GROUNDWATER CONDITIONS AND BEHAVIOUR

IN THE

MURRUMBIDGEE IRRIGATION AREAS

Annual Report 2008

GROUNDWATER CONDITIONS AND BEHAVIOUR IN THE MIA
(2008 Report)

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SUMMARY

During 2007/08 the irrigation volumes were even less than for 2006/07. Rainfall in 2007 up to the end of October was 160 mm. This combined with groundwater pumping to the south and west caused groundwater levels to continue to drop for September 2007. Rainfall in November and December 2007 was too late to save the irrigation winter crops. With minimum irrigation during summer 2007/08 the higher summer rainfall did not result in higher groundwater levels for March 2008. This has now been an ongoing trend since about December 2001.

The data for September 2007 and March 2008 have been analysed and compared to the baseline data since September 1996. The groundwater balance has been considered and outcomes compared to targets for as far as possible.

The specific results and conclusions are summarised in the table below. This table is organised according to the requirements for reporting as per the Terms of Reference (Appendix A).

Heading	Requirement	Summary / Conclusion	Reference
Maps and Statistics	Map showing shallow Shepparton GW conditions	Continuing drop of GW levels. MIA average depth now 4.84m (March 08).	Maps 1 and 2, pages 9 and 10
	Map showing deep Shepparton GW conditions	Continuing drop of GW levels. MIA average depth now 8.43m (Sep 07)	Map 4, page 13
	Map showing Calivil GW levels	Continuing drop of GW levels due to groundwater pumping. Leakage gradients have been increasing. Average depth beneath MIA now 17.64m (Sep 07)	Map 7, page 16
	Map showing AHD contours	No change in general shape. Gradients to south and west.	Map 6, page 15
	Map showing change shallow GW conditions	Continuing drop, mostly in southern sub-districts. Average drop Sep01 to Sep07 was 2.09m.	Map 3. page 12
	Map showing change deep Shepparton GW conditions	Continuing drop, highest in southern Benerembah. Average drop Sep01 to Sep07 was 3.32m.	Map 5, page 14
	Map showing change Calivil GW conditions	Continuing drop end of irrigation season, strongest to the south of the MIA. Average drop beneath MIA Sep01 to Sep07 was 4.74m	Figure 8, page 17
	Salinity groundwater analysis, shallow and deep aquifers	No sampling 07/08, due now if five year cycle	
	Hydrograph seasonal behaviour 8 sub-districts	Bi-monthly data not averaged as in previous years. Average hydrographs for all sub-districts produced from calculated grid heights over full area each sub-district as defined (except Lake Wyangan). There is a continuing drop in all areas and less seasonal change since 2002. The March 2008 levels were deeper than Sept 2007.	Section 4, Fig7, p19, Fig8, p20, Fig9, p21, Fig10, p22, Fig11, p23, Fig12, p24, Fig13, p27.
	Frequency Tables 8 sub-districts, shallow GW	Continuing drop of areas within 2 metres from surface to nil in many sub-districts.	Tables 4-10 Pages 15-22
	Frequency Tables, 8 sub-districts, deep GW	Continuing drop of areas within 2 and 4m from surface to nil in many sub-districts.	Tables 4-10 Pages 20-27

	Frequency Table GW salinity 12-35m aquifer	No sampling carried out this year	
	Piezometer sites location maps.	Sufficient piezometers monitored. Fewer available piezometers in Wah Wah shallow, Lake Wyangan, Kooba and parts of the Yenda sub-district.	Appendix C Page 44-45
	Groundwater sub-districts	Sub-districts delineated and mapped	Fig 2, p7, and Fig 6, p18
Other Monitoring Outcomes	Effect on areas adjacent to MIA	No effect detected for 2007/08, rather the reverse (increased leakage from MIA)	Section 5 Page 28
	Effect Floodway lands	No flood event occurred.	Section 5, page 28
Performance Indicators	Target for accessions and extractions GW	*Rice target*: Only 63 ha of rice grown. This was a major reason for continued groundwater level drop. Channel Seepage. Potential channel seepage volumes are increasing due to deeper GW depth, and that this may now a major component in total accessions. However, the channel was run at lower levels this year, which would have limited the actual volumes.	Section 6.2 page30, Table 13, page 33
	Areas and Distribution targets WT within 2 metres	Areas within 2m are hugely below LWMP targets, to the extent that the targets listed in the LWMP need reviewing	Section 6.1, page 30
	Pressure level deep aquifer target	Areas within any criterion are less than expected.	Figure 5, p16.
Other Requirements	DWE comments, address any issues raised	Comments received on the 2007 have been responded to. Useful suggestions have been incorporated.	Appendix B
	Effect GW trend Mar07 to Sep07 and Sep07 to Mar08 due to cropping	*Irrigated crops*: No effect summer crops found, but there may be accessions from autumn irrigated crops. These were less than 20% of long term average during 2007.	Fig 15, page 26, Text page 24, 26
Beyond Requirement	Future trend groundwater levels.	Three scenarios are being presented. GW will return to early 1990's situation if all factors including rice growing restored. However, a lesser return would occur if rice only 2/3rd, or rainfall remains less. Effect on soil salinity not known.	Page 25
			Page 26

1. INTRODUCTION / CONTEXT

The author has been contracted by Murrumbidgee Irrigation to produce the annual groundwater report to meet the requirements of the Irrigation Corporations Water Management Works License (IC5) for 2007/08. The annual reports are reviewed by the Corporate Licensing Unit (CLU) of the NSW Department of Water and Energy. The terms of reference for groundwater reporting are at Appendix A. The comments received by CLU have been considered and a response is provided at Appendix B.

