
4250
4000
3750
3500
3250
1968 1972 1976 1980 1984 1988 1992 1996 2000 2004 2008


FRL 12
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
10
8
6
4
2
0
-2
4500
4000
3500
3000
2500
2000
1968 1972 1976 1980 1984 1988 1992 1996 2000 2004 2008

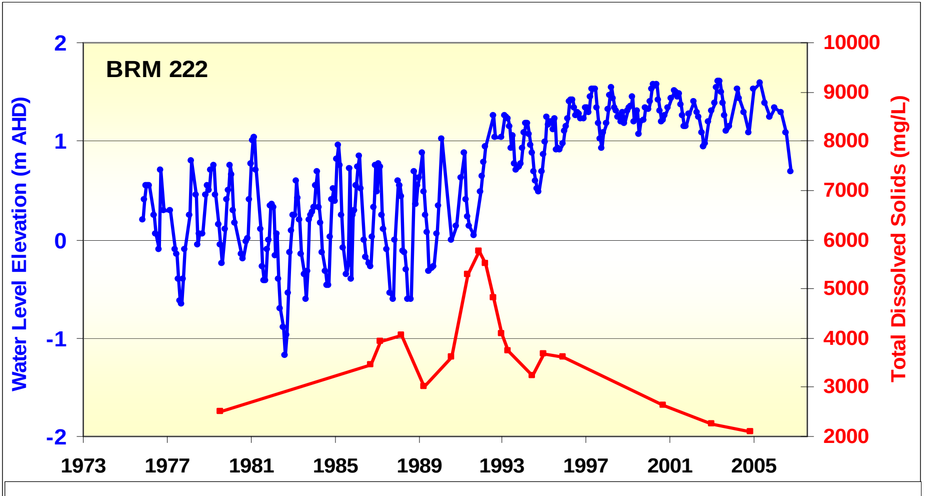

FRL 64
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
10
8
6
4
2
0
-2
-4
-6
2750
2250
1750
1250
750
1973
1977
1981
1985
1989
1993
1997
2001
2005

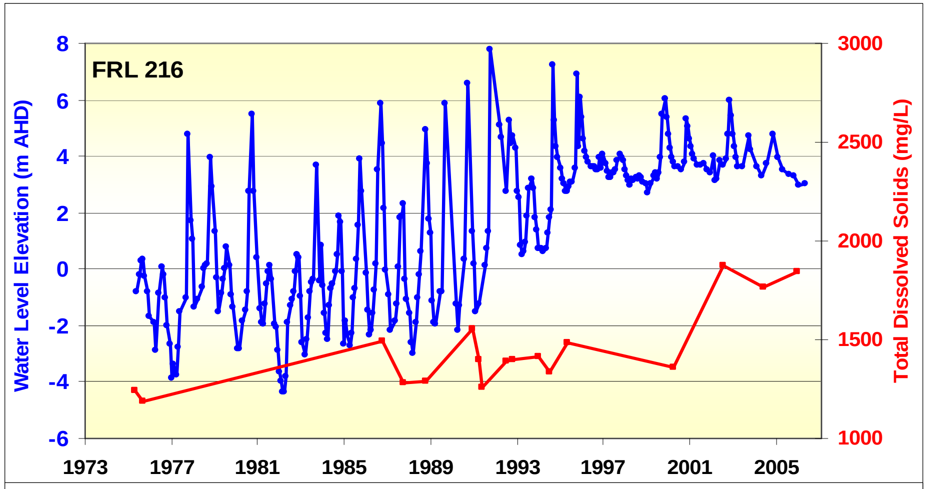

FRL 158
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
3
2
1
0
-1
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
1973
1977
1981
1985
1989
1993
1997
2001
2005

