DWLBC REPORT

Booborowie Valley Groundwater Monitoring Status Report 2005

2005/31

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

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Paul Magarey and David Deane

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

May 2005

Report DWLBC 2005/31

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

action
Salinity & Water
AUSTRALIA

Government of South Australia
Northern and Yorke Natural Resources Management Board

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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

Booborowie Township is situated approximately 32 km north-northeast of Clare, and 150 km north of Adelaide in South Australia's mid-north. Booborowie Valley is an alluvium filled valley, which provides limited but important sources of groundwater to landowners in the region.

The Valley was hydrogeologically investigated by Cobb and Smith (1977), which included water well surveys, geophysical surveys and test drilling. It was concluded that recharge to the alluvial and basement aquifers was primarily from incident rainfall, with a component of recharge to alluvial aquifers from abutting basement rock.

Aquifer testing by Cobb and Smith (1977) attempted to quantify aquifer parameters such as transmissivity and hydraulic conductivity, although it is recognised that initial estimates of these parameters require further refining (Clarke, 1990; Magarey and Deane, 2004).

The aim of this report is to summarise existing knowledge of groundwater resources, analyse groundwater level and salinity trends, and estimate existing water use and landuse practices. It is hoped that findings from the report will help to determine whether further action should be taken to ensure the long-term sustainability of the groundwater resources.

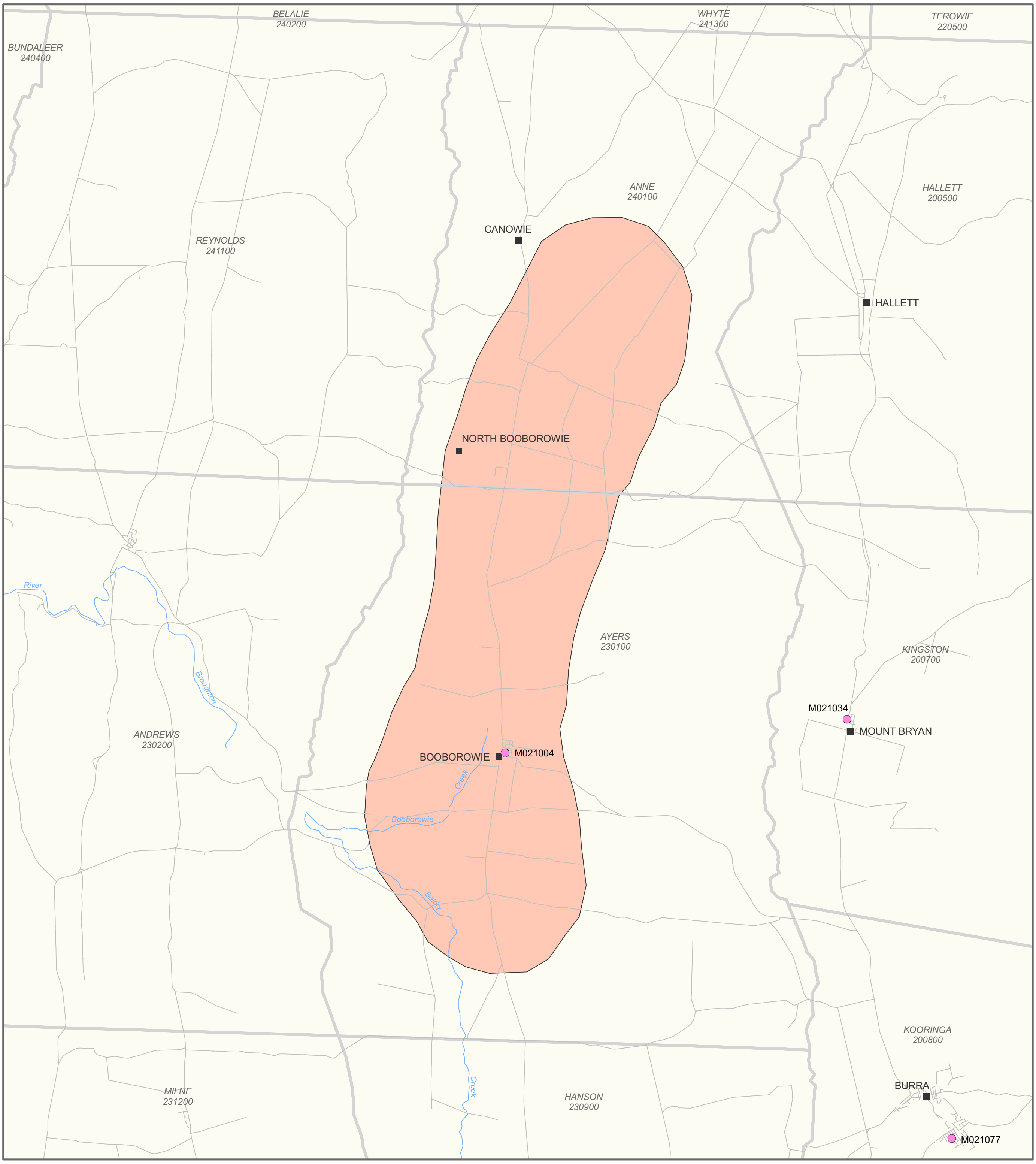

Figure 1.
Location Map, Booborowie Valley

■	Town		Booborowie Valley
●	Rainfall Station		Hundred Boundary
—	Drainage		NYAD Boundary
—	Road		

N

0 2.5 5 km

Datum: Geocentric Datum of Australia 1994 South Australia Lambert
Projection: Lambert Conformal Conic

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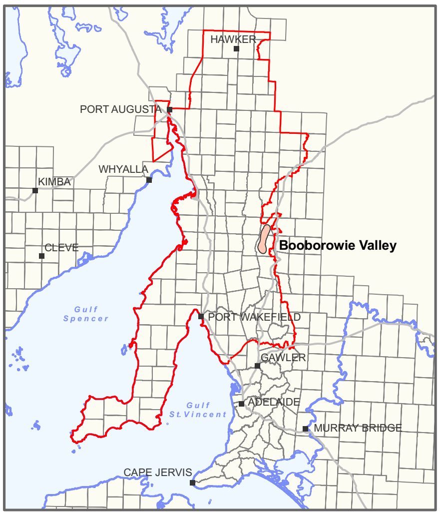
Date: October 2005



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2. METHODOLOGY.

The methodology for the following report involved three components: (1) Literature review; (2) community and agency consultation; and (3) analysis of monitoring records for standing water level and salinity.

Literature Review

Literature was obtained on previous hydrogeological investigations and geophysical surveys for the Booborowie Valley area which included reports by Flint, (1972), McPharlin, (1974), Cobb and Smith, (1977), Clarke (1990), Clarke (1996) and the unpublished pump test report by Dennis (1998). It was noted from the literature that there has not been significant investigative work (hydrogeologically) since Cobb and Smiths investigations in 1977. Clarke (1990) summarised water level and salinity trends, while Dennis (1998) performed an aquifer test for a private owner on water well 6631 01114.

Consultation

The aims of the consultation phase were to raise awareness regarding the project objectives, improve estimates of average water use and to provide opportunities for the community to relate their experience and understanding of resource condition. As irrigation is the largest single demand on water resources in the region, irrigators were the focus of consultations. The process included a public meetings, surveys, telephone or personal interviews and field inspections.

Known irrigators in the area were initially identified through meetings with members and staff of the Northern and Yorke NRM Board, Primary Industries and Resources, Jamestown, Local Government and Animal and Pest Plant Control Board. These interviews also provided opportunity for some historical resource use to be identified.

Irrigators were contacted by telephone, and the aims of the project explained. Water use surveys were sent out and irrigators were invited to document details of their water use and return them to the project team for collation.

A public meeting was held in Booborowie at project commencement to enable participation of members of the local community not specifically targeted through identified use of water for irrigation.

The meeting introduced the project, and outlined the aim and scope of work to be done. Opportunity was given to those present to make comment or raise any concerns with regard to water resources in the region. The meeting was well attended, with good historical information and general information on the water resources coming to light. The attendance list is seen in Appendix A.

Field visits took place to a number of landholders to gain further insight into farming practices and to quantify application rates of groundwater irrigated for crops. These helped improve the understanding gained through the survey sheets, which included the irrigation, groundwater extraction rate/use, water quality and bore yield. A copy of the survey form can be seen in Appendix B.

Where appropriate, a water sample was taken from landowners bores and measured for salinity (electrical conductivity).

Analysis of Monitoring Network

The groundwater monitoring network was analysed to determine trends in groundwater level and salinity. Clarke (1990) previously summarised readings from the monitoring network but no analysis has been done since. Components of this analysis include:

- Collation of rainfall records and trends for the monitored period in question.
- Analysis of groundwater level trends in government drilled/owned observation wells.
- Noting of groundwater level trends in private observation bores.
- Observed changes in salinity
- Establishment of hydraulic gradients
- Determining the effect that irrigation may be having on groundwater level

This information was used to determine the level of risk imposed on the resource.

3. REGIONAL SETTING

Geology

Booborowie Valley is located in the mid-north of South Australia, which geologically is part of the Adelaide Geosyncline (Preiss, 1987). The Adelaide Geosyncline is a failed continental rift valley, which is exposed today as ranges extending from Kangaroo Island in the south to Freeling Heights in the north of South Australia (Love, et al 2002). Booborowie Valley is an elongate, northerly trending eroded anticline (Cobb and Smith, 1977), comprising basement rocks of the Burra and Umberatana groups. The central section of the valley contains alluvial and piedmont deposits primarily of Quaternary age, with limited Tertiary sediments (Cobb and Smith, 1977). Figure 2 shows that the main geological formations which include Quaternary sediments, Saddleworth Formation, Undalya Quartzite, Woolshed Flat Shale, Mintaro Shale and Appila Tillite.

Geography/Topography

Booborowie Valley proper commences about 17 km north of the township and ends two to three kilometres south of the town where it merges with the upper part of the Broughton River Valley. The Valley bottom averages about two kilometres wide, and beyond this the land surface gradually steepens toward the hills which rise typically 150-200 metres above the valley floor. Booborowie Township itself is 390 m above sea level, with the larger hills furthest from the valley bottom rising to 750 m at their highest (Clarke, 1990).

Surface water drainage consists of the ephemeral Booborowie Creek, which flows in a southerly direction through the valley. A number of small ephemeral creeks drain the surrounding hills. Most defined drainage lines do not reach the valley bottom, and any surface flow quickly infiltrates into the porous sediments when runoff does occur. The last significant flow in Booborowie Creek was during flooding events in 1992 (Affolter, Woodgate pers. comm., 2005).

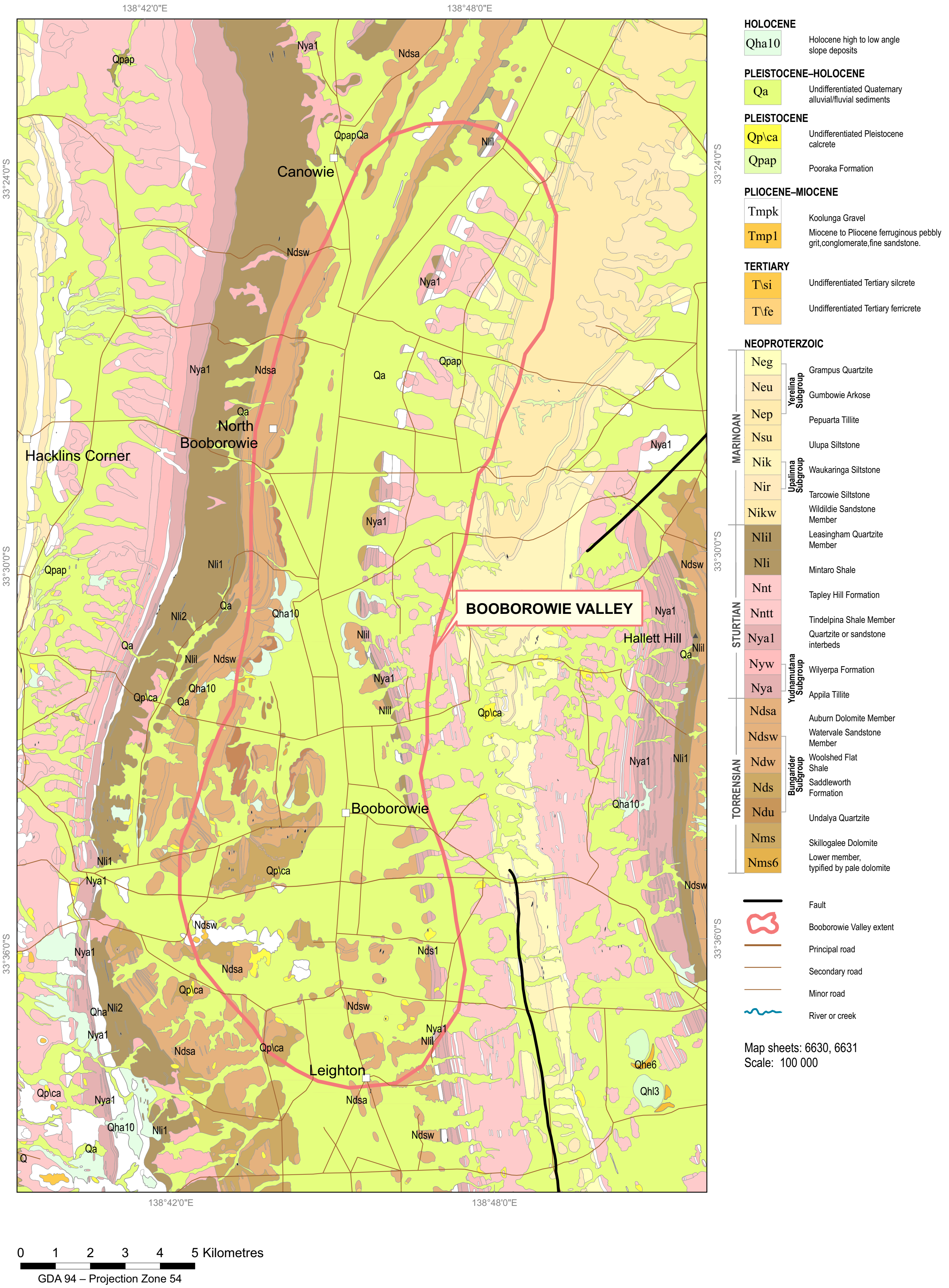
Hydrogeology

The main hydrogeologic units are Quaternary alluvial and piedmont deposits which are underlain by fractured rocks. Alluvial sediments comprise mostly brown clayey silt, occasional gravel and boulder beds with lenses of black carbonaceous silt. Pleistocene piedmont deposits comprise clayey silts with red gravel and boulder beds and poorly sorted piedmont gravels and silts which are found in the floor of the valley (DME, 1964). Wells are drilled into the fractured rocks in valley bottom and adjacent ranges but yields are generally less than 1 L/s (SA Geodata, 2005). Highest yielding wells are in the central to northern section of the valley, and are associated with piedmont gravels (SA Geodata, 2005). A number of stock wells drilled on the slopes and valley floor intersect both fractured rock and sedimentary aquifers (SA Geodata, 2005; Clarke, 1990).

Recharge to aquifers is by direct rainfall that falls in the valley and surrounding hills (Cobb and Smith, 1977; Clarke 1990). Salinity of groundwater generally ranges between 1200-3000 mg/L TDS, with higher salinities located in the south.

Aquifer testing (Cobb and Smith, 1977) took place at observation well AYS 36. A transmissivity value of 200 m^3/day/m was derived but was noted by Clarke (1990) to be ambiguous in several ways. Further aquifer testing was conducted by Dennis (1998) on irrigation well 6631 01114, where a transmissivity value of 520 m^3/day/m was calculated. This was based on a 480 minute constant rate discharge test of which results can be seen in Appendix C.

Figure 2: Regional Geology



100 000 GEOLOGY – SOUTH AUSTRALIA

BOOBOROWIE VALLEY

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PIRSA: 202898_001

Historical Landuse

Booborowie Valley was first settled by the Browne brothers, William and John in 1842 who took up tracks that were to become the Booborowie and Canowie runs (Cobb and Smith, 1977). The Browne's were successful in breeding Merino sheep and Shorthorn Cattle.

During the early period of settlement the shallowness of the water table was of considerable concern to landowners and the valley was often waterlogged in winter with inches of water lying on the surface. After the surface dried out water was still within easy reach; fencing posts would strike water within the first few inches (Cobb and Smith, 1977).

The 1920s saw the beginnings of the lucerne seed industry that was to become the singular economic importance to the district (Cobb and Smith, 1977). Booborowie Valley has been described as the "nursery of the South Australian lucerne seed industry," and between 1930-31 South Australia's total area sown to lucerne for seed was within the Hundreds of Anne and Ayres. The fertile soils and abundance of water were ideal conditions for growth. In the 1920s it was possible to get seven cuts of lucerne per year (Cobb and Smith 1977).

The lucerne industry continued to flourish, and reached its peak between 1968 and 1970. The period 1968-1969 marked the highest recorded acreage under cultivation (20,250 ha), and the following year stock was at record numbers totalling 149,000. The benefits of irrigating lucerne were being actively investigated in the 1950s although at the time of Cobb and Smiths investigation in the early 1970s only two areas of irrigated lucerne had been established, and in any one year the total area under irrigation only averaged 70 ha (Cobb and Smith, 1977, pg3).

In the late 1970s and early 1980s, the lucerne seed industry was decimated by aphid outbreaks (Clarke, 1996), but has since recovered. The Booborowie Valley and districts continue to cultivate lucerne both in an irrigated and non-irrigated form, with present day irrigation predominantly taking place close to the Hundred of Anne/Ayres boundary.

Current Landuse

Current landuse incorporates a mixture of dryland cropping, grazing, grazing of modified pastures, irrigated grasses, oil seeds (canola) and oleaginous fruits (BRS, 1999). There is also a small section of irrigated carobs. The pie graph below (Figure 3) is a summary of current landuse.

It can be seen from the graph that crop grazing rotation and grazing of modified pastures are clearly the most common land use within the Valley. Irrigated grasses and irrigated vine fruits only comprise a small percentage of total landuse.

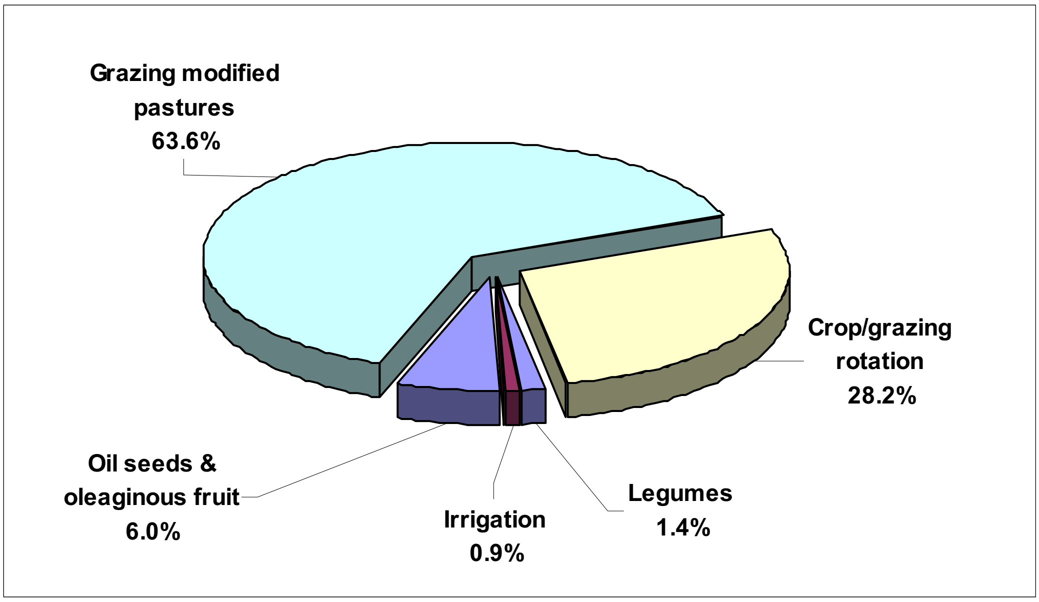


Figure 3: Major landuse within the Booborowie Valley (Source, BRS, 1999).