The focus of this report is on the piezometer data of September 2007 and March 2008 and the analysis of this dataset in relation to other factors. The requirements are:

- Read over 800 piezometers on a 6 monthly and some on a 2 monthly basis.
- Produce statistics re data collection and storage.
- Produce maps, hydrographs and frequency tables to show groundwater behaviour.
- Analyse trends of groundwater levels against baselines and targets.
- Consider variation within and between eight sub-districts.
- Consider the possible impacts of the shallow groundwater conditions in the MIA on deeper groundwater systems and lands adjacent to the MIA.
- Determine the effect of flooding on groundwater in the Lower Mirrool Creek area.
- Report any incidences of contamination of groundwater.
- Monitor and report on the salinity of groundwater.
- Report on how LWMP and recharge/discharge targets have been achieved
- Produce maps in acceptable format.
- Respond to any comments received by DWE Corporate Licensing Unit

This reporting work is an annual recurrence which has occurred since 1996, which is the reference year for changes which may have occurred. The main purpose of reporting annually is to ensure each year that any adverse situations or trend which may start to develop is detected and reported.

The reporting of trends requires consideration of factors other than groundwater and depends on the availability of suitable methods of analysis, some of which still may be considered in development and hence require a research effort. In this respect quite extensive work was undertaken by the author during 2006, resulting in a comprehensive report for datasets from 1990 up to March 2006. The work resulted in the trends being quite accurately estimated from the various contributing recharge and discharge factors in groundwater change every six months over the reference period.

Previous reports have included recommendations regarding licence change which so far have not been acted upon, but which now seems likely to happen during 2008. This report covers the various requirements of the licence. Because of the impending review it has been considered useful to present the aspects of groundwater trends and recharge targets in a more comprehensive form than during 2007 and to include some discussion on the status of groundwater monitoring in the MIA relative to sustainability issues.

2. DATA COLLECTION AND ANALYSIS

2.1. Data Collection and Statistics

Since 1996 more than 900 piezometers have been used for groundwater monitoring in and adjacent to the MIA. Figure 1 shows how this number has gradually dropped to 858 in September 2007 and 855 in March 2008.

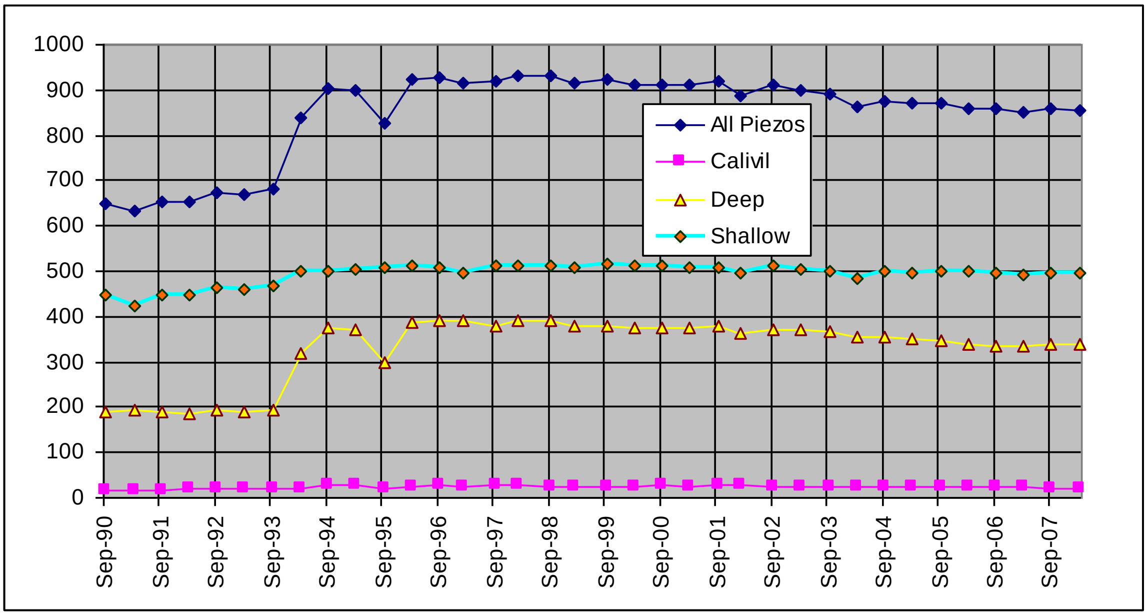

Figure 1: Number of piezometers monitored in shallow and deep Shepparton Formation aquifers of the MIA since 1990.

Before 1990 a larger number of piezometers were actually read and recorded, however a review by the then Department of Water Resources saw a large reduction from 1990 to 1994, after which the numbers were increased again for accuracy of mapping purposes.

Appendix C shows the location of "shallow" and "deep" Shepparton Formation piezometers in the MIA and the Wah Wah District used for monitoring during September 2007. Only piezometers which recorded a reliable reading were included. The piezometers are visited and readings taken by staff of Murrumbidgee Irrigation at Leeton and at Griffith during March and September each year. The statistics of piezometers read at selected dates up to March 2008 are shown in Table 1.

Table 1. Availability of piezometer readings for various dates and categories of piezometers, Murrumbidgee Irrigation Areas and the Wah Wah Irrigation District.

Type of Piezometer	***Listed in Database***	***Read Sep96***	***Read Sep00***	***Read Sep07***	***Read Mar08***
Shallow (*1)	417	465	459	437	438
Shallow (WW)	30	22	23	12	12
Total Shallow	***447***	***487***	***482***	***449***	***450***
Deep (*2)	359	363	362	331	330
Deep >35m	19	28	28	26	25
Deep (WW)	35	44	43	39	39
Total Deep	***413***	***435***	***433***	***396***	***394***

*1. Piezometers in aquifer within 12 metres in aquifers 12-18m which behave as if in the shallow zone
*2. Aquifers 12 – 35 metres, all piezometers not categorised as "shallow".

The Environmental Management Conditions (EMC), Part 2 of IC5, identifies that a minimum of 850 piezometers are to be used for six-monthly monitoring. Actually, the official piezometer list issued with the licence identifies 877 piezometers, of which 58 piezometers are outside the MIA boundaries. Table 1 shows Leeton and Griffith staff over the last ten years have included other piezometers over and above the official listing in the bore monitoring program.