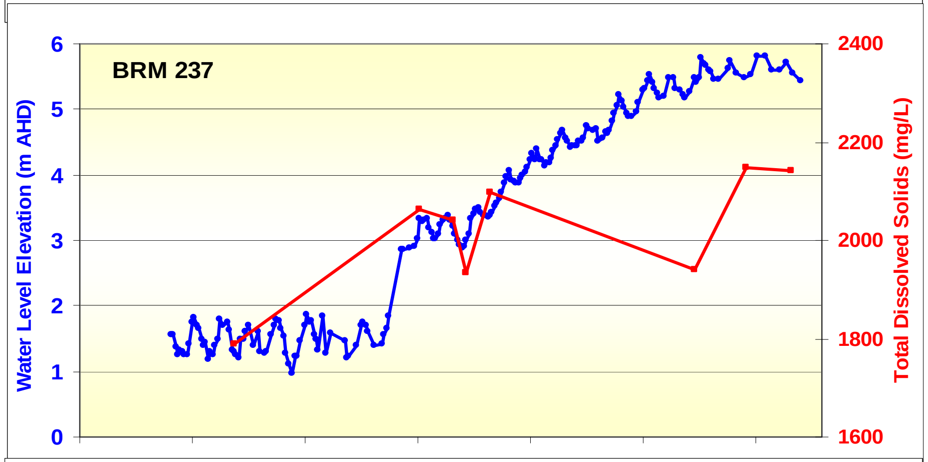

FRL 65
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
3
2
1
0
-1
-2
3500
3000
2500
2000
1973
1977
1981
1985
1989
1993
1997
2001
2005

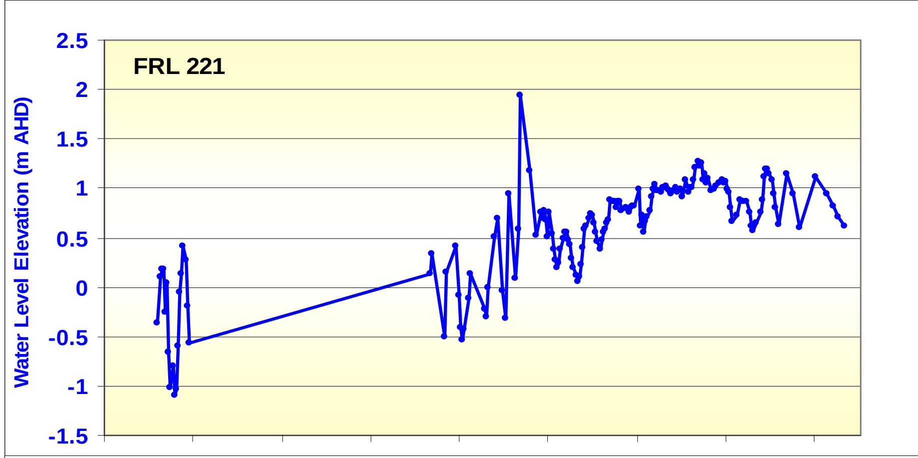

STY 110
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
13
12
11
10
9
8
1500
1400
1300
1200
1100
1000
1973
1977
1981
1985
1989
1993
1997
2001
2005