Climate

The climate is typically Mediterranean, characterised by winter dominant rainfall. Rainfall considered representative of the area has been collected from three rainfall stations: Booborowie Post Office (Station 21004), Mt Bryan (Station 21034) and Burra Post office (Station 21077). Annual average rainfalls for the selected stations are 440, 436 and 445 mm respectively. The average monthly rainfall is shown in Table 1.

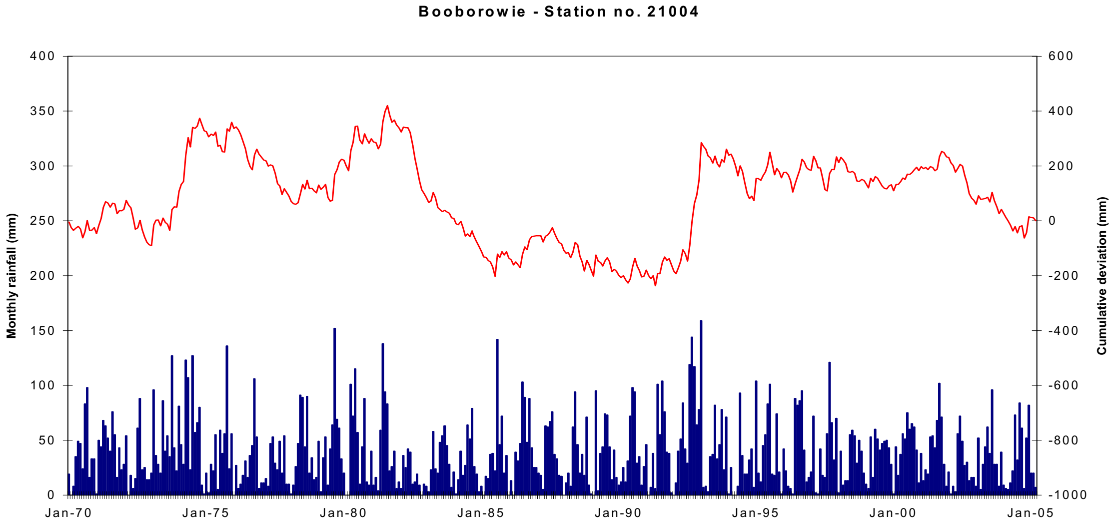
Table 1. Average monthly rainfall (mm).

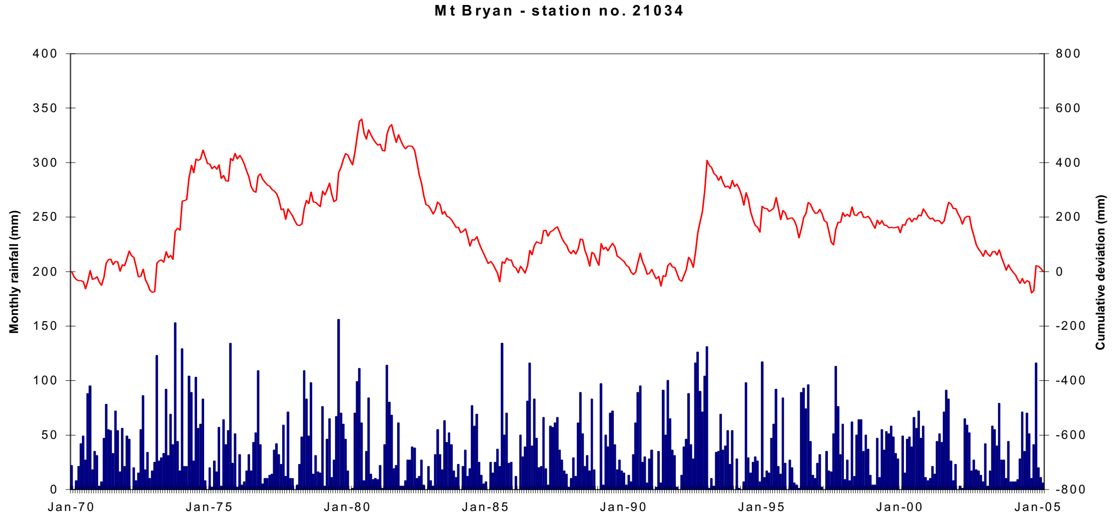
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Booborowie	21	21	16	27	45	49	56	58	50	45	29	23
Mt Bryan	19	22	16	26	44	51	54	58	51	41	28	25
Burra	20	20	19	29	48	54	55	56	50	43	26	25

The rainfall record at Booborowie Post Office has been collected since 1925, with a complete record over the 80 year period. Mt Bryan has had rainfall collected since 1895, while Burra has a complete record from 1859. All three stations show similar short term trends such as above average rainfall during the years 1973 - 1974, 1978 - 1980, and in 1992. Below average rainfall was recorded during the years 1976 - 1977, 1982 - 1985 (inclusive), 1993 - 1994 and from 2002 to March 2005.

Figure 4 shows the monthly rainfall and cumulative deviation from the monthly mean for the period 1970 to April 2005 for the above mentioned rainfall stations. The period 1970 to April 2005 was selected to coincide with the commencement of monitoring for SWL. As the aquifer systems are responsive to incident rainfall, the cumulative deviation of the monthly mean rainfall may correlate with hydrographs of groundwater level observations.

Figure 5 shows the modelled annual rainfall, cumulative deviation and monthly mean from Bureau of Meteorology SILO data (2005) (refer Discussion).





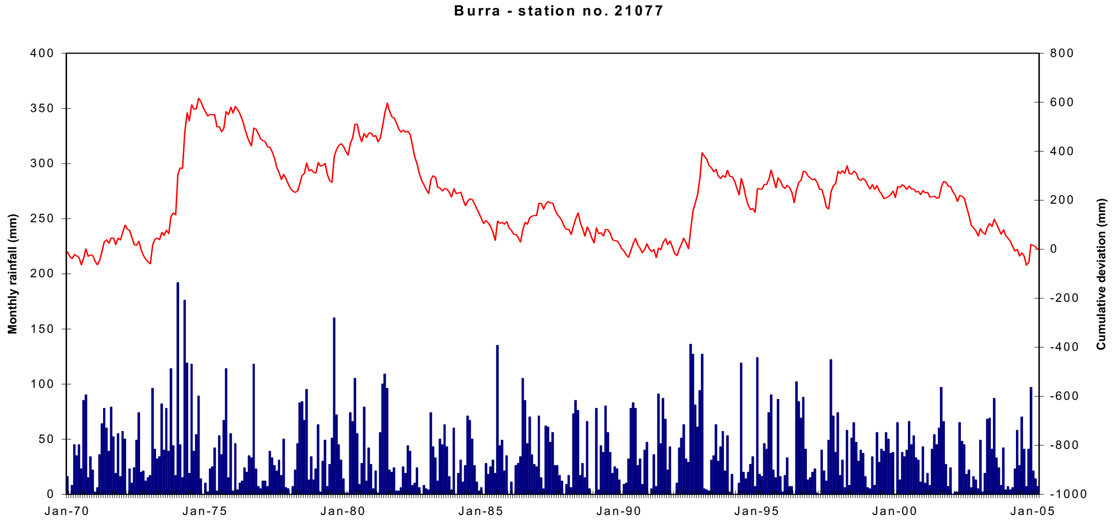


Figure 4: Monthly rainfall and cumulative deviation.

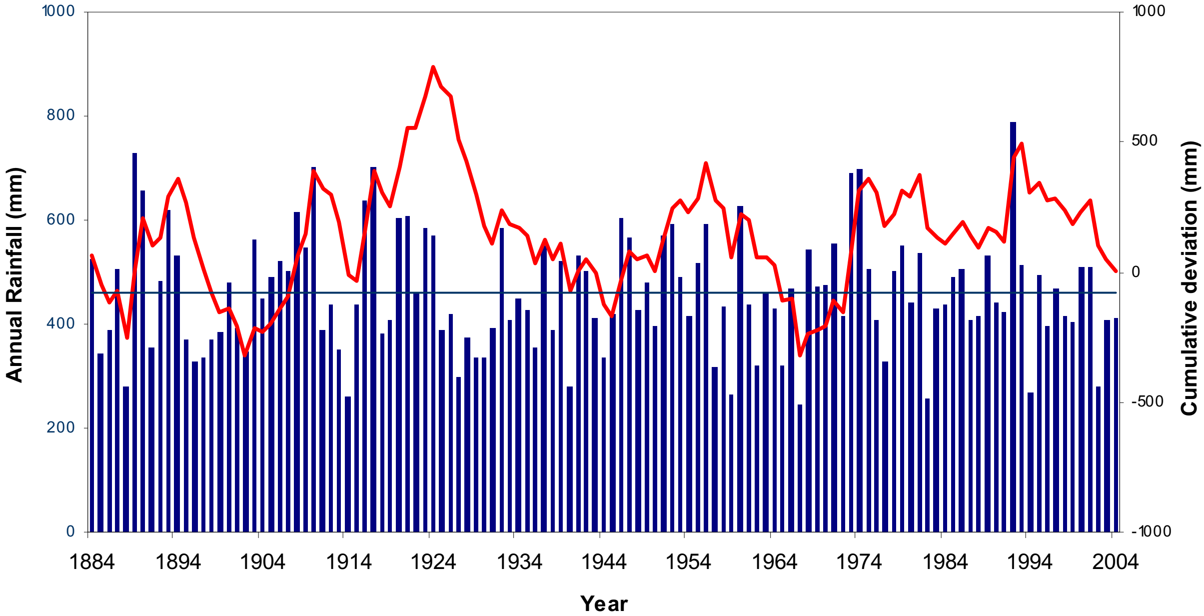


Figure 5: Modelled annual rainfall and cumulative deviation.

4. IDENTIFIED GROUNDWATER USE

Field inspections and community consultation identified five landowners who currently use groundwater for the irrigation of lucerne. The main irrigated parcels are concentrated between the township of Booborowie and the Hundred of Ayres/Anne boundary. Hydrogeologically this area coincides with the part of the valley that has the highest yields. Groundwater of salinity between 2000-3000 mg/L TDS is pumped from a sand/gravel aquifer, and is found at depths between 40-60 m (SA Geodata, 2005). Groundwater is distributed by centre pivot and overhead sprinklers – as well as drip irrigation for the smaller irrigated plots.

Estimated Water Use

Based on area under irrigation, application rates for lucerne, well yield, and pumping information provided by landholders, an estimated 950 ML/yr is used for the irrigation of lucerne. Previous estimates of water use for irrigation were 1100 ML/yr by Flint (1972) and 1200 ML/yr by Clarke (1990). Comparison with these previously published figures supports a modest decrease in water use. Discussions with a local irrigator suggest that the level of current usage is lower than in previous years with savings being attributed to improved management/application regimes (Phin pers. comm. 2005).

Water used for stock purposes has been estimated by using generalised regional stocking rates (MNGWG/AIMS 2004, SOE 2001) and landuse data (BRS 1999) to obtain a total number of dry sheep equivalents (DSE). Water use is calculated by multiplying the volume of water required per day per DSE by the estimated number of stock in the Valley (for further details see Appendix D). Water use for stock was estimated at 250 ML/yr, giving current estimate of total water use for the valley at 1200 ML/yr.

5. MONITORING NETWORKS

The groundwater monitoring network for the Booborowie Valley was established in the early 1970s, in order to monitor groundwater levels and salinity. The purpose of the network is to observe aquifer response to groundwater extraction, seasonal fluctuations in the water table and identify areas that may be under stress due to over-pumping or areas that may be at risk of salinisation.

As part of investigations by Cobb and Smith (1977), waterwell surveys were undertaken from which 53 wells were selected to form the Booborowie monitoring network. A further six wells were added to the network as part of investigative drilling, and completed as water table observation points.

Currently there are 40 wells that are monitored for water level and 30 wells monitored for salinity. The Field Services group within the Knowledge and Information Division DWLBC carries out monitoring on a quarterly basis (Szalay, pers. comm. 2005). The monitoring wells are completed in Quaternary sediments in the floor of the valley, and fractured rock aquifers in the ranges. Some wells have multiple completions in both alluvial sediments and basement rocks. Due to limited well construction information in SA Geodata, the geological formation in which private monitoring wells are completed cannot be identified unless downhole video and/or geophysical techniques are implemented. This is not considered a high priority from a monitoring perspective, as sufficient coverage is provided by Government obswells where the completion details are well documented.

The location of the monitoring network is presented in Figure 6.

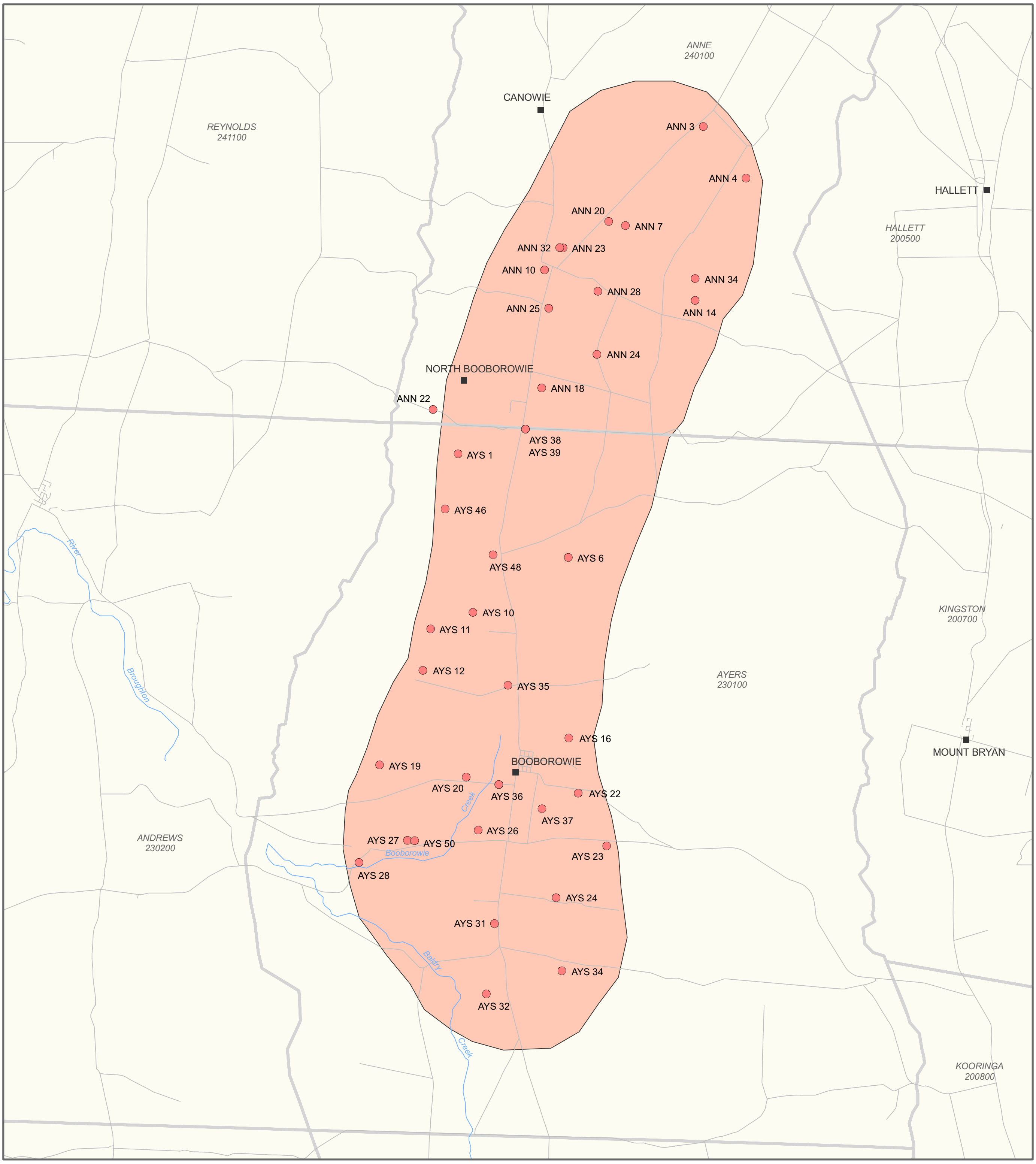


Figure 6.
Current Groundwater Monitoring etwor

- ■ Town
- Drainage
- Road
- Booborowie Valley
- Hundred Boundary
- NYAD Boundary

Monitoring etwor

- ● AYS 10 Obs.No

N

0 2.5 5 km

Datum: Geocentric Datum of Australia 1994 South Australia Lambert
Projection: Lambert Conformal Conic

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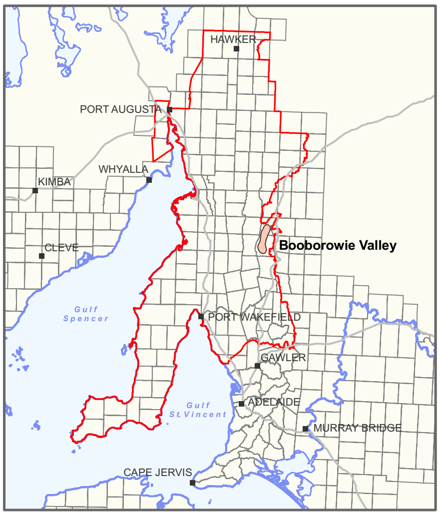
Date: October 2005



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6. WATER LEVEL ANALYSIS

Regular departmental monitoring of standing water levels commenced in 1973. Six Government observations wells – AYS 35, AYS 36, AYS 37, AYS 38/39^ and ANN 20 have the most complete SWL records of any of the observation wells. A number of private wells have consistent monitoring data from ~ 1990 onwards.

There is a correlation between the cumulative deviation from the mean of monthly rainfall, and the annual changes in standing water levels recorded in the six Departmental monitoring wells. This shows that aquifer water levels have a direct response to climatic trends, in particular, above average rainfall events. Hydrographs for three Government observation wells are seen in Figures 7, 8 and 9. The remaining Government observation wells are included in Appendix E.