Despite a number of piezometers having become lost over time, particularly in the 2000 to 2004 period, the 850 requirement specified in the licence is still being met. However, in some cases a piezometer of the original list has been lost and alternative piezometers still available in the field from before 1990 have been used to make up for this loss of data. This substitution has a small effect on accuracy by which groundwater statistics between years may be compared. No piezometers were replaced by a drilling program over the last 12 years.

The maps of Appendix C show that there is a considerable variation in coverage across the area. In the Wah Wah District there is a much smaller coverage of piezometer sites. The same applies for the Lake Wyangan area. Piezometers are also lacking (and are not feasible to construct) in areas of the MIA where there are no underlying sands, such as in parts of the Yenda area and north Benerembah (shallow). The situation of apparent shortage varies for the deep and shallow piezometer sets.

Most deep piezometers in Wah Wah have not been surveyed for AHD level, with the consequence that it is not possible to determine an accurate AHD groundwater contour map ([1]) for that area.

During 2007/08 453 (53%) of the piezometer sites in the MIA have been visited for GPS based coordinate determination. Some coordinates were found to be out by up to 2 km, more in isolated instances. The amended coordinates have been used for this report and the changes on result comparison between years considered as to their effect (which proved to be small).

The licence also ([2]) requires that a minimum subset of 60 piezometers is to be used for two-monthly monitoring to determine seasonal trends. The bi-monthly reading list used since 1995 has 108 piezometers, of which 101 provided readings during the 2007/08 year. The data is available, hence the requirement has been met, but it will not be reported upon for this report (see Section 3).

Groundwater was last sampled for salinity during 2002 and this has been reported (Murrumbidgee Irrigation report by van der Lely, January 2003).

Groundwater levels for Calivil Formation piezometers were obtained from the Department of Water and Energy at Leeton. Aquifers of this Formation are below the deeper Shepparton Formation, which is below about 35 metres in the North of the area to below about 70 metres in the South.

2.2. Analysis of Data Sets

The method of analysis is based on the superimposition of a 350 metres grid over the MIA, and then calculating a groundwater level for each grid cell and for each layer based on nearby piezometer information for that layer. The calculation of grid data is based on kriging for the deeper Shepparton and Calivil Formation piezometer readings, whilst the “inverse distance to power 2.5” method was used for shallower piezometer readings ([3]).

The shallow groundwater zone is defined by piezometers to 12 metres depth, plus a selection of any piezometer from the 12-18 metres zone in which groundwater behaves as in a shallow

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[1] AHD = Australian Height Datum (metres above sea level).

[2] In the 2006 report it was recommended that bi-monthly monitoring be abandoned since it no longer serves a useful purpose, however there has not been a review and the reporting conditions still exists.

[3] Both are statistical techniques. Kriging is usually preferred to calculate a surface through many data points, however the interpolated curvature of this surface may rise a little above the higher or below the lower points, which in turn may cause groundwater to show higher than the highest data point (closer to the surface, even negative). For that reason inverse distance to power 2.5 was used for the shallow aquifer.

piezometer. The deeper groundwater zone is defined by the piezometers installed to depths ranging from 12-35 metres, except for those reclassified as “shallow”.

Murrumbidgee Irrigation piezometers installed deeper than 35 metres were classified as Calivil, and combined with the dataset obtained from the Department of Water and Energy. In the northern part of the MIA the deeper than 35 metres stratigraphy is of the Calivil Formation.

For all three layers (shallow, deep and Calivil), the required contour maps of this report were produced from the grid depths calculated. The grid depths were also used to produce statistics such as averages and frequency tables for the MIA overall and the various sub-districts individually.

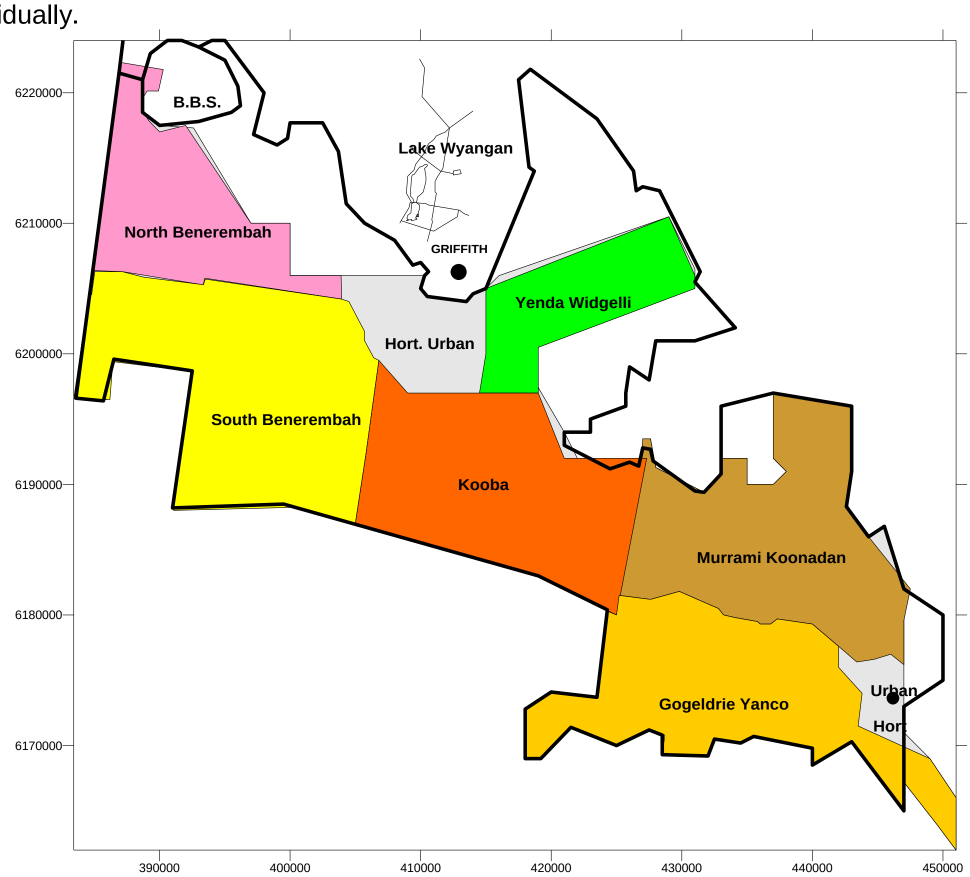


Figure 2. Extent of the MIA irrigated areas, the extent of shallow groundwater aquifers (to 12m, grey) and location of selected sub-districts in the MIA (except Wah Wah).