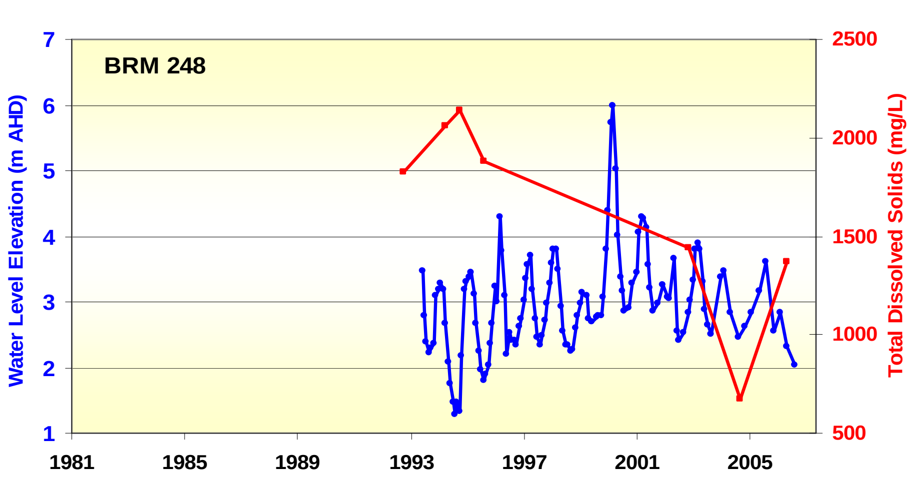
APPENDIX B. SELECTED QUATERNARY HYDROGRAPHS OF WATER LEVEL AND SALINITY

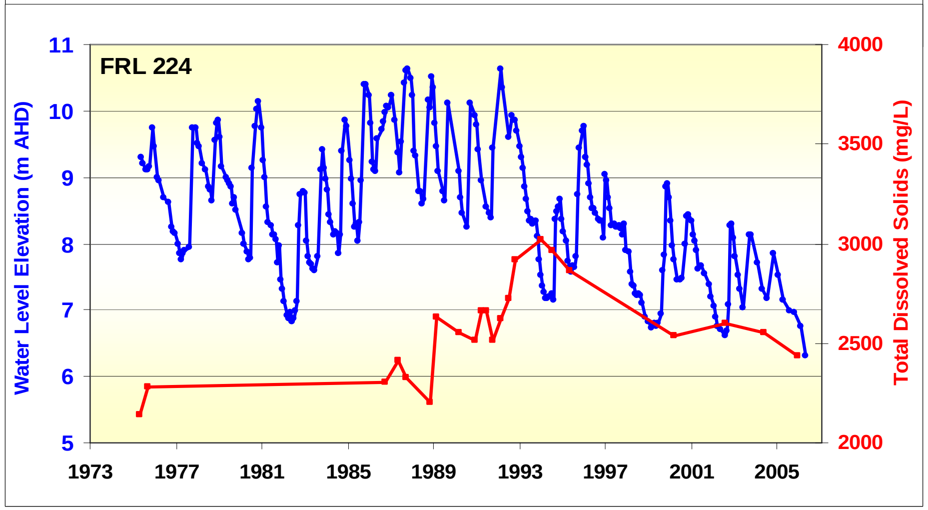

BRM 222
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
2
1
0
-1
-2
10000
9000
8000
7000
6000
5000
4000
3000
2000
1973
1977
1981
1985
1989
1993
1997
2001
2005

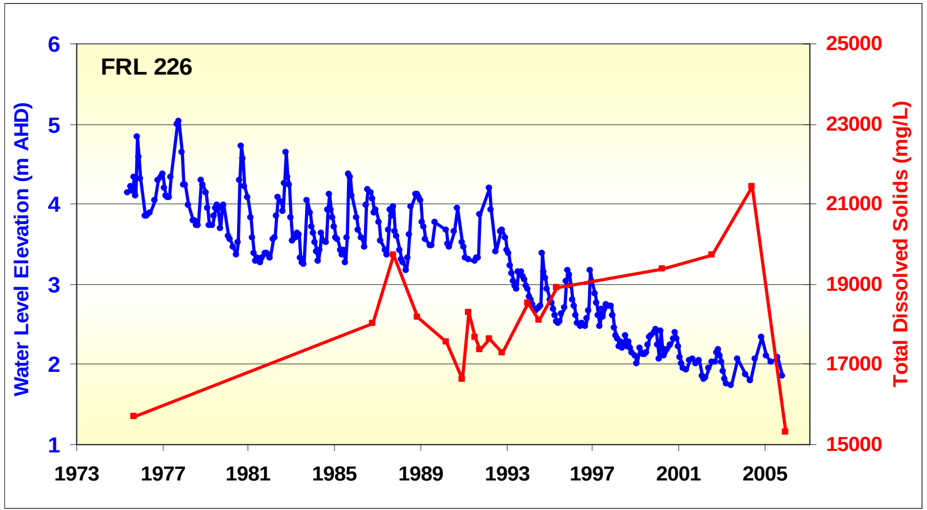

FRL 216
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
8
6
4
2
0
-2
-4
-6
3000
2500
2000
1500
1000
1973
1977
1981
1985
1989
1993
1997
2001
2005