Of particular interest is that in each of the wells:

- A rise in the SWL occurs in all wells in 1974 corresponding to the very wet season in 1973/74.
- A fall in SWL occurs in all wells in 1976-77 corresponding to the well below average rainfall during that period.
- A rise in the SWL in all wells in 1978-81 corresponding to the above average rainfalls over that period.
- A rise of SWL level in all wells in 1992/93 which correlate to exceptionally wet winter, spring and summer rainfall at that time.
- A fall in SWL occurs in all wells between 2002-2004, which correspond to below average rainfall over that period.
- During the period from 1978 to 1982 a continuous rise in water level is observed in all wells which corresponds to above average rainfall during that period. It is noted that the nature and magnitude of rises is much greater for this period than for similar above average rainfall events*.

^ AYS38/39 is a single well with a double completion.

*This is attributed to the aphid outbreaks that decimated the lucerne industry during this period, in which lucerne production and hence water use decreased.

Individual well observations include:

- ANN 20 is constructed into low yielding material and exhibits a different pattern of behaviour when compared with obswells AYS 35, AYS 36, AYS 37, AYS 38/39.
- AYS 37 shows a consistent decline from 1992, where other wells exhibit relatively steady SWL trends from ~2000.
- AYS 36 shows a decline in water levels between the years 1986-1991 (Figure 9). Declines in water level for this period has been attributed to extraction for irrigation.

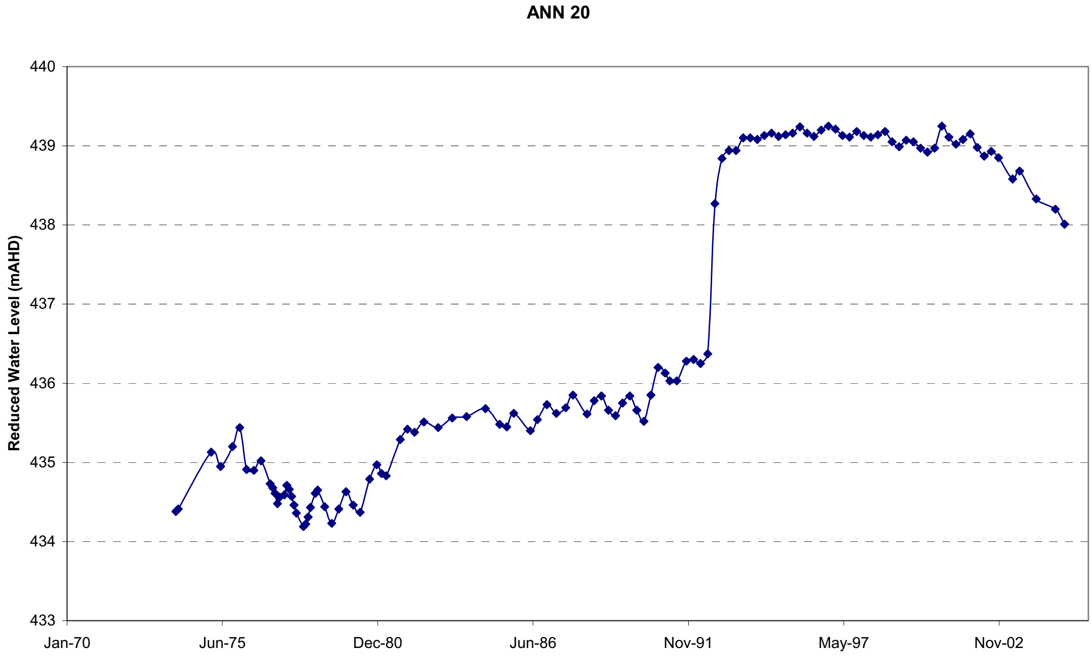

Figure 7: Government observation well ANN 20 hydrograph.

ANN 20 (Figure 7) is located north of the major irrigation areas in the Valley, and upgradient from major extractive pressure.

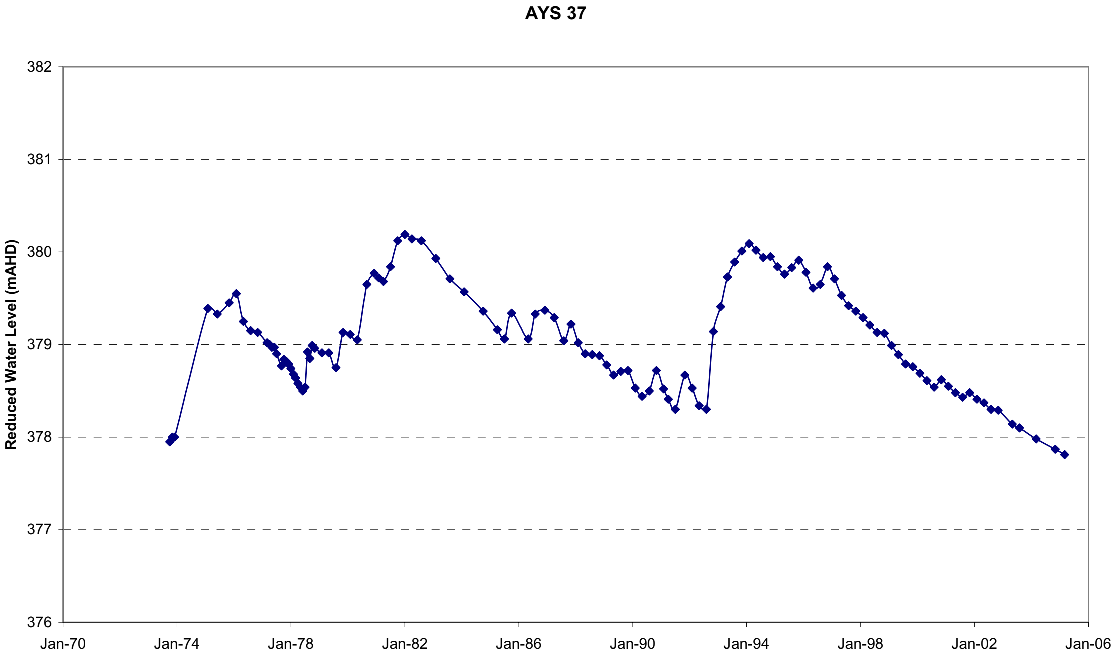

Figure 8: Government Observation well AYS 37 hydrograph.

Figure 8 shows that there is consistent decline of SWL at AYS 37 from 1992 onwards. The current water level is at the lowest level seen since the commencement of monitoring.

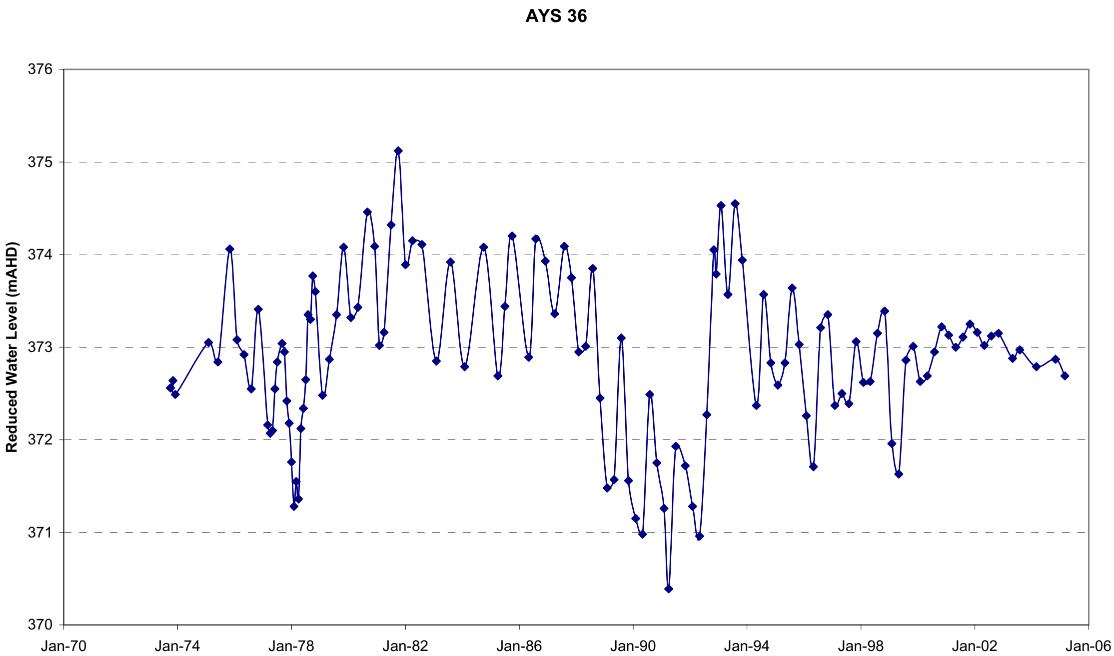

Figure 9: Government observation well AYS 36 hydrograph.

Private monitoring wells

A number of private wells have been monitored for SWL commencing between 1987 and 1990. Trends of selected private wells show a significant rise in groundwater levels after the above average winter, spring and summer months of 1992/93. Hydrographs from selected wells are presented in Appendix E.

Hydraulic gradients/groundwater flow

Potentiometric surfaces were generated using Reduced Standing Water Level (RSWL) measurements taken from observation wells in March 2005. RSWL for 38 observation wells were uploaded to the computer package Surfer® and potentiometric surfaces generated using Kriging interpolation (Figure 10).

Figure 10 shows that groundwater flow potential is from the ranges to the valley floor. As the observation wells are not distributed evenly in a uniform isotropic aquifer, flow lines cannot be drawn to illustrate the direction in which groundwater flows. This is particularly the case in fractured rock aquifers where groundwater flow movement is controlled by fracture orientation as well as hydraulic gradient.

Hydraulic gradients however do suggest that movement is from the ranges to the valley floor, as well as in a north to south direction. In the south western section of the valley hydraulic contours suggest that groundwater flow parallels the surface water flow, and movement is along the line of the of the Booborowie and Baldry Creeks as they merge to flow into the Broughton River.

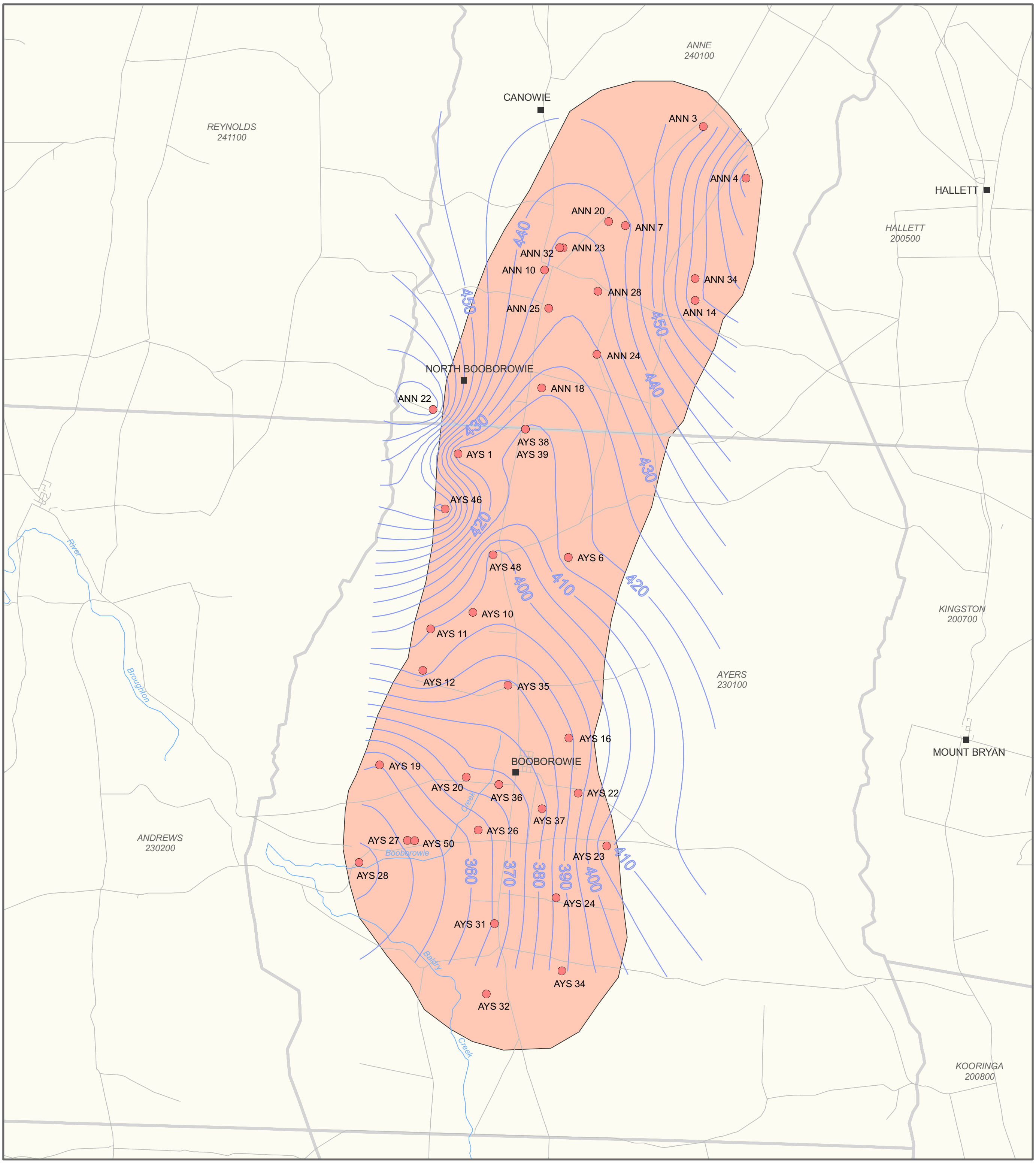

Figure 10.
Potentiometric Surface Contours, March 2005

Town

Drainage

Road

Potentiometric Surface Contour

Booborowie Valley

Hundred Boundary

NYAD Boundary

Monitoring Network

AYS 10 Obs.No

N

0 2.5 5 km

Datum: Geocentric Datum of Australia 1994 South Australia Lambert
Projection: Lambert Conformal Conic

Produced by: Water Information Group
Knowledge and Information Division
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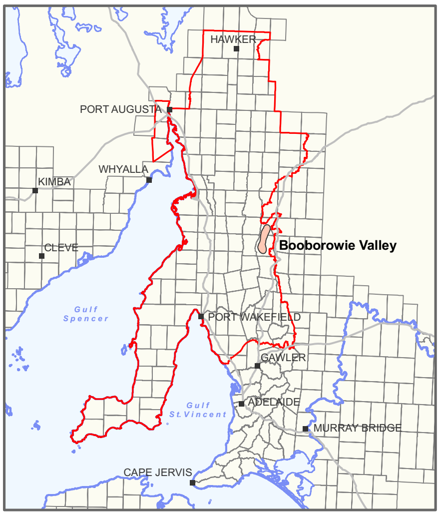

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7. SALINITY ANALYSIS

A network consisting of monitoring wells constructed into Quaternary sediments and fractured rock was established in 1971 as part of Cobb and Smith investigations. Salinity sampling ceased in 1973, but was reactivated by Clarke in 1987. Current sampling occurs on an opportunistic basis, with the most recent readings taken in May 2003 and August 2004.

Figure 11 shows the salinity monitoring network and latest salinity readings for 30 monitoring wells constructed in the valley fill and adjacent ranges (fractured rock). It can be seen that highest salinities are located in the southern section of the valley. Salinities vary between 892 and 6079 mg/L TDS with the highest recorded salinity taken from obswell AYS 29. Although there is no consistent trend in salinities throughout the valley, the southern section tends to be higher.

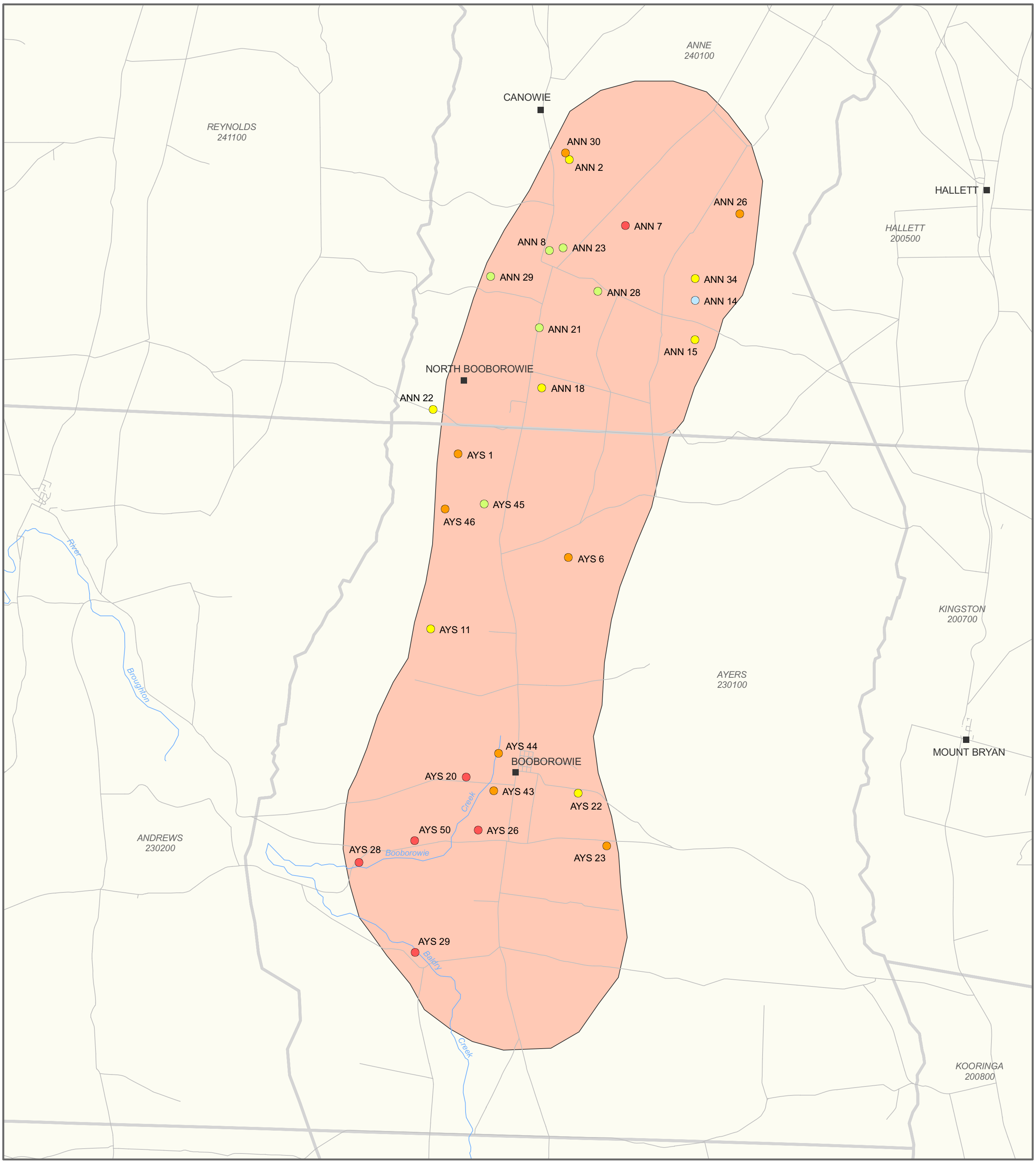

Figure 11.
Current Salinity Monitoring Wells

Town

Drainage

Road

Monitoring Wells TDS

500 - 1000

1001 - 1500

1501 - 2000

2001 - 3000

> 3000

Obs. No

ANN 14

Booborowie Valley

Hundred Boundary

NYAD Boundary

N

0 2.5 5 km

Datum: Geocentric Datum of Australia 1994 South Australia Lambert
Projection: Lambert Conformal Conic

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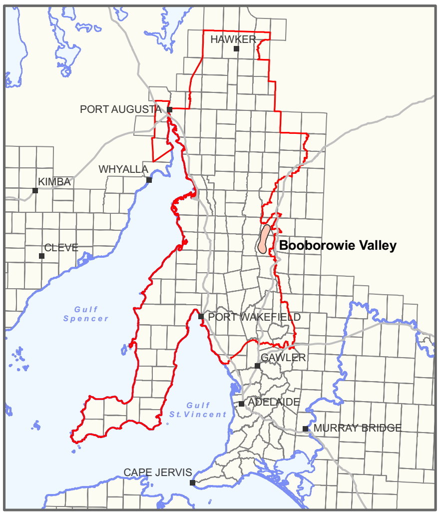

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Table 2 shows salinity at the commencement of monitoring, the latest salinity and the overall change in salinity for each observation well. The Table shows that the majority of obswells have increased in salinity since the establishment of the observation network. An average increase in salinity of 140 mg/L TDS is observed since the 1970s. Marked increases are noted in wells located in the mid to southern section of the valley where irrigation takes place.