Figure 2 shows the outline of the MIA area which is actually irrigated (except Lake Wyangan, Tabita and Wah Wah). This area is less than the full area over which MI has control in terms of water management. The piezometer location maps of Appendix C show that shallow and deep Shepparton groundwater zones do not occur over all of the outlined irrigated area of the MIA. There are areas with clays extending to large depth preventing analysis of groundwater behaviour. Henceforth, the shallow and deep groundwater zones as defined to delineate sub-districts more or less conform to the area where piezometers are located. Groundwater contour maps and related statistics have been limited to these areas. For instance, the shallow groundwater zone of the MIA (except Wah Wah) is about 135,000 ha, smaller than the area of large area farm land (>160,000 ha).

Another aspect to be considered in analysis of groundwater behaviour relative to irrigation practices is that the MIA contains both horticulture and large area farm lands. In the last ten years a significant area of large area farm land has been converted to horticulture (grapes mostly) and the distinction between the two has become blurred. For mapping purposes this does not matter, however the analysis of trends and groundwater recharge/discharge including water use aspects needs to try to make a distinction. The assessment of groundwater depth averages for subdistricts has aimed to restrict itself to large area farming land mostly. Figure 2, showing the location of shallow aquifer sub-districts reflects this. The old horticultural areas are mostly tile drained and groundwater issues for a long time have not been considered an issue any more.

No map is presented in this report to show the location of deep Shepparton aquifer sub-districts. Actually, they are similar to those in Figure 2, the main exceptions being that North Benerembah extends further north, and the Murrami-Koonadan sub-district is smaller by omitting the northern parts.

The analysis of groundwater pressure levels in the deeper Shepparton and the Calivil Formations has been based on the boundaries of the sub-districts of Figure 2 to ensure the best possible comparison of averages between the three different layers ([4]).

2.3. Data storage.

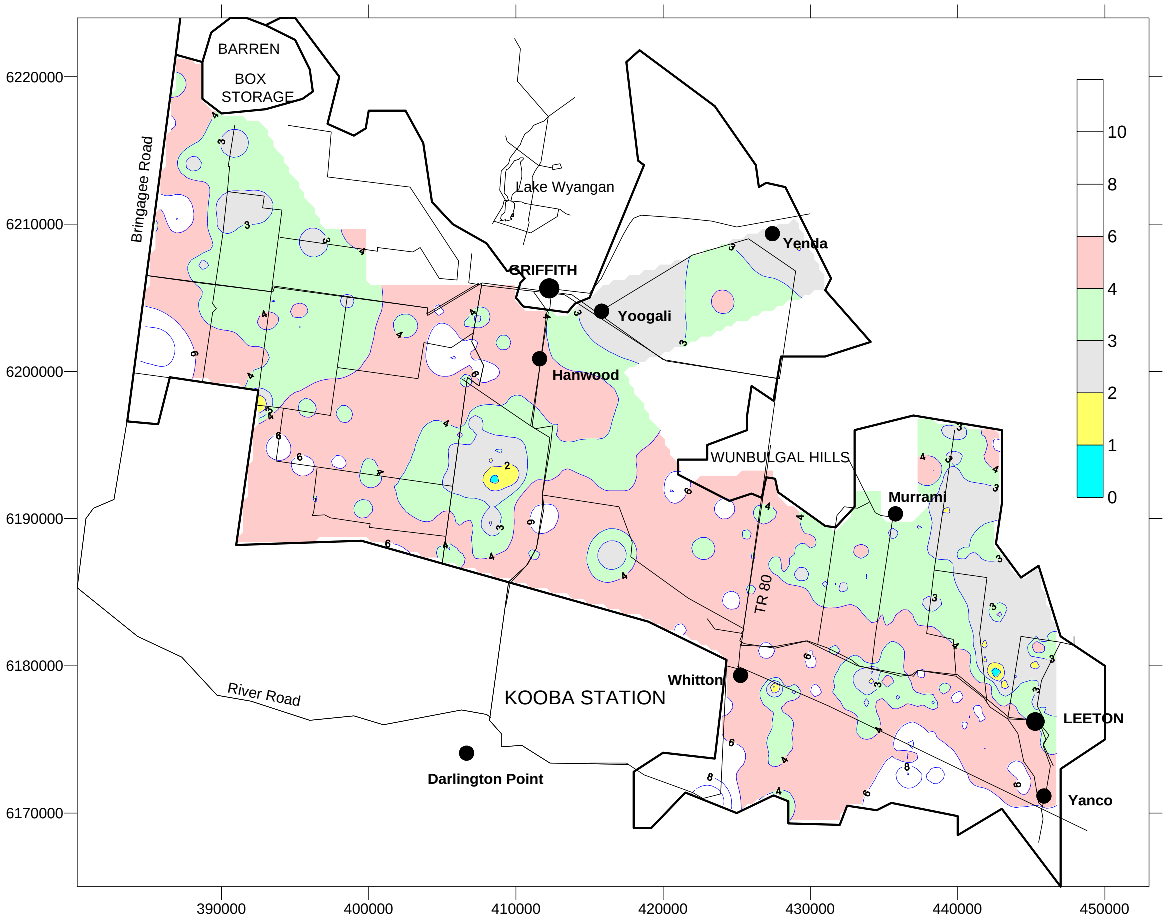
All data are kept in an ACCESS database from which sub-sets may be extracted. A copy of the data in ACCESS or EXCEL format would be made available to DWE on request.