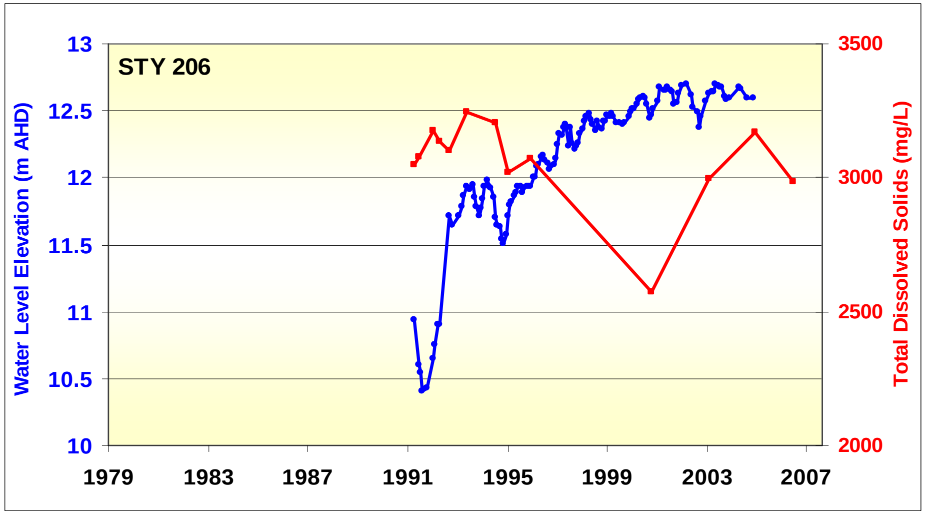

BRM 237
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
6
5
4
3
2
1
0
2400
2200
2000
1800
1600

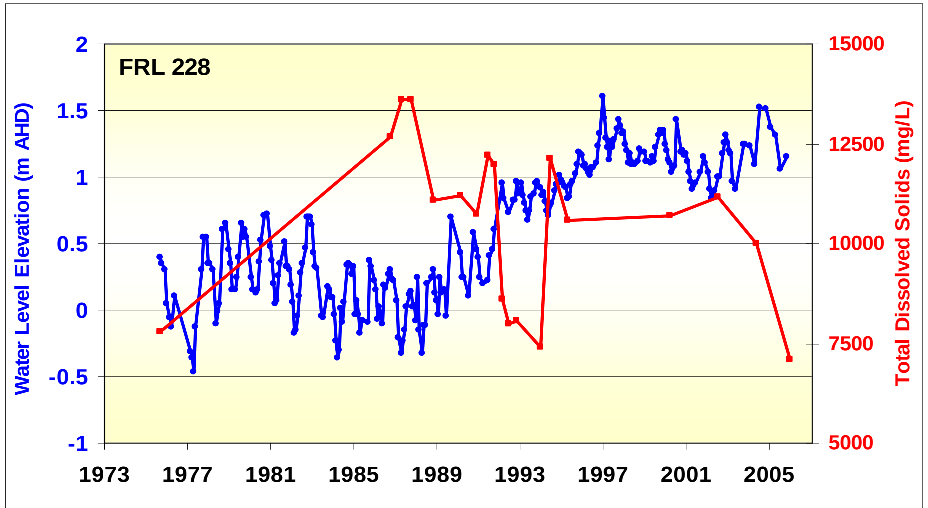

FRL 221
Water Level Elevation (m AHD)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5


BRM 248
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
7
6
5
4
3
2
1
2500
2000
1500
1000
500
1981
1985
1989
1993
1997
2001
2005


FRL 224
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
11
10
9
8
7
6
5
4000
3500
3000
2500
2000
1973
1977
1981
1985
1989
1993
1997
2001
2005


FRL 226
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
1
2
3
4
5
6
15000
17000
19000
21000
23000
25000
1973
1977
1981
1985
1989
1993
1997
2001
2005


STY 206
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
10
10.5
11
11.5
12
12.5
13
2000
2500
3000
3500
1979
1983
1987
1991
1995
1999
2003
2007


FRL 228
Water Level Elevation (m AHD)
Total Dissolved Solids (mg/L)
-1
-0.5
0
0.5
1
1.5
2
5000
7500
10000
12500
15000
1973
1977
1981
1985
1989
1993
1997
2001
2005

GLOSSARY

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through.

Aquifer, confined — Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

ASR — Aquifer, storage and recovery. The process of recharging water into an aquifer for the purpose of storage and subsequent withdrawal.

Aquifer test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resource available for development from the well.

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them.

BoM — Bureau of Metrology, Australia.

Bore — *See well.*

^{14}C — Carbon-14 isotope (percent modern Carbon; pmC).

Catchment — That area of land determined by topographic features within which rainfall will contribute to runoff at a particular point.

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge. Continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality.

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia).

Irrigation — Watering land by any means for the purpose of growing plants.

Irrigation season — The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May.

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer; the unit is metres (m).

Tertiary aquifer — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago).

T — Transmissivity**.** A parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow); the unit is m^2/d.

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

Water allocation — (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

WAP — Water allocation plan**.** A plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with Division 3 of Part 7 of the Act.

Well — (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

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