Table 2. Observation wells and observed salinity changes from earliest records.

Observation Well	Date First Record	Initial Salinity (mg/L)	Date Latest Record	Latest Salinity (mg/L)	Δ Salinity (mg/L)
ANN 2	13/04/1972	1645	6/05/2003	1939	+ 264
ANN 7	7/01/1972	3455	6/05/2003	3218	- 237
ANN 8	7/01/1972	1200	6/05/2003	1228	+ 28
ANN 14	24/11/1971	700	5/11/2002	892	+ 192
ANN 15	26/01/1972	1570	6/05/2003	1726	+ 156
ANN 18	8/01/1972	1830	6/05/2003	1759	- 71
ANN 21	25/1/1972	1320	6/05/2003	1317	- 3
ANN 22	17/11/1987	1759	7/05/1999	3240	+ 1481
ANN 23	10/03/1960	1501	6/05/2003	1278	- 223
ANN 26	26/11/1987	2227	7/05/1998	2245	+ 18
ANN 28	26/11/1987	1306	6/05/2003	1396	+ 90
ANN 29	4/04/1991	1062	7/05/1998	1199	+ 137
ANN 30	4/04/1991	2358	11/11/1997	2613	+ 255
ANN 34	26/11/1987	1546	6/05/2003	1889	+ 343
AYS 1	6/1/1972	1830	7/05/2003	2047	+ 217
AYS 6	24/11/1971	1570	7/05/2003	2448	+ 878
AYS 11	24/11/1971	1170	11/8/2004	1631	+ 461
AYS 20	07/01/1972	5212	25/05/2002	3879	- 1333
AYS 22	17/10/1972	1955	6/11/2002	1979	+ 24
AYS 23	24/11/1971	2155	9/8/2004	2545	+ 390
AYS 26	26/10/1971	2285	9/08/2004	3035	+ 750
AYS 28	24/11/1971	5215	9/08/2004	5086	- 126
AYS 29	15/11/1990	4963	9/8/2004	6079	+ 1116
AYS 34	6/01/1972	4700	16/11/1998	2659	- 2041
AYS 43	24/04/1968	1320	4/05/1999	2312	+ 992
AYS 44	24/06/1987	2188	15/5/1996	2745	+ 557
AYS 45	24/11/1971	1455	11/08/2004	1490	+ 45
AYS 46	16/02/1977	1687	11/08/2004	2949	+ 1262
AYS 50	11/05/1995	3476	9/08/2004	3488	+ 12

8. DISCUSSION

Booborowie Valley is an alluvium filled valley that yields relatively small quantities of groundwater of moderate to poor quality. Irrigation is limited to salt tolerant crops, and major extractions are used for irrigation of lucerne.

Community consultation has identified five irrigators who currently utilise groundwater for irrigation. The part of the valley where extraction is most intense is the section roughly between the Hundred of Anne/Ayres boundary and Booborowie Township with current withdrawls for irrigation estimated at 950 ML/yr.

Although the largest extractions occur in sand and gravel aquifers, it seems likely that there is reasonable exchange of groundwater between fractured rock aquifers and overlying sediments. In Cobb and Smiths initial investigation in 1977, an annual water balance suggested that 50 ML out of 490 ML was attributed to inflow from adjacent hard rock.

The recharge estimate of 490ML/yr was based on investigations undertaken over a 12-month period in 1971-72, both above average rainfall years. As recharge will vary every year, this cannot be considered a definitive long-term average volume. Irrespective of this, the amount is considerably less than the estimated use of 1200 ML/yr. This discrepancy implies that the extra volume being extracted results in a drawing down of storage, a decrease in groundwater discharge leaving the Valley or both. Well hydrographs support a decrease in storage, indicated by the steady decline in water levels during all but extremely wet years. The impacts of extraction on groundwater flow out of the Valley is unknown.

Historical records and information provided by landholders shows that groundwater and surface water was much more prevalent in the early part of the century (Flint 1972, Cobb and Smith, 1977, Tayler per comm. 2005). The introduction of the lucerne seed industry is considered the main factor in the reduction of these waters, while in recent times irrigation has played a smaller role (Cobb and Smith, 1977).

An apparent affect of reduced water tables and groundwater levels is the loss of permanent springs, waterholes and baseflow along the valleys tributaries. Present day flows only occur during very high rainfall events, with any surface flow during moderate rainfall events is quickly absorbed into porous sediments on the valley slopes and flats.

Analysis of standing water levels shows that local groundwater resources responds to seasonal variation in rainfall, and, in particular to well above average rainfall events. This is shown by sharp rises in groundwater level in 1974 and 1992. When comparing cumulative deviation from the monthly mean (rainfall) and hydrographs of water level both graphs have similar shapes. This suggests that groundwater levels in the valley respond directly to incident rainfall or lack thereof.

Groundwater level readings are currently taken on a quarterly basis. Government drilled investigation wells are adequate for collecting this information, while salinity readings can be taken from privately equipped wells and windmills. Given that government wells were drilled over 30 years ago, some rehabilitative work such as purging and cleaning should be considered to ensure reliable data is captured.

Given the relatively small size of the Valley area the monitoring network is rather extensive. In the future the size of the network could be cut back to reduce the resources required for monitoring. This could be done by reducing the number of private wells.

Monitoring records show that there has been a gradual increase in salinity since monitoring commenced in the early 1970s. This may be attributed to cyclic concentration of salt from irrigation activity but there are no consistent trends.

The rise in groundwater level observed between the years 1978 and 1982 is likely related to reduced volumes of extraction in the late 1970s and early 1980s as a result of aphid outbreaks which decimated the lucerne industry (Clarke 1996). This was also combined with consecutive years of above average rainfall. Given that lucerne is deep rooted, a reduction in non-irrigated lucerne during this period may also have increased recharge rates to the sedimentary aquifers.

Of note within the groundwater monitoring data is the fact that in obswells AYS 35, AYS 36, AYS 37 and AYS 38/39 groundwater levels fell during the periods 1986-1991 and 1995-1998. These were not the driest periods on record and received close to average rainfall, which suggests that groundwater declines during these periods is attributed to water use for irrigation.

Regionally the importance of very high rainfall events to fully replenish groundwater reserves can be seen from inspection of all hydrograph records. Excluding the major recharge following 1992 and the gradual raising of the water table during the years that lucerne production was interrupted by the aphid outbreak, the trend in water levels is that of decline. This is despite periods of average and better rainfall. Recovery is apparent following most irrigation seasons, however levels do not appear to be capable of recovering to the same point during near average rainfall.

The implications of this for resource users are potentially serious, as this may mean that the resource is being used beyond a sustainable level based on recharge during average rainfall years. Rather very high rainfall events appear to replenish the supply periodically, and the resource is gradually drawn down over subsequent seasons. Long-term sustainability may then depend on the capacity of the resource to withstand extractive use during the period between high rainfall, and hence high recharge years. The robustness of this resource to withstand current irrigation activity depends on the storage capacity of the resource, which for the fractured rock is poorly understood.

A statewide observation is that very high rainfall events appear to be occurring less frequently than in past eras. Inspection of Figure 5, long-term annual rainfall, shows that the frequency of events greater than 600 mm has decreased. Annual rainfall in excess of 600 mm has occurred on 14 occasions during the 120 year record presented, but only one of these was in the last 30 years.

It should be noted that lucerne has been successfully irrigated in the valley during this period. Additionally current water levels in nearly all observation wells are around those found when monitoring first commenced over thirty years ago. All irrigators interviewed in the preparation of this report consider the resource to be stable and have experienced no problems with groundwater supply. There appears to be no perceived need for concern or action other than to be aware of the need to ensure that monitoring and evaluation occur regularly.

9. CONCLUSIONS

From analysis of standing water levels it is apparent that water levels have fallen in the Booborowie area since the last major rainfall event in 1992. Major recharge appears to be closely linked to very high rainfall years and the sustainability of current groundwater extractions may rely on these events.

Total water use from the valley was found to be around 1200 ML/yr, of which 950 ML/yr is used for irrigation of lucerne. This figure supports previous estimates made in 1977 and 1990, suggesting that water use has decreased slightly.

Data on aquifer parameters and connectivity between fractured rock and sedimentary aquifers is still lacking, but given the relatively small size of the resource and costs involved in investigative drilling, further investment does not seem warranted. Continued review of the resource (monitoring data and irrigation activity) should be undertaken – possibly every 4-5 years.

The age of Government owned wells is over 30 years, and well maintenance should be carried out to ensure reliable data is captured. An initial step would be to airlift the wells to clear them of any accumulated sediment. The monitoring of private wells could also be cut back to target areas where major groundwater extraction is taking place.

There is sufficient indication that the water resources of Booborowie area are at least close to, if not at, the sustainable limits of use. Regulation of water use is the best method to ensure long-term sustainability. At the least, any further pressure on the resource that would introduce additional demands on the groundwater of the area, such as irrigation development, intensive animal keeping or other high water use development should be avoided.

Contemporary natural resource management recognises the conjunctive nature of surface and groundwater resources and the need to consider all impacts within the context of a total catchment management approach. The Booborowie area is thought to contribute significant baseflow to the Broughton River system, of which it forms part (Cresswell 2000). Since the development of the lucerne irrigation industry, the region contributes very little flow to the system. Immediately downstream of the confluence of Booborowie and Baldry Creeks marks the start of Yakilo Creek, where permanent surface water is present (Favier et al 2004). This is likely to be dependent on baseflow from the Booborowie and Baldry catchments. Hence, it is important from an environmental water perspective that the extraction of groundwater is factored into monitoring and management of the Broughton River catchment as a whole.

10. RECOMMENDATIONS

- Consider regulation of water extraction activities in the Valley
- Avoid any future increase in water resource development for irrigation or other high volume water uses
- Consider the impacts of extraction within a total catchment management approach, and monitor any impacts on downstream users, including the environment
- Undertake periodic reviews of groundwater monitoring data

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12. GLOSSARY

Alluvial Applied to the environments, actions and products of rivers or streams. Alluvial deposits (alluvium) are clastic, detrital materials transported by a stream or river and deposited as the river floodplain.
Alluvium *See alluvial

Anticline An arch shaped fold in rocks, closing upwards, with the oldest rocks found in the core.

Aquifer An underground layer of rock or sediment which holds and transmits economic quantities of water and allows water to percolate through.

Australian Height Datum (AHD) The datum used for the determination of elevations in Australia. The determination set mean sea level as zero elevation.

Bore (also called a '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 (groundwater).

Catchment A catchment is an area of land that is surrounded by high topographic features such as hills or ridges. An imaginary line that runs along the highest point through that high ground defines its boundary. All surface water within this bounded region has the potential to flow to the lowest point in the catchment.

Datum The reference point from which elevations are measured. Given the value of zero mAHD.

Depth to Water (DTW) The distance from the reference point to the water surface (that is not affected by pumping). Usually measured in metres.

Geographic Information System (GIS) Computer software that allows for the linking of geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

Ground Elevation The elevation of the ground surface above the datum. Units are in mAHD.

Groundwater Water occurring naturally below ground level or water pumped, diverted or released into a bore for storage underground.

Hydraulic Conductivity In general, the ability for a rock, sediment or soil to permit fluids to flow through it.

Hydrogeology The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers. (See: hydrology)

Hydrology The study of the characteristics, occurrence, movement and utilisation of water on and below the earth's surface and within its atmosphere. (See: hydrogeology)

Neoproterozoic The most recent part of the Proterozoic, from about 1000-575 million years ago.

Piedmont The tract of country at the foot of a mountain range.

Pleistocene The first of two epochs of the Quaternary Period, conventionally thought to have lasted from 1.64 Ma to 10, 000 years ago at the beginning of the Holocene.

Potentiometric Surface A hypothetical surface defined by the level to which water in a confined aquifer rises in observation boreholes. In practise, the potentiometric surface is mapped by interpolation between borehole measurements.

Quaternary A sub era of the Cainozoic Era that covers the last 1.64 million years. The Quaternary comprises of the Pleistocene and Holocene Epochs.

Reduced Standing Water Level (RSWL) The elevation of the water level, typically measured in mAHD. It is calculated by subtracting the depth to water from the reference elevation.

Reference Elevation The elevation of the reference point above the datum measured in mAHD.

Reference Point The point at the surface from where the depth to water is measured. Sometimes called the 'stick up'.

Standing Water Level (SWL) The distance from the natural ground surface (natural surface) to the water surface. Usually measured in metres.

Transmissivity The rate at which groundwater is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

13. TERMS AND SYMBOLS

Common SI Units

Name of unit	Symbol	Definition in terms of other metric units	Commodity
Millimetre	mm	10^{-3} m	length
Metre	m	-	length
Kilometre	km	10^{3} m	length
Hectare	ha	10^{4} m^{2}	area
Microlitre	µL	10^{-9} m^{3}	volume
Millilitre	mL	10^{-6} m^{3}	volume
Litre	L	10^{-3} m^{3}	volume
Kilolitre	kL	1 m^{3}	volume
Megalitre	ML	10^{3} m^{3}	volume
Gigalitres	GL	10^{6} m^{3}	volume
Microgram	µg	10^{-6} g	mass
Milligram	mg	10^{-3} g	mass
Gram	g	-	mass
Kilogram	kg	10^{3} g	mass
Second	s	-	time

Abbreviations

Abbreviation	Name	Units of measure
SWL	Standing Water Level	m
RSWL	Reduced Standing water level	mAHD
AHD	Australian Height Datum	mAHD
TDS	Total Dissolved Solids	mg/L
EC	Electrical Conductivity	µS/cm
pH	Acidity	-
Obswell	Groundwater Monitoring Observation Well	mg/L
L/s	Litres per second	L/s
DME	Department of Mines and Energy	
GIS	Geographic Information Systems	
PIRSA	Primary Industries and Resources of SA	
DWLBC	Department of Water, Land and Biodiversity Conservation	

APPENDIX A. MEETING ATTENDANCE LIST

A public meeting was held at the Booborowie Town Hall on 16/03/2005. Community members present included:

Joan Taylor
Les Taylor (Windmill maintenance).
Peter Harris (APCB Authorised Officer)
John Affolter (Irrigator)
Ashley Woodgate (landowner).
Kev Cousins

Others present:

David Deane (DWLBC)
Paul Magarey (DWLBC)
David Sloper (NRM Officer, Jamestown).

Those pictured above were in attendance at the Booborowie Town Hall for an outline of the NYAD water resource project.

APPENDIX B. SURVEY SHEET

Department of Water, Land and Biodiversity Conservation

Northern and Yorke Agricultural District INRM Committee

Water Use Survey

Catchment (please circle)	Willochra Ck; Broughton River; Booborowie Valley, Mambray Coast.	Other	

Owner(s) Name(s)			Address		
Postcode		Phone		Fax	
Alternative Contact				Preferred contact method	

Source of Water used (for more than one source, additional tables at end of survey)

Source Type	Dam:		Watercourse Diversion:		Underground:		Source ID:	

Underground Only	Well Unit number (if known)		Casing/Outlet Size		Salinity	

Dam Only	Type		Surveyed Capacity		Wall Height		Surface Area (m²)	

Pump Type/Power		Pump Pipe Size		Pump Flow Rate		Photo	

Easting		Northing		Interim Source		Destination	

Comments :

Do you have any disused/abandoned wells

Location (parcel)		Year last used	

Comments (eg rusted out, collapsed, too saline):

.1.1 IRRIGATION WATER USE QUESTIONNAIRE

Crop	Period of Irrigation		Hours per Irrigation	Number of Irrigations	Amount Applied	Emitter Type/Output	Irrigated Every Year (Y/N)
	From	To					

Report DWLBC 2005

Predominant Soil Type		Method of Irrigation	

Further Comments

Local history and knowledge of resource use is valuable information. Please feel free to record any recollections you have regarding changes to resource condition or the levels of water-use that have occurred during your time in the region. Additional information relating to climate, such as unusually dry or wet periods is also of interest. (Attach further pages if required)

Resource condition – please record any concerns you have regarding the resource that should be considered for future management

Name of person completing survey: ……………………………………….. Contact Telephone………………………..…………..

Date : …………..

****** Thank you for your assistance ******

APPENDIX C: PUMP TESTING REPORT – (K DENNIS, 1998)

KJD:SJS 15 April 1998
8352-0122

The step test results were analysed by the method outlined in Hazel 1973.

Care must be exercised when using data contained in this report that has been extrapolated from real time data. This data does not take into account hydraulic or geological boundaries that may be encountered beyond the limits of the real time data set.

Pump installation and development was first attempted on 4-2-98 but was aborted when aquifer material blocked the pump. The pump was pulled, cleaned and replaced. An amended pump setting of 26.5 metres was used rather than the original designed pump setting of 33 metres. The well developed quickly and testing was carried out on 5-2-98.

The test was carried out for a period of 8 hours comprising of 3 x 100 minute variable yield steps and a 3 hour constant discharge test.

Tabled below are the water levels and flow rates observed at the end of each step and the end of the constant discharge test.

P42776B		**SWL 7.5M**	
	Time (mins)	**Flow Rate (ℓ/s)**	**WL (m)**
Step 1	100	12	2.17
Step 2	200	18	3.60
Step 3	300	25	5.55
End of Test	480	25	5.69

2/.

D98100KD.DOC

When data from the step tests is substituted into the well equation it over predicts the drawdown in the long term.

		DRAWDOWN (M) @	
	Yield (ℓ/s)	300 mins	480 mins
Real Time Data	25	5.55	5.69
Extrapolated Data	25	5.66	5.73

By substituting different flow rates into the well equation the following drawdown versus time, data set is produced.

P42776B		SWL 7.5M	
	DRAWDOWN (M) @		
Yield ℓ/s	300	480	1440
25	5.66	5.73	5.88
30	7.17	7.25	7.43
35	8.8	8.89	9.10

After 4 hours and 40 minutes discharge at a constant rate of 25 ℓ/s a drawdown of 5.69m was observed. A transmissivity of 520m^3/day/m was calculated from the constant discharge test which is lower than the average T value calculated from the step test results (valid for early time only) of 670m^3/d/m.