[4] Of course such a match can never be fully achieved in the northern sub-districts as each layer has a different boundary and leakage does not necessarily take place over the full area of the shallow zone as defined.

3. REGIONAL GROUND WATER CONDITIONS

3.1. Shallow Shepparton Formation Aquifers

The discussion of this section is for the MIA, with the exception of the Wah Wah District. The latter area is discussed in Section 4 on Sub-Districts. Maps 1 and 2 show the contour depths of groundwater in the shallow groundwater zone (as defined) for September 2007 and March 2008. The shallow groundwater zone shown includes horticultural areas around Hanwood and near Leeton.

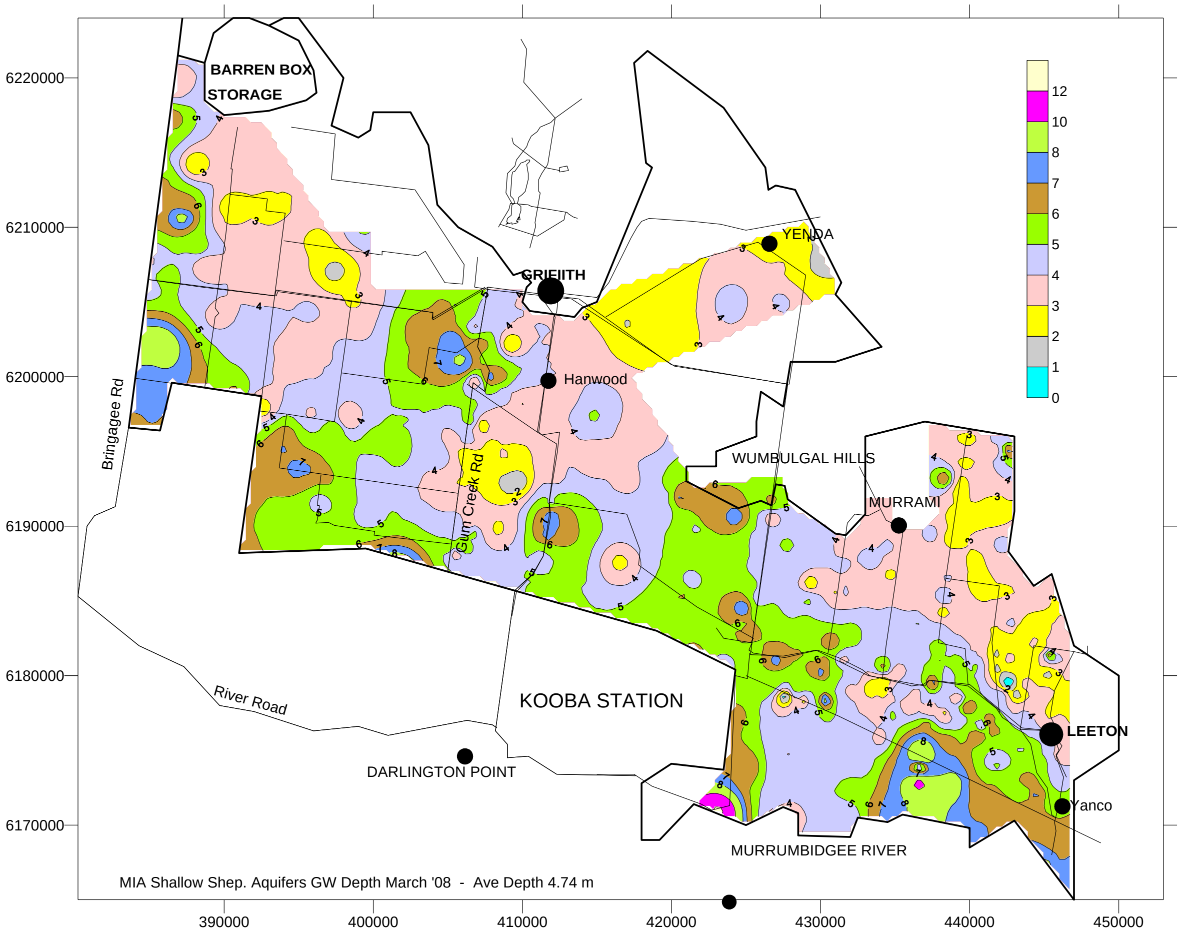


Map 1: Depth to shallow groundwater in the MIA, September 2007.

High groundwater levels within two metres were almost non-existent and confined to small areas near Mirrool Creek in Mirrool and in the Yanco district, possibly related to channel seepage locations. The highest groundwater areas generally are in the Koonadan area north-west of Leeton, and around Yoogali and Yenda. Even in these areas they have retreated to between 2 and 3 metres depth.

The small pockets of high groundwater in Northern Benerembah are related to a depressed prior stream site, a soil ridge formation with down slope seepage and probably some channel seepage spots.

Map 2 shows that during March 2008, the end of an almost zero irrigation summer season, the high watertable areas are even smaller. The watertable levels dropped this season rather than rose, which is the norm. The irrigation water allocation was less than 10%, which is even less than for 2006/07. Only three commercial rice crops were grown, involving only 63 hectares instead of 30 - 35,000 hectares as in the 1990's.



Map 2: Depth to shallow groundwater in the MIA, March 2008.

These maps may be regarding the "depth to watertable" maps for the MIA. Figure 2 corresponds to Maps 1 and 2 and show the "% of area within specified depth" for selected years since 1996.