Tabled below is the water quality data collected during pumping.

P42776		
TIME (MINS)	CONDUCTIVITY (EC)	SALINITY mg/ℓ
3	4060	2262
60	4130	2301
160	4140	2307
205	4140	2307
280	4100	2284
300	4120	2295
360	4120	2295
420	4120	2295
480	4100	2284

The observed data shows little change in salinity over the period of the test.

Recovery data collected at the cessation of pumping showed that the well was slow to recover. Measurements taken 960 minutes after the pump had stopped show the well still had 0.08 metres left to recover. If pumping cycles are repeated before full recovery is completed a cumulative drawdown effect occurs which is additional to the drawdown effect produced from pumping. The long term effects of both this and seasonal variations in water levels can lead to the pump running out of water if the intake is set too shallow.

3/.

In conclusion taking into consideration the problems mentioned above a long term yield of 30 ℓ/s could be expected from this well from a pump intake setting of 26 metres. It was noticed during pumping that an intake depth greater than 26.5 metres produced considerable sands and fine gravels which could not be developed out of the well. It is apparent that the well construction methodology is the cause of this problem. Construction methodology should be revised if consideration is to be given to sinking of a new well in the area.

Water levels and quality should be monitored regularly to assist in water resource management.

If you have any further questions please feel free to contact K Dennis (
or at the above address.

Yours faithfully

K J DENNIS
<u>SUPERVISING TECHNICAL OFFICER</u>

D98100KD.DOC

... BOOBOROWIE... TESTED.5 FEB 98

PERMIT NO.42776B

3 STAGE 8HR STEP DRAWDOWN TEST

PUMPING RATES

0-100 MINS 12.0 L/S
101-200 MINS 18.0 L/S
201-480 MINS 25.0 L/S

SWL. 8.44 M BELOW MEASURING POINT

MEASURING POINT 0.79 M ABOVE GROUND LEVEL

PUMP SET AT 26.5 M (SUBMERSIBLE)

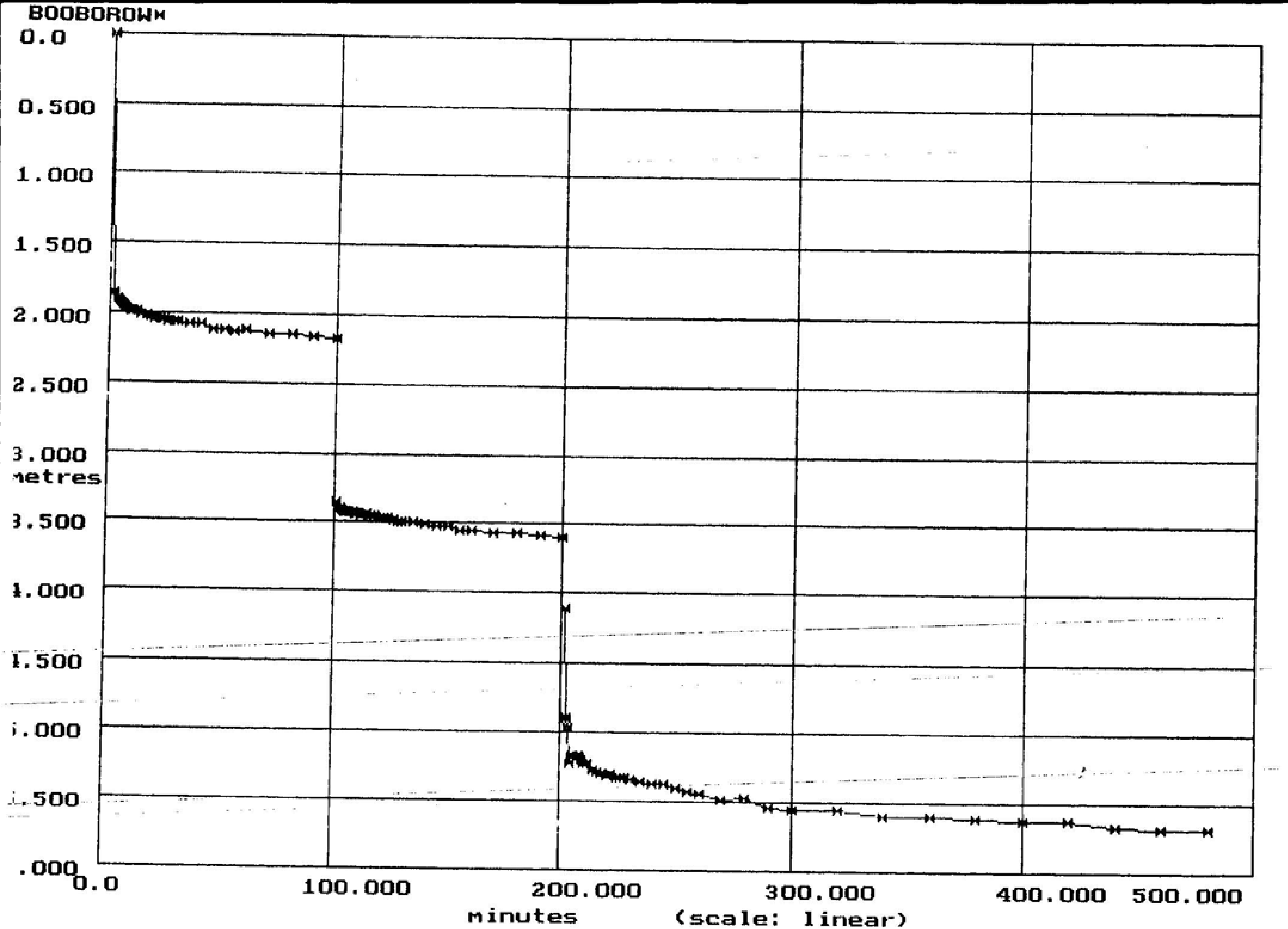
TESTED BY J. GRAHAM

File name, BOOBOROW

CGEdit: Clarke Groundwater discharge test EDITor

Pumped well data: R (aq.) = 0.20000 metres. R (w.l.) = 0.20000 metres

No.	time minutes	Drawdown metres	Rate m^3/day	No.	time minutes	Drawdown metres	Rate m^3/day
1	0.0	0.0	1036.800	2	2.000000	1.860000	1036.800
3	3.000000	1.900000	1036.800	4	4.000000	1.920000	1036.800
5	5.000000	1.930000	1036.800	6	6.000000	1.940000	1036.800
7	7.000000	1.950000	1036.800	8	8.000000	1.970000	1036.800
9	9.000000	1.980000	1036.800	10	10.00000	1.980000	1036.800
11	12.00000	1.990000	1036.800	12	14.00000	2.010000	1036.800
13	16.00000	2.020000	1036.800	14	18.00000	2.030000	1036.800
15	20.00000	2.040000	1036.800	16	22.00000	2.050000	1036.800
17	24.00000	2.040000	1036.800	18	26.00000	2.060000	1036.800
19	28.00000	2.060000	1036.800	20	30.00000	2.060000	1036.800
21	35.00000	2.070000	1036.800	22	40.00000	2.070000	1036.800
23	45.00000	2.110000	1036.800	24	50.00000	2.110000	1036.800
25	55.00000	2.130000	1036.800	26	60.00000	2.120000	1036.800
27	70.00000	2.140000	1036.800	28	80.00000	2.140000	1036.800
29	90.00000	2.160000	1036.800	30	100.0000	2.170000	1036.800
31	101.0000	3.350000	1555.200	32	102.0000	3.390000	1555.200
33	103.0000	3.410000	1555.200	34	104.0000	3.420000	1555.200
35	105.0000	3.420000	1555.200	36	106.0000	3.420000	1555.200
37	107.0000	3.430000	1555.200	38	108.0000	3.430000	1555.200
39	109.0000	3.440000	1555.200	40	110.0000	3.440000	1555.200
41	112.0000	3.450000	1555.200	42	114.0000	3.440000	1555.200
43	116.0000	3.460000	1555.200	44	118.0000	3.460000	1555.200
45	120.0000	3.470000	1555.200	46	122.0000	3.470000	1555.200
47	124.0000	3.470000	1555.200	48	126.0000	3.480000	1555.200
49	128.0000	3.490000	1555.200	50	130.0000	3.490000	1555.200
51	135.0000	3.500000	1555.200	52	140.0000	3.510000	1555.200
53	145.0000	3.520000	1555.200	54	150.0000	3.530000	1555.200
55	155.0000	3.550000	1555.200	56	160.0000	3.550000	1555.200
57	170.0000	3.570000	1555.200	58	180.0000	3.570000	1555.200
59	190.0000	3.580000	1555.200	60	200.0000	3.600000	1555.200
61	201.0000	4.110000	2160.000	62	202.0000	4.890000	2160.000
63	203.0000	4.970000	2160.000	64	204.0000	5.220000	2160.000
65	205.0000	5.160000	2160.000	66	206.0000	5.160000	2160.000
67	207.0000	5.170000	2160.000	68	208.0000	5.170000	2160.000
69	209.0000	5.200000	2160.000	70	210.0000	5.230000	2160.000
71	212.0000	5.230000	2160.000	72	214.0000	5.270000	2160.000
73	216.0000	5.280000	2160.000	74	218.0000	5.290000	2160.000
75	220.0000	5.310000	2160.000	76	222.0000	5.300000	2160.000
77	224.0000	5.320000	2160.000	78	226.0000	5.330000	2160.000
79	228.0000	5.330000	2160.000	80	230.0000	5.340000	2160.000
81	235.0000	5.350000	2160.000	82	240.0000	5.360000	2160.000
83	245.0000	5.370000	2160.000	84	250.0000	5.400000	2160.000
85	255.0000	5.430000	2160.000	86	260.0000	5.440000	2160.000
87	270.0000	5.480000	2160.000	88	280.0000	5.470000	2160.000
89	290.0000	5.540000	2160.000	90	300.0000	5.550000	2160.000
91	320.0000	5.550000	2160.000	92	340.0000	5.590000	2160.000
93	360.0000	5.590000	2160.000	94	380.0000	5.610000	2160.000
95	400.0000	5.620000	2160.000	96	420.0000	5.630000	2160.000
97	440.0000	5.670000	2160.000	98	460.0000	5.680000	2160.000
99	480.0000	5.690000	2160.000				


BOOBOROWM
0.0
0.500
1.000
1.500
2.000
2.500
3.000
metres
3.500
.000
0.0
100.000
200.000
300.000
400.000
500.000
minutes
(scale: linear)

APPENDIX D. STOCK AND DOMESTIC WATER USE METHODOLOGY.

These calculations were based on the use of: BRS (1999) data to obtain a likely total grazing area; a typical regional average of stock numbers using dry sheep equivalents (DSE); and, an average daily water use averaged over a year for each DSE.

Stock use was assumed to be the major user of water in this category and domestic use was considered inconsequential and no attempt has been made to quantify this.

The majority of stock watering appears to be based on groundwater extraction, although surface water is used opportunistically. As surface water use is already factored into the surface water modelling, all estimated stock and domestic water use has been included as being groundwater sourced.

The major method of watering stock is from troughs rather than farm dams, and no allowance has been made for evaporative losses from troughs. These are assumed to be relatively small due to the small surface area of water available for evaporative transfer. Additionally this was considered a way in which the opportunistic stock use of surface water from dams could be offset, as this was not possible to estimate.

Landuse types and associated areas for grazing calculations

Landuse type	Total area (ha)
Crop/grazing rotation	9513
Grazing modified pastures	21472
Total grazing area	31425

A uniform stocking rate of 2.6DSE was used for the catchment. DSE is a scaling system used to allow for comparison between different stock types to allow for productivity comparison. The rate used was based on landholder survey work undertaken by the Mid-North Grasslands Working Group and Agricultural Information and Monitoring Systems (MNGWG/AIMS 2004). It was also cross checked with information from the Australian State of the Environment (Hamblin 2001) regional stocking rates.

A water requirement of 6 litres per day per DSE was assumed. This rate although lower than peak demand during dry months, or when grazing on low water content feed, was selected to makes allowance for the reduced water requirement when feeding on green feed during wetter months.

Total water use was the simple product of the total number of stock and the average water use, i.e.:

Total stock use = DSE/Ha x total grazed ha x average daily water use x 365

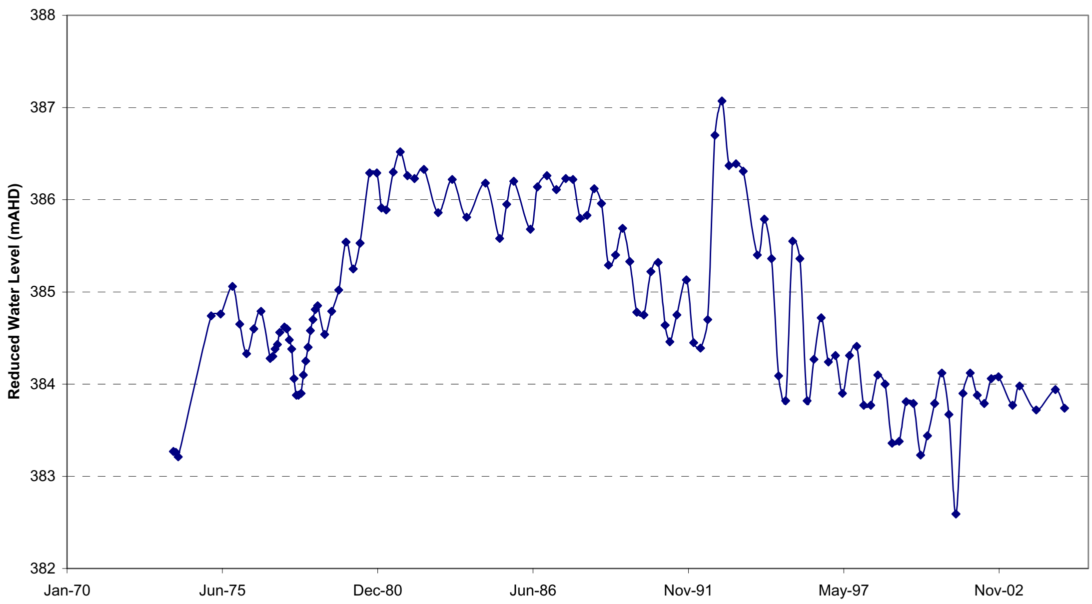
This produced a total water use figure of 178ML per annum.

2.6 x 31425 x 6 x 365 = 178ML

An additional 30% was added to allow for evaporative loss and wastage.

APPENDIX E. GOVERNMENT MONITORING WELL HYDROGRAPHS

AYS 35



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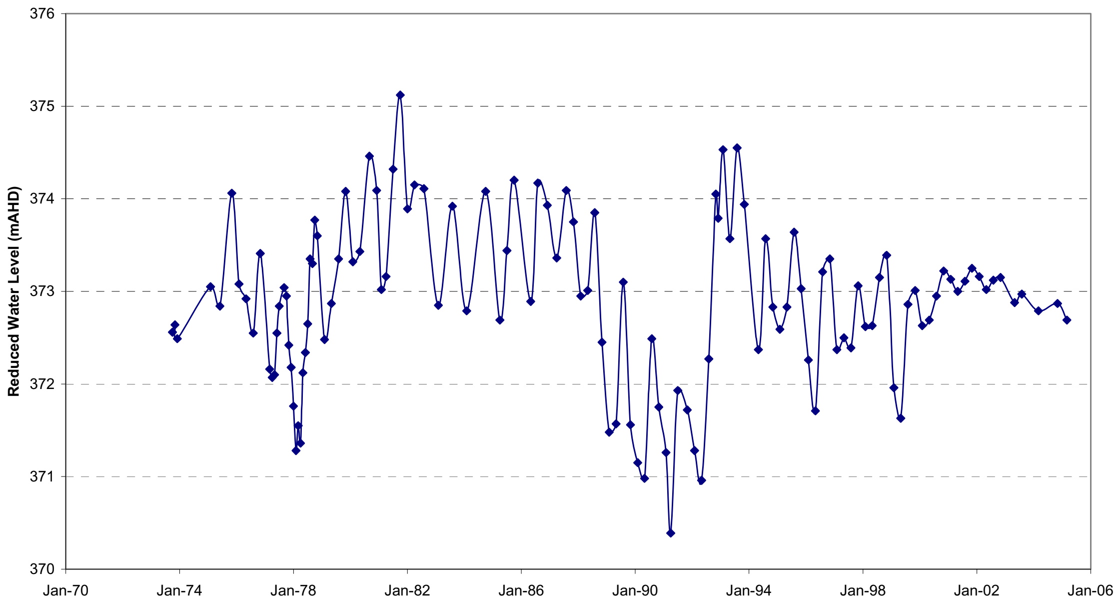

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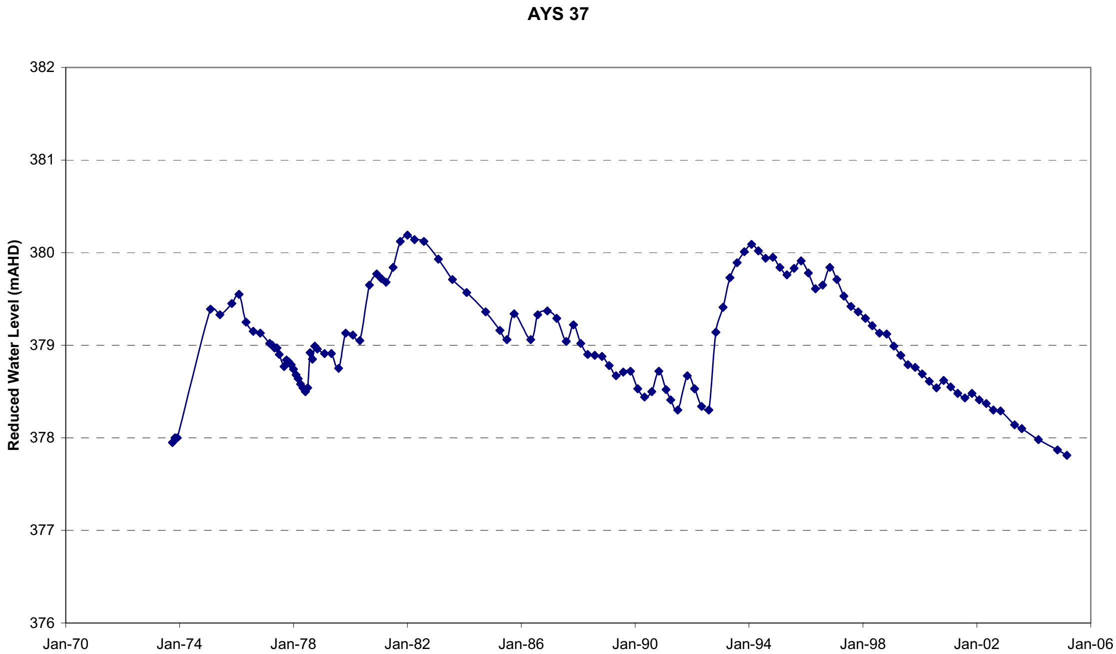
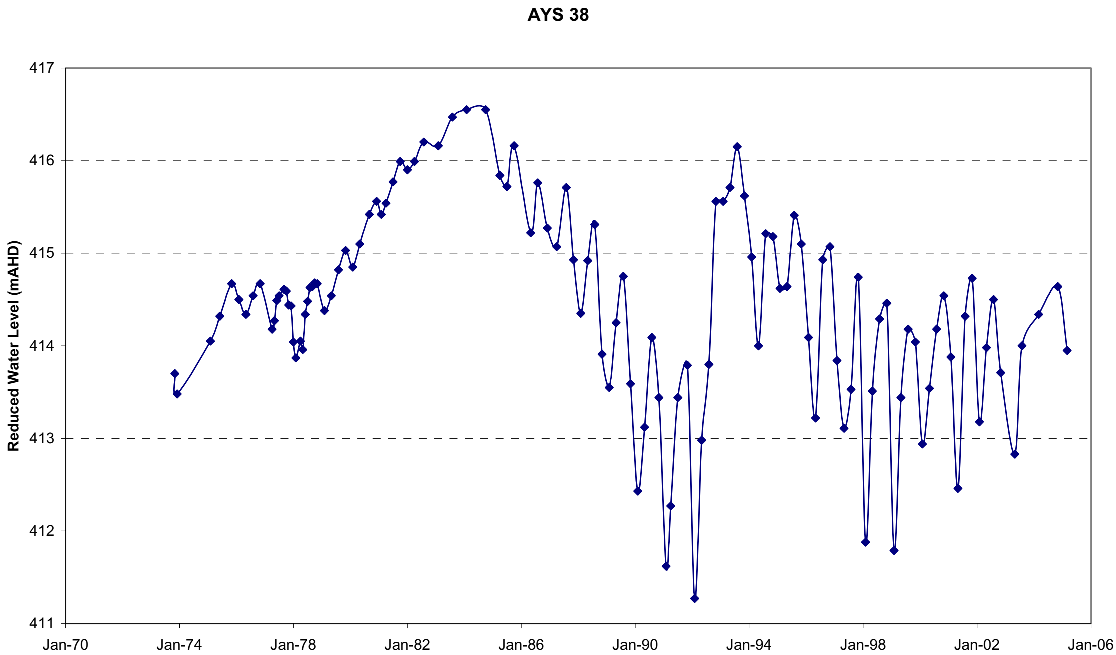
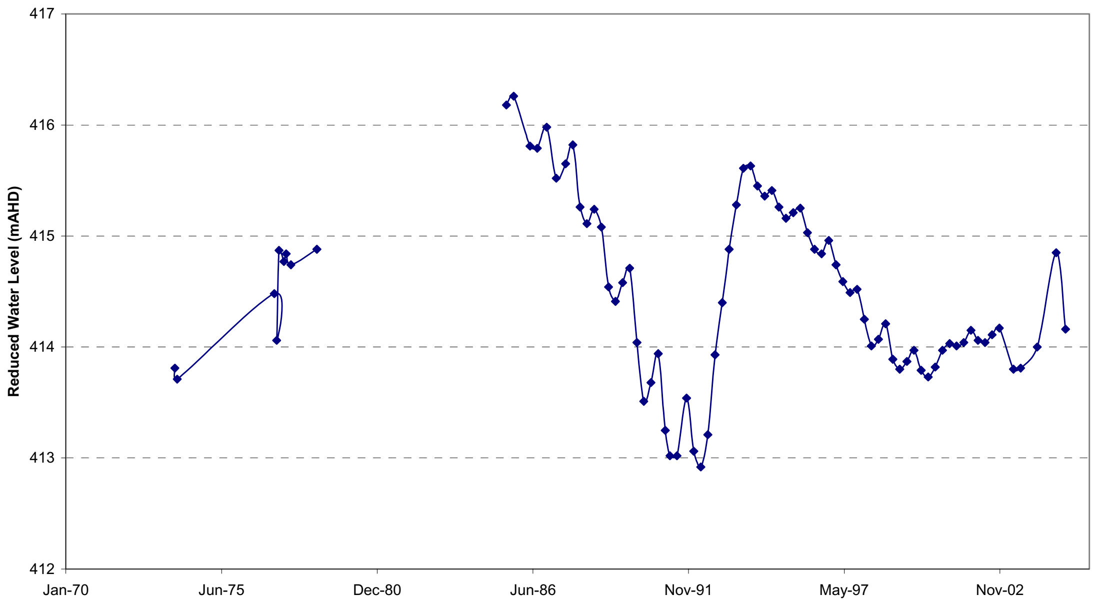
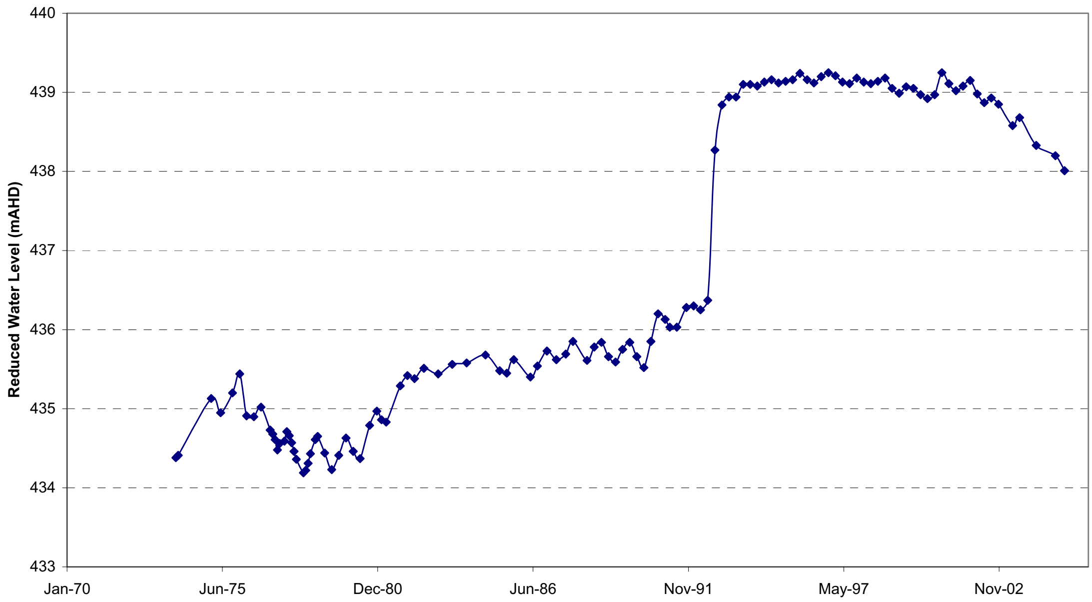

AYS 37
Reduced Water Level (mAHD)
382
381
380
379
378
377
376
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06


AYS 38
Reduced Water Level (mAHD)
417
416
415
414
413
412
411
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

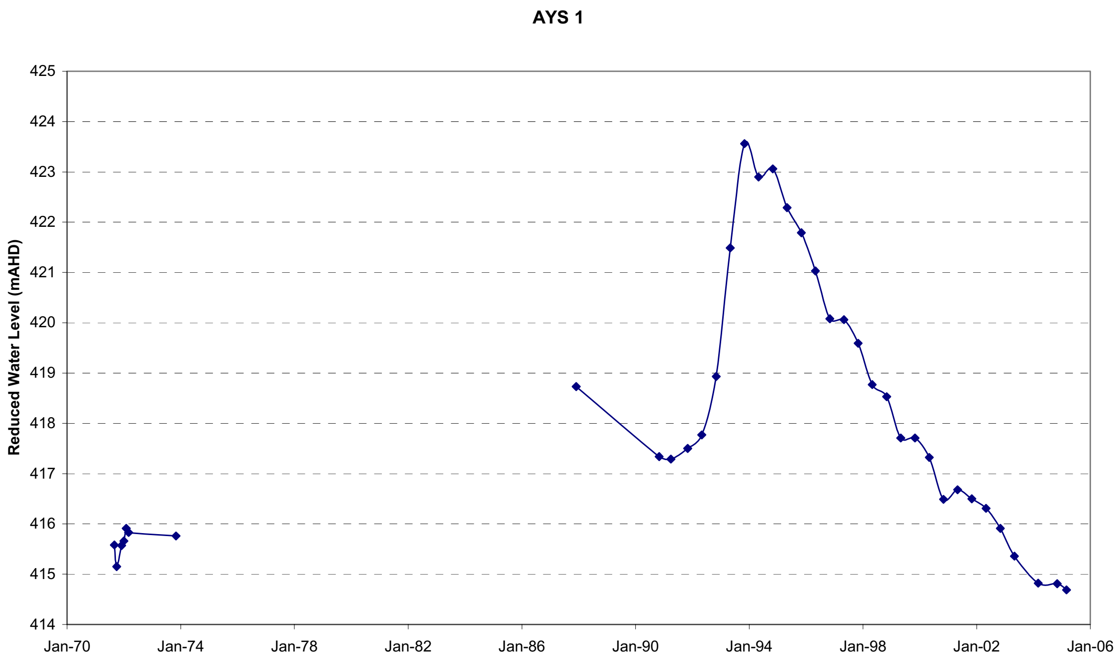
AYS 39

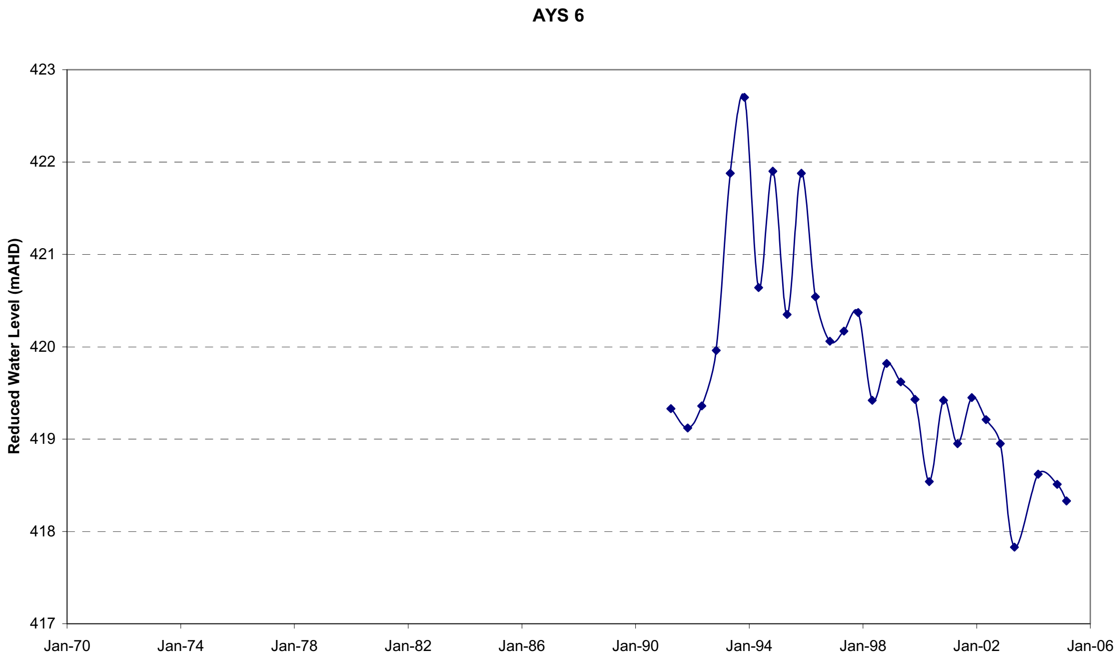

Reduced Water Level (mAHD)
417
416
415
414
413
412
Jan-70
Jun-75
Dec-80
Jun-86
Nov-91
May-97
Nov-02

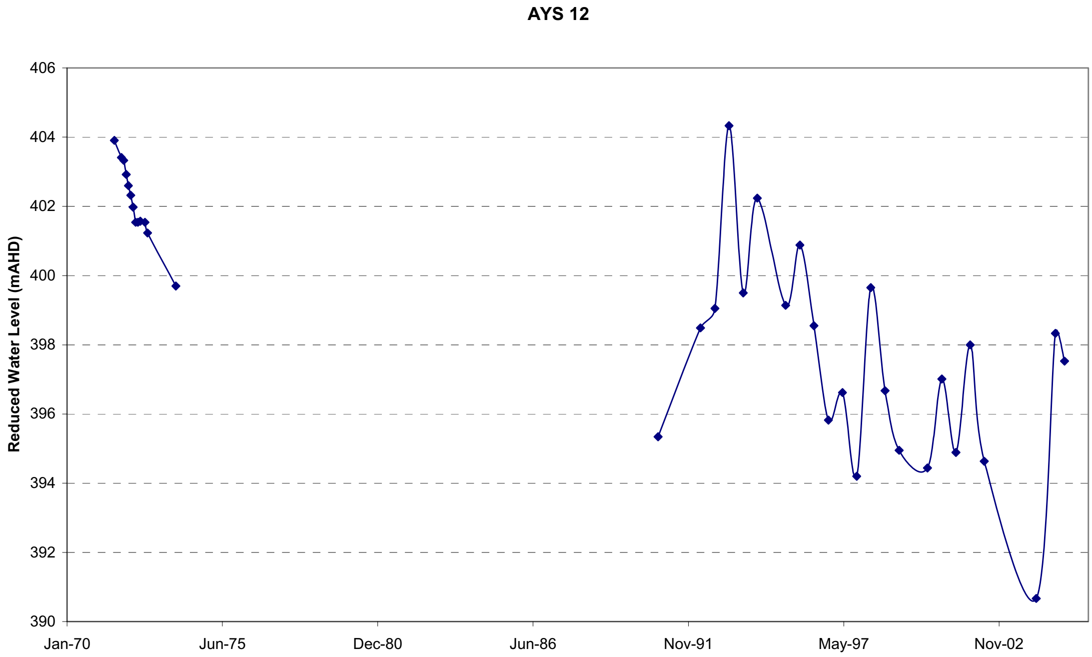
ANN 20

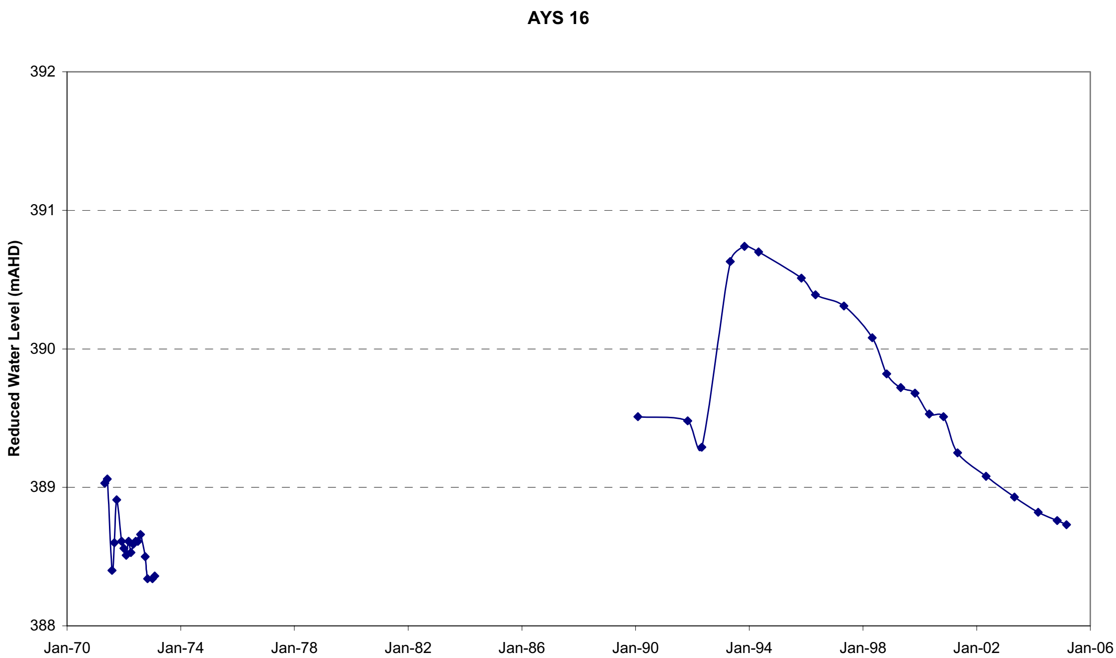

Reduced Water Level (mAHD)
440
439
438
437
436
435
434
433
Jan-70
Jun-75
Dec-80
Jun-86
Nov-91
May-97
Nov-02

APPENDIX E: PRIVATE MONITORING WELL HYDROGRAPHS

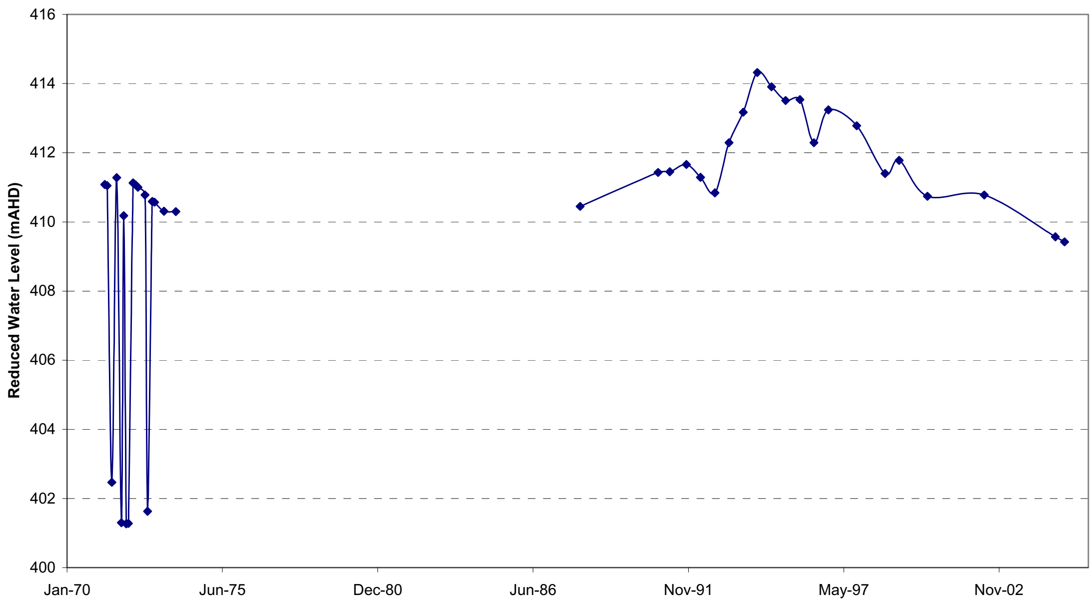




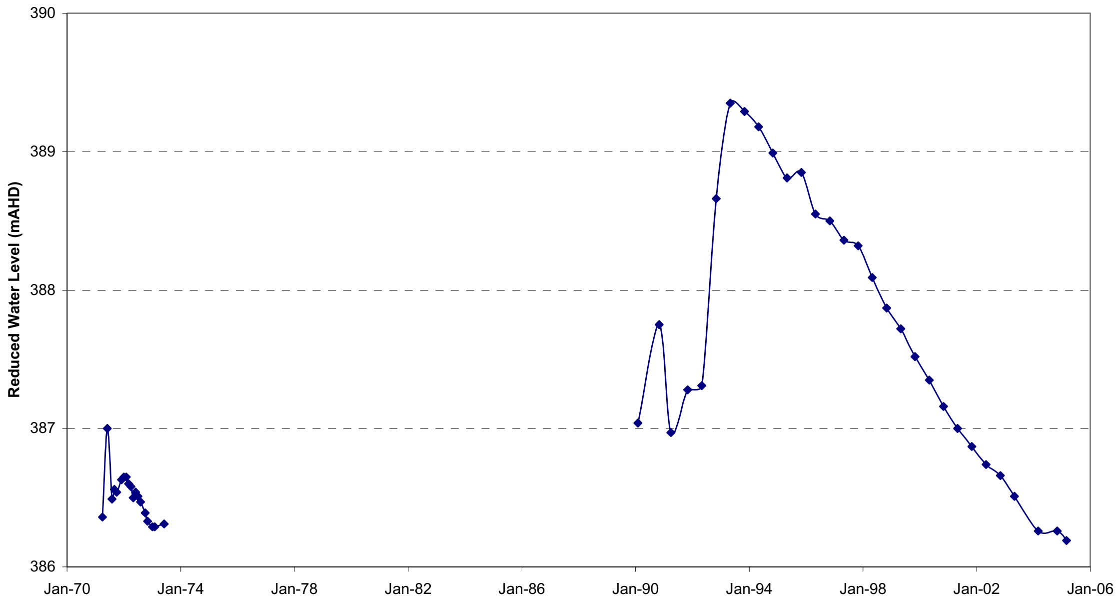

AYS 12
Reduced Water Level (mAHD)
406
404
402
400
398
396
394
392
390
Jan-70
Jun-75
Dec-80
Jun-86
Nov-91
May-97
Nov-02