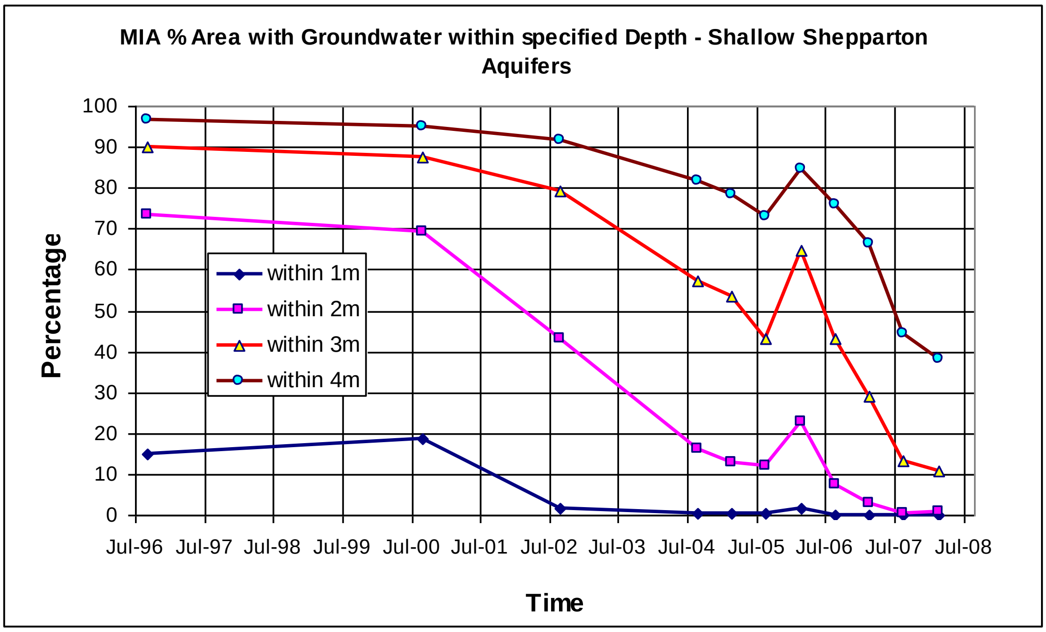


Figure 2: Shallow groundwater aquifer zone MIA (excluding Wah Wah): Percentage of land with groundwater levels within depth specified.

The actual data of Figure 2 are provided in the next section. A very large decline in the proportion of land with groundwater within 2 metres is indicated, from over 70% before 2000 to zero by September 2007. There was a kick up in March 2006, at the end of a season with increased irrigation activity and more rice growing.

The history of average depth to groundwater from 1996 is shown at Figure 3. This is the reference year when Murrumbidgee's responsibility for groundwater monitoring began.

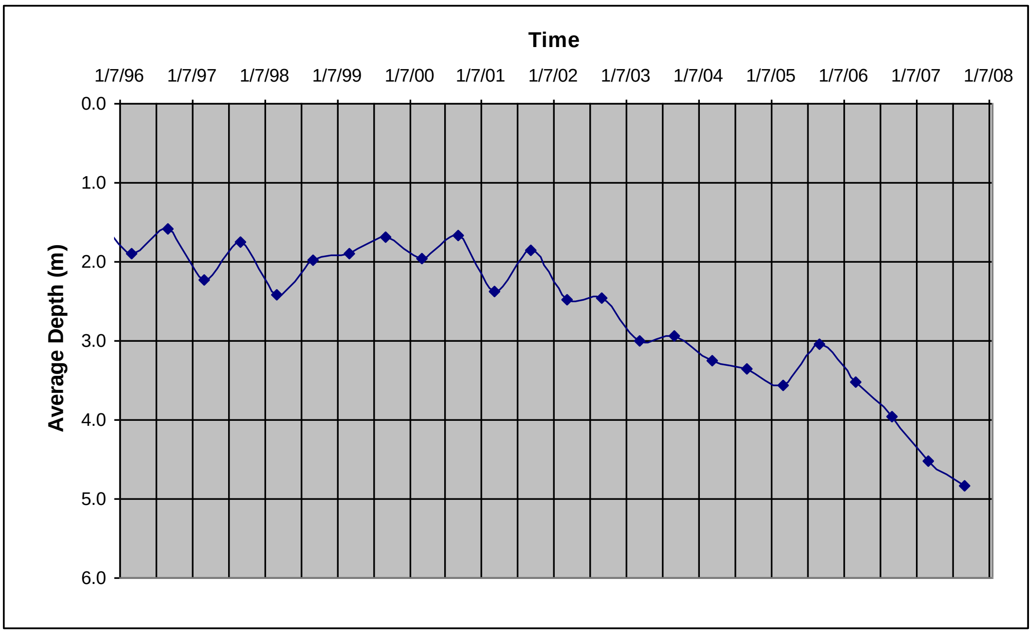


Figure 3: Hydrograph of average depth to groundwater in shallow groundwater zone of the MIA, 2000 to 2007.

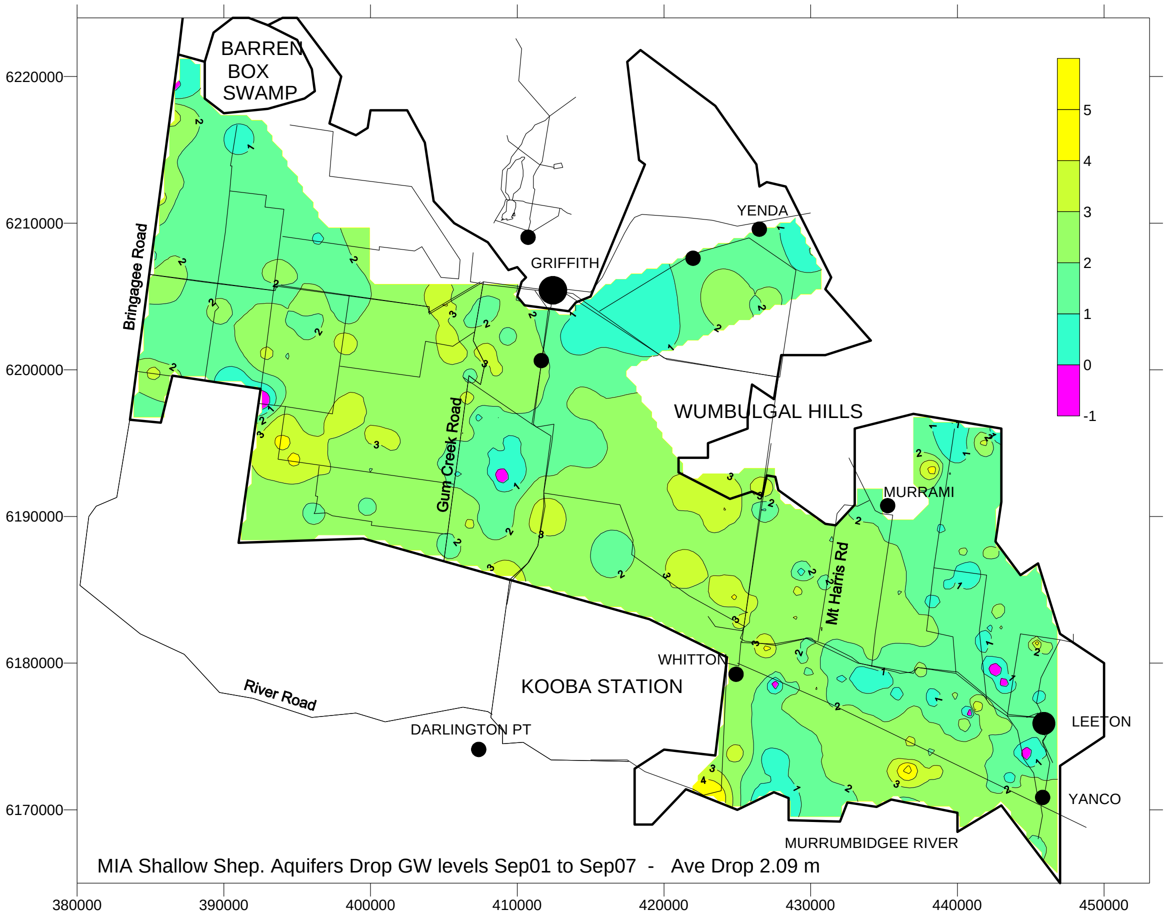
During the 1990's the averages were about 1.5 to 2.0 metres, with averages deeper in September than March each year. At that time the annual variation due to irrigation in summer and variable rainfall recharge during autumn and winter is clearly indicated. After 2001, because of lesser irrigation water availability and reduced rice areas, groundwater levels declined sharply to reach an all time low in March 2008. The annual variation due to irrigation recharge became less.

The average drop in groundwater level from September 2001 to September 2007 (in m) is shown at Map 3. The average drop over this period was 2.09 metres. The smallest drops were recorded for the area north west of Leeton (Koonadan), the Yoogali – Yenda area, and north-west Benerembah. These are also the areas where the smallest leakage of groundwater from shallow to deep groundwater aquifers is expected.

Some of the "hotspots" for low drop in groundwater levels in the Yanco area may be related to the management of drainage tube wells, some of which would have been operated less towards the end of the period.

The largest drops in groundwater levels were in the Kooba and South Benerembah areas, extending into the Murrami and west of Hanwood areas. The latter area obviously has relatively good deep lateral drainage, in contrast to the Yoogali- Yenda area, where pressure levels always tend to remain high (see also Maps 1 and 2). Earlier soil surveys reported a soil ridge probably linked to a fault line just east of Griffith, running south.

The trends shown for the current year are discussed at Section 6 in the context of groundwater recharges and discharges from all sources.



Map 3: Drop (in m) of shallow groundwater levels in the MIA, Sep01 to Sep07.

3.2. Deep Shepparton Formation Aquifers

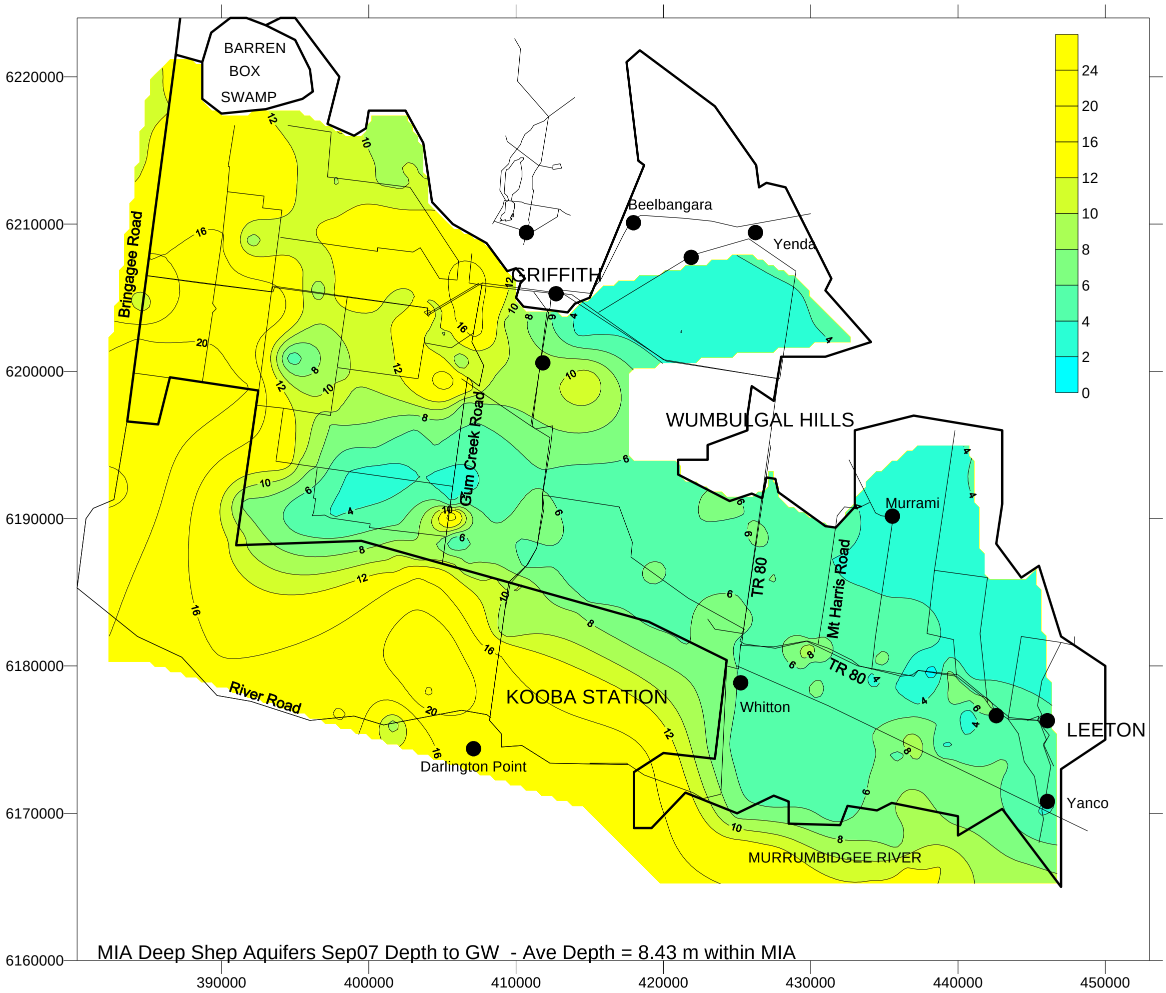
The deep Shepparton aquifer system is defined as intermediary between the more shallow aquifers and the Calivil Formation aquifers. It receives groundwater from the top, and passes most of it on to deeper zones. Via this aquifer system there is also a (probably small) component of lateral groundwater movement away from the MIA to the South and West.