AYS 16
Reduced Water Level (mAHD)
392
391
390
389
388
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

AYS 23



AYS 24



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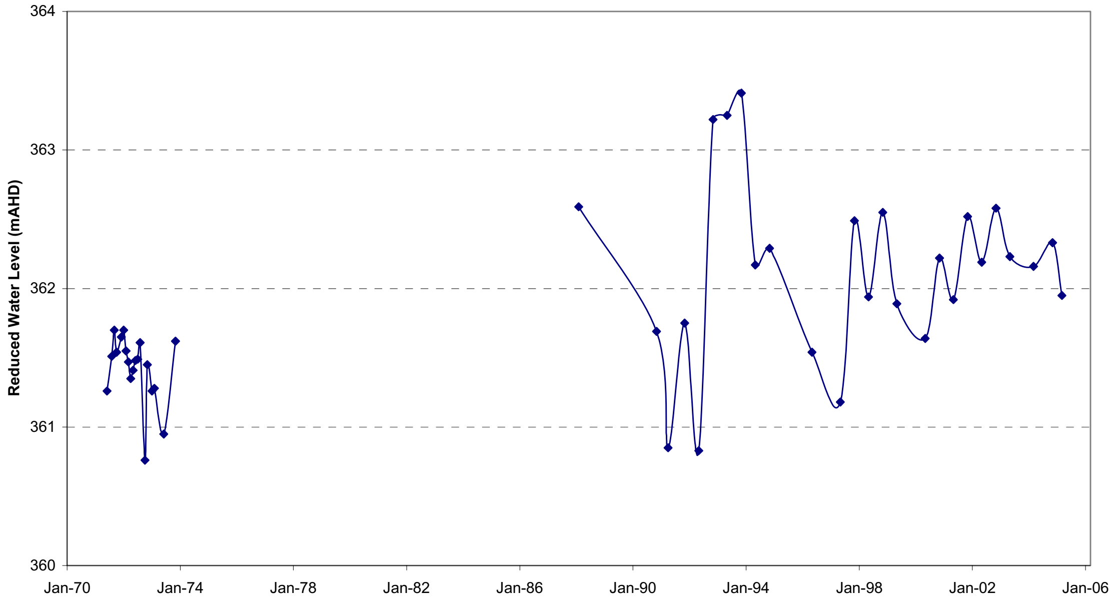
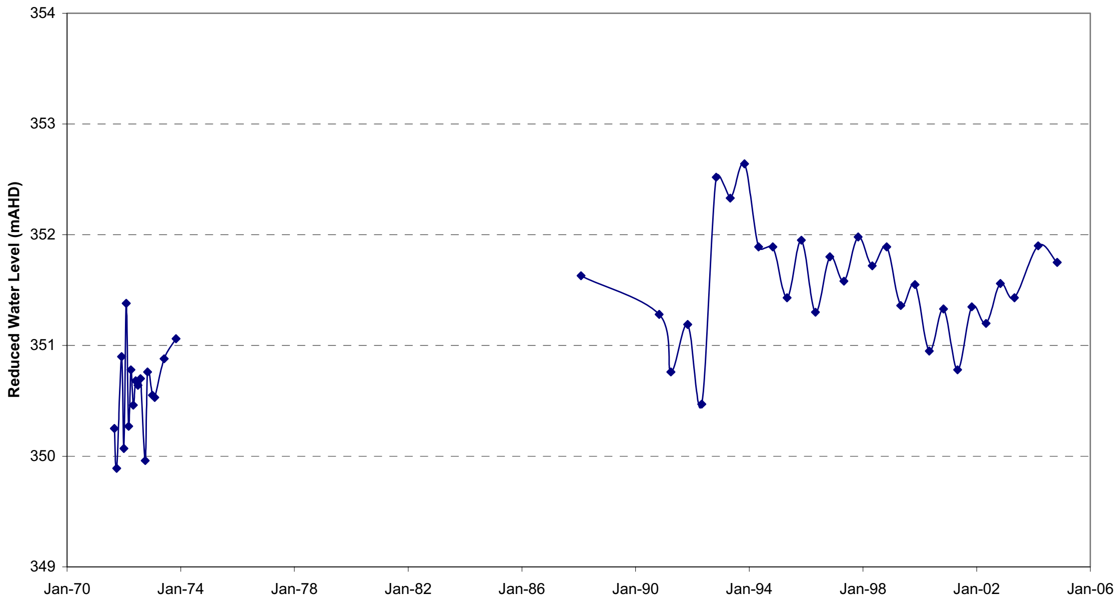
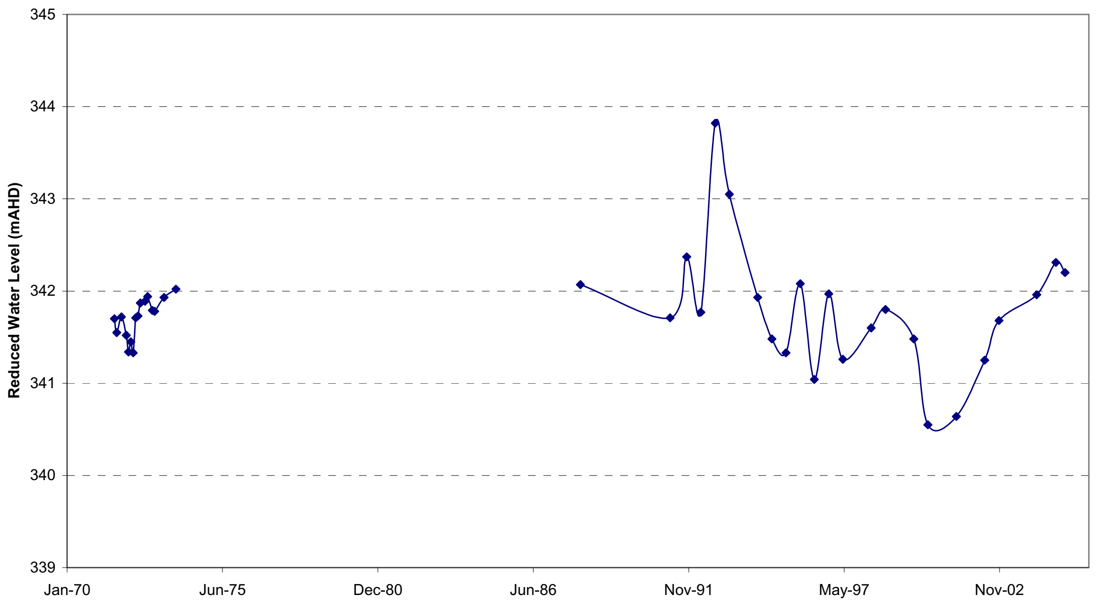
AYS 26


364
363
362
361
360
Reduced Water Level (mAHD)
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

AYS 27

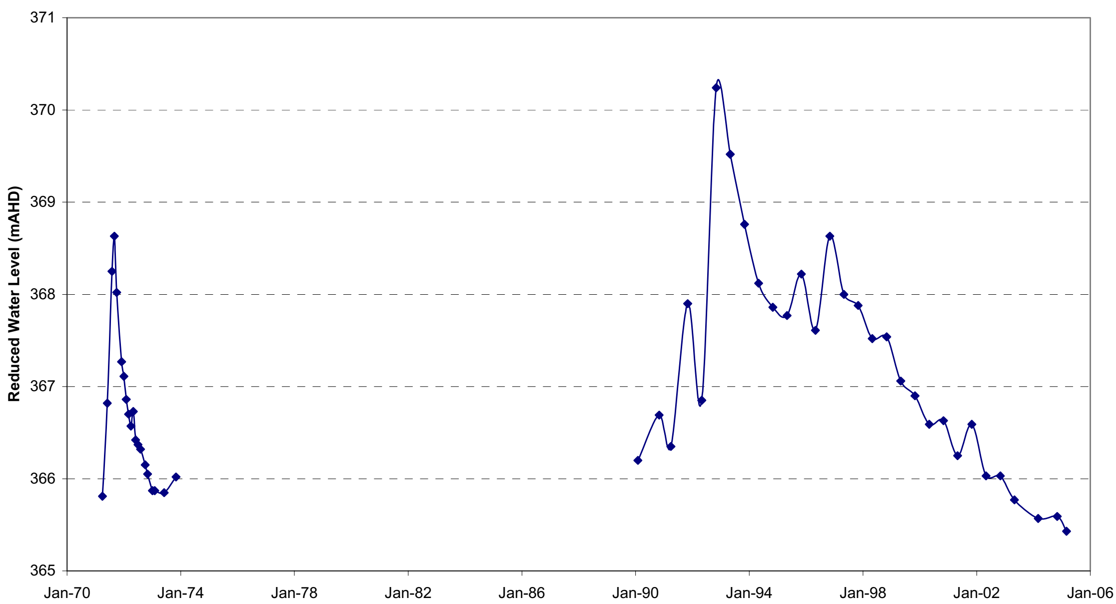

354
353
352
351
350
349
Reduced Water Level (mAHD)
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

AYS 28

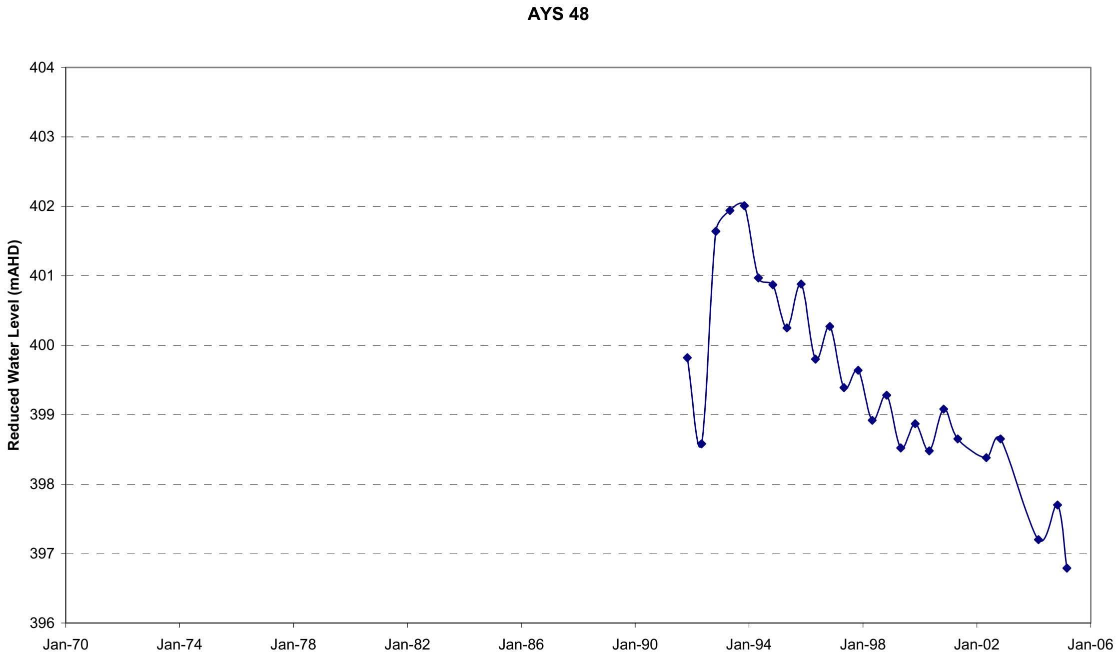


345
344
343
342
341
340
339
Reduced Water Level (mAHD)
Jan-70
Jun-75
Dec-80
Jun-86
Nov-91
May-97
Nov-02

AYS 31



371
370
369
368
367
366
365
Reduced Water Level (mAHD)
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06


AYS 48
Reduced Water Level (mAHD)
404
403
402
401
400
399
398
397
396
Jan-70
Jan-74
Jan-78
Jan-82
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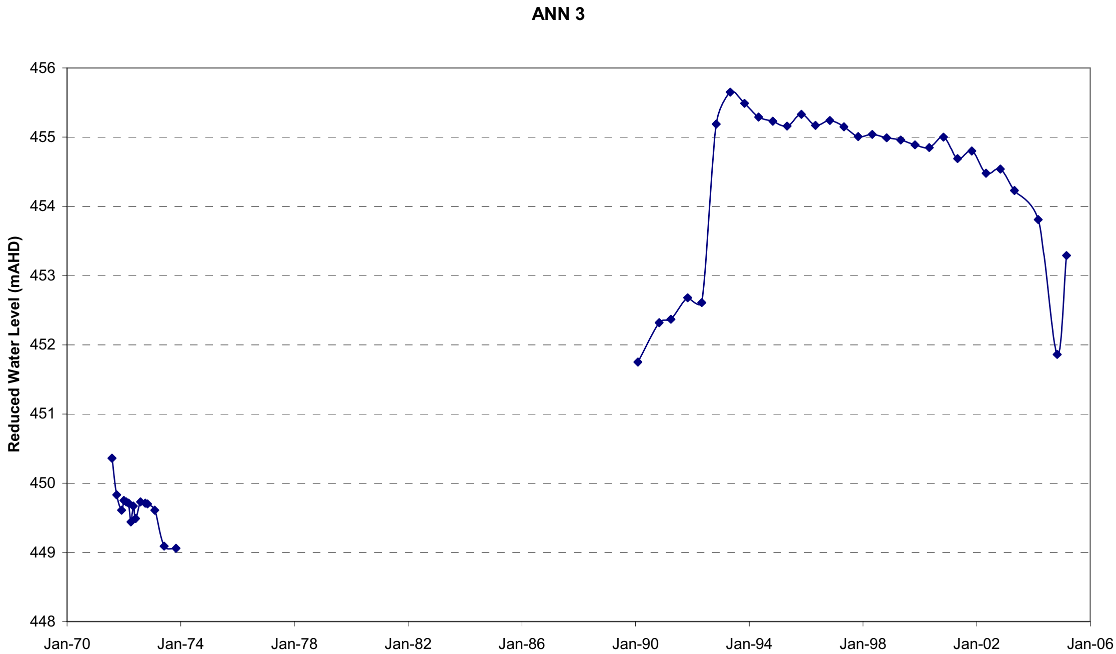
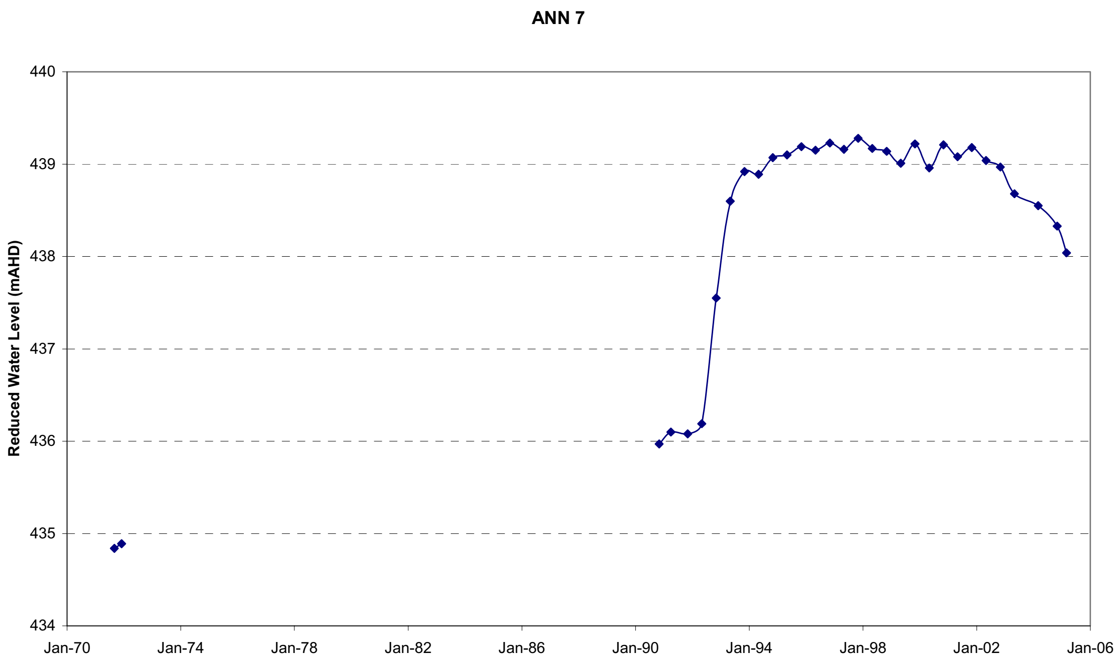
Jan-98
Jan-02
Jan-06