Map 4 shows pressure level contours (depth to top of water in piezometers extending to this aquifer system) for the deep groundwater zone for September 2007. Table 2 corresponds to Maps 1 and 4 and shows the distribution of areas within each groundwater depth range for both the shallow and deep Shepparton aquifers systems.

*Table 2. Percentage of contoured area of the MIA with ground water pressure in the shallow and deeper aquifer within the depth from surface as indicated (*1).*

Shallow Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1m	0	1	0	1	0	0	0	0	0
within 2m	31	27	12	4	1	1	1	0	1
within 3m	62	56	44	31	20	13	9	13	11
within 4m	95	82	68	50	43	44	37	44	38
Deep Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1 m	1	2	0	0	0	0	0	0	0
within 2m	27	23	5	1	0	0	0	0	0
within 3m	58	48	37	13	9	7	2	5	3
within 4m	87	73	61	36	37	36	20	14	11

*(*1) Depth ranges of shallow and deep aquifers as defined at Section 2.*



Map 4: Depth to deep Shepparton pressure levels in the MIA, September 2007.

Only two March readings are included in Table 2, March ‘07 and March ’08. On both occasions the percentage found was less than the previous September. This was a rare feature during the 1990’s and an indication of how little irrigation water was applied to the land.

The differences in pressure level between the shallow and the deeper Shepparton groundwater aquifer systems are the largest in the north-west of Mirrool and the Benerembah district (compare Maps 1 and 4). In the Yanco area extending into Kooba the difference is quite small, often less than 1 metre (also see Section 4).

Figure 4 shows that the depth to average ground water reduced from 4.5 – 5.0 metres in the late 1990’s to almost 9 metres in March 2008. It is shown that the fluctuation from March to September and vice versa is less pronounced than for shallow Shepparton aquifers (Figure 3), and less so for the 2002 to 2008 period than before.

The annual average drop in pressure levels in the deep Shepparton aquifer zone from September 2001 to September 2007 is shown at Map 5. The greatest drop in deep Shepparton pressure levels have occurred in the Benerembah District. It may have been influenced by deep aquifer pumping. Map 5 suggests a varying degree of connectivity and deep leakage potential between sub-districts. The lowest drops occurred in the north east Yanco Irrigation Area (Koonadan) and the Yoogali – Yenda area, the same as for the shallower aquifers. The rises found may be related to tube well operations, as the groundwater levels are not really high at these locations (Map 4). The small hotspot south of Yanco is unexplained.

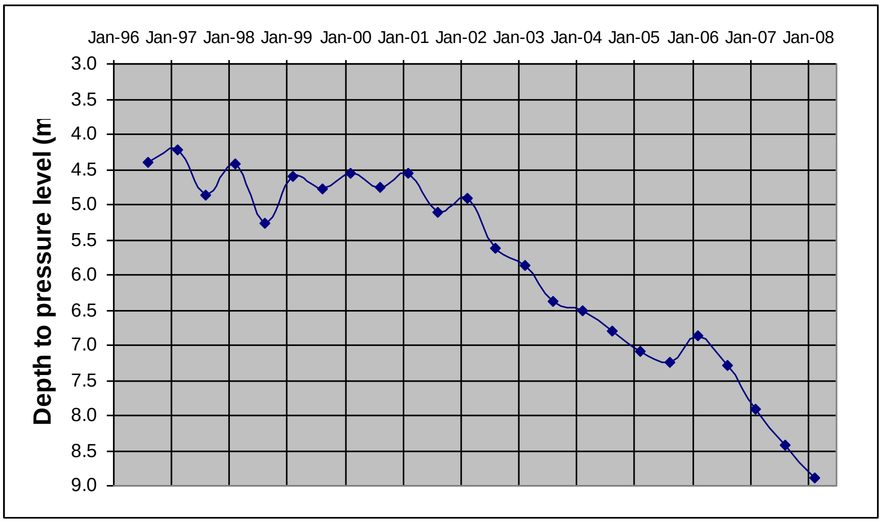