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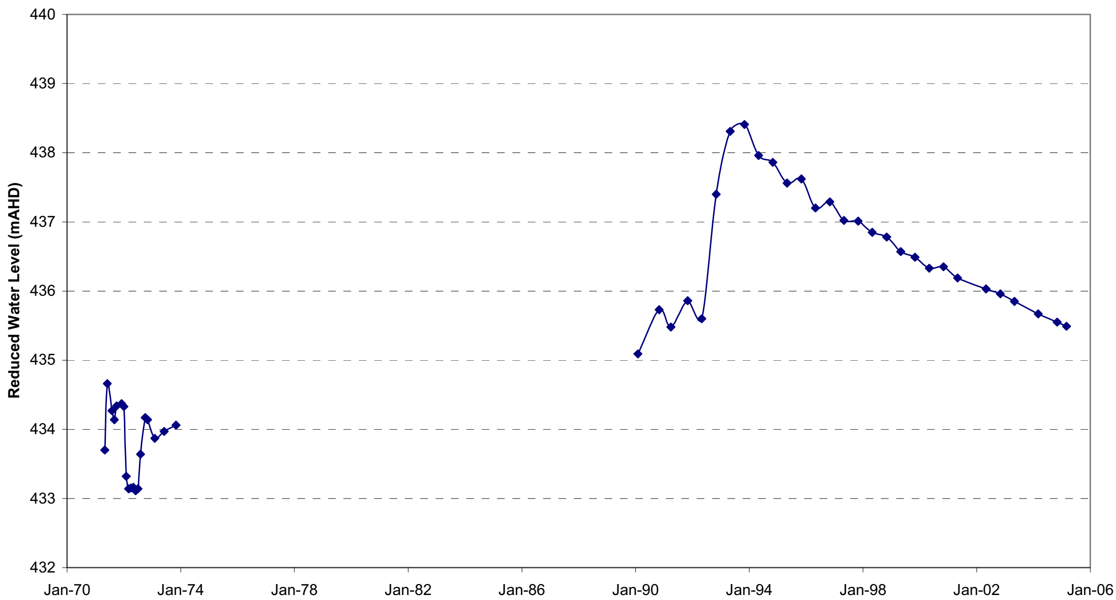
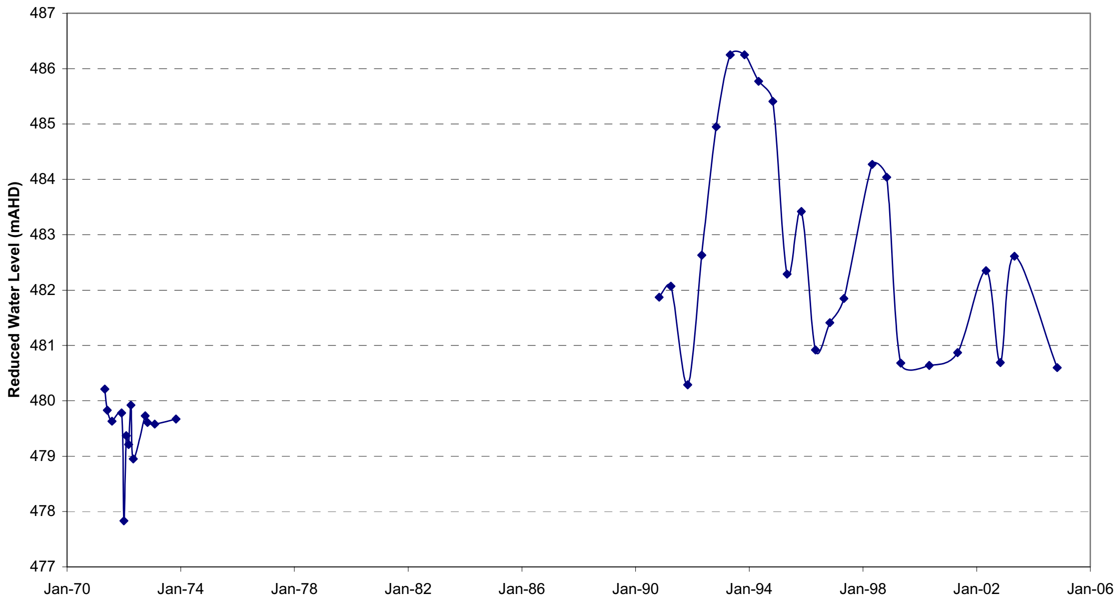
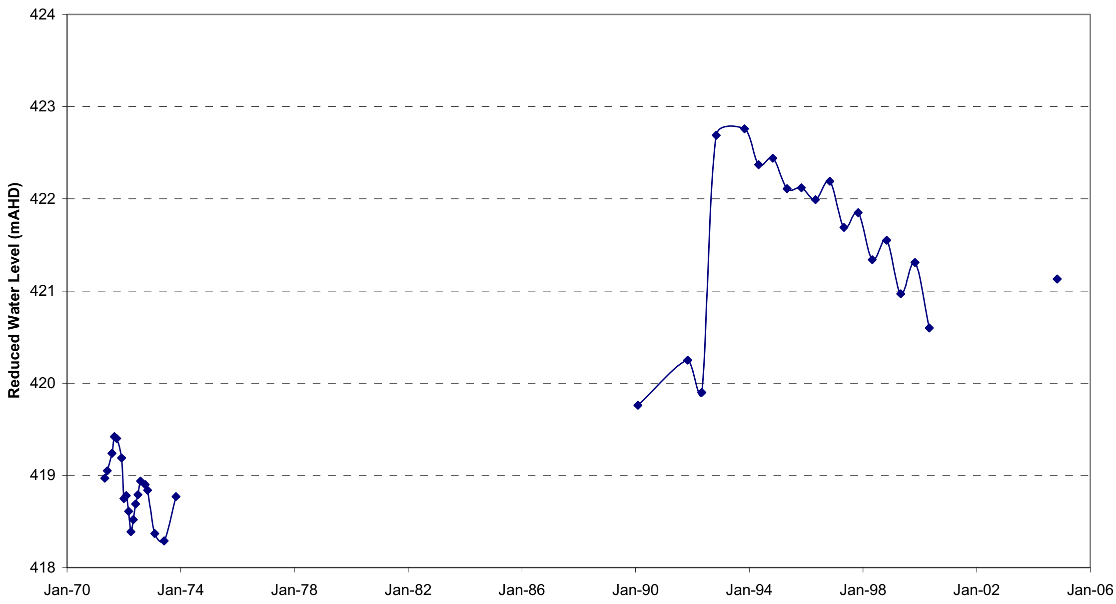
ANN 10


Reduced Water Level (mAHD)
440
439
438
437
436
435
434
433
432
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

ANN 14

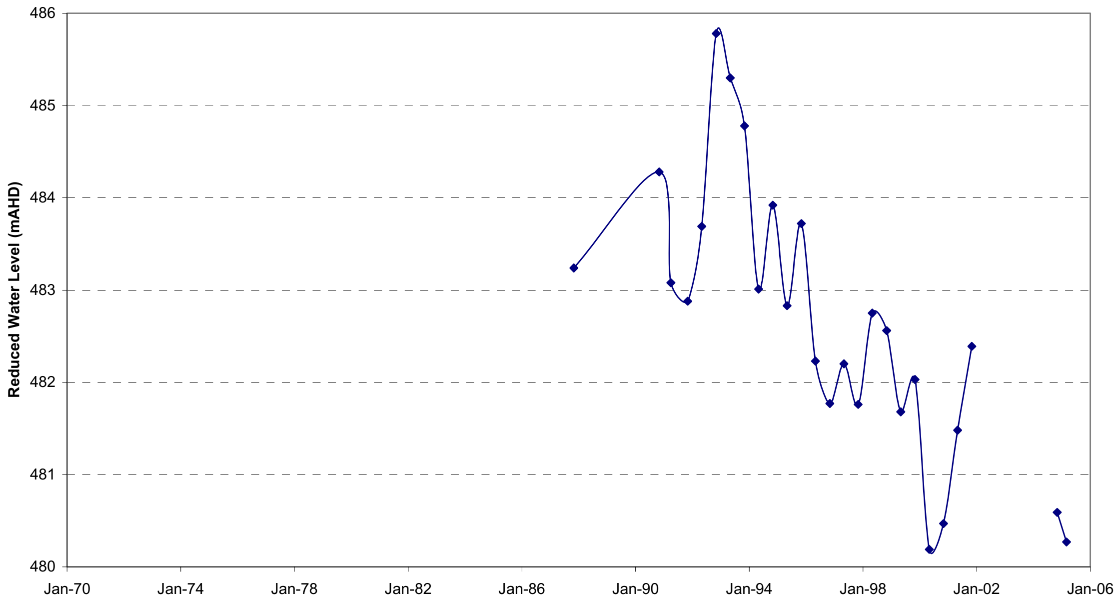

Reduced Water Level (mAHD)
487
486
485
484
483
482
481
480
479
478
477
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

ANN 18



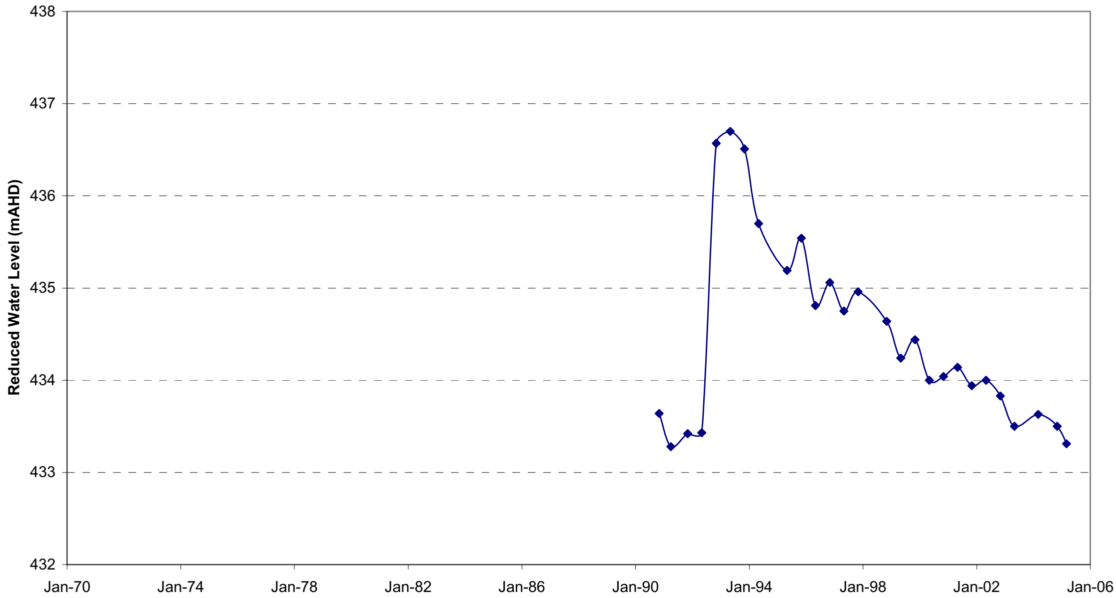
424
423
422
421
420
419
418
Reduced Water Level (mAHD)
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

ANN 22



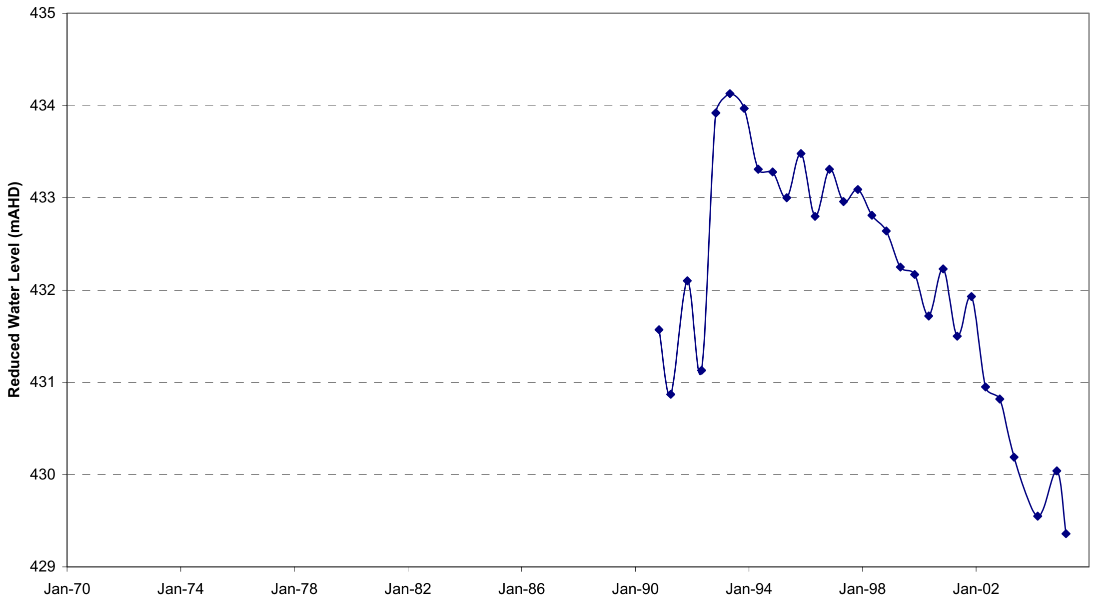
486
485
484
483
482
481
480
Reduced Water Level (mAHD)
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

ANN 23



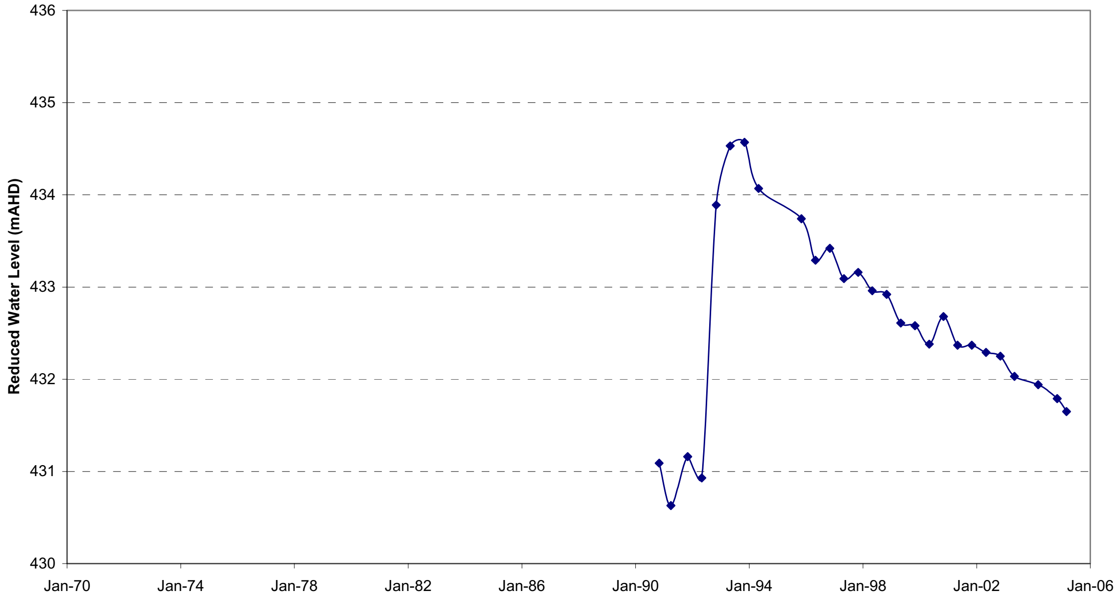
Reduced Water Level (mAHD)
438
437
436
435
434
433
432
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

ANN 24



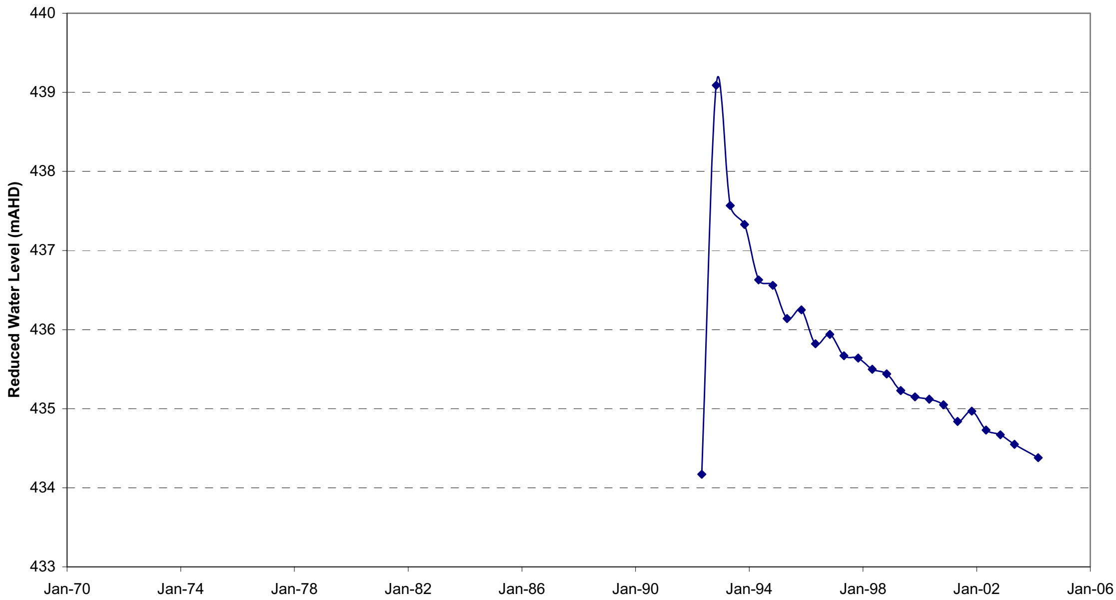
Reduced Water Level (mAHD)
435
434
433
432
431
430
429
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02

ANN 28

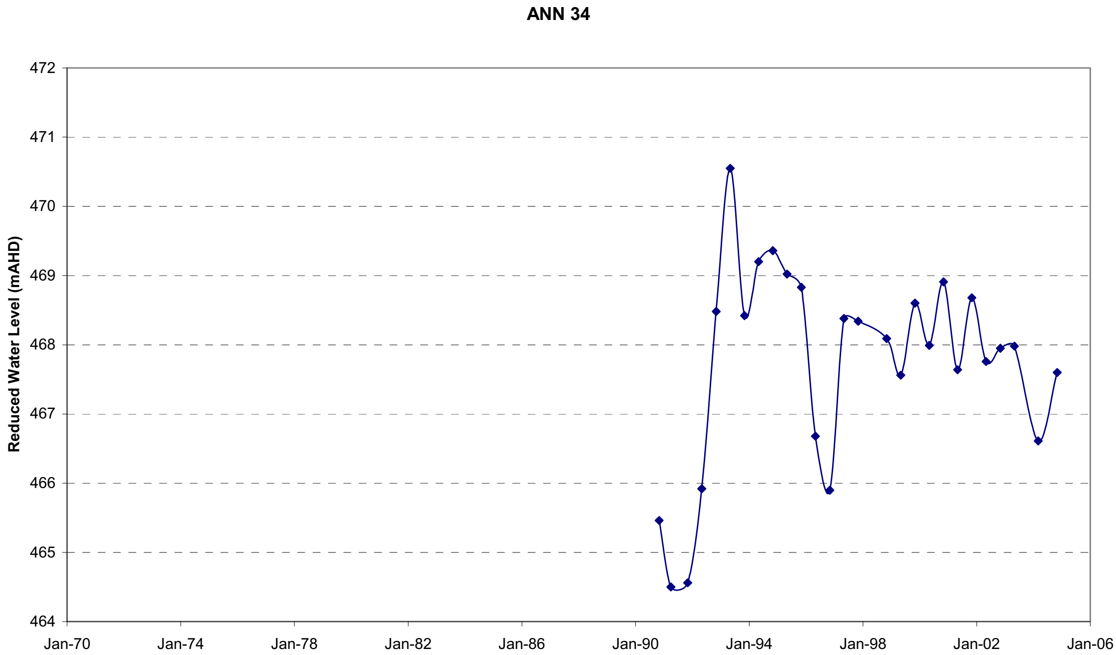


Reduced Water Level (mAHD)
436
435
434
433
432
431
430
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06

ANN 32



Reduced Water Level (mAHD)
440
439
438
437
436
435
434
433
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06


ANN 34
Reduced Water Level (mAHD)
472
471
470
469
468
467
466
465
464
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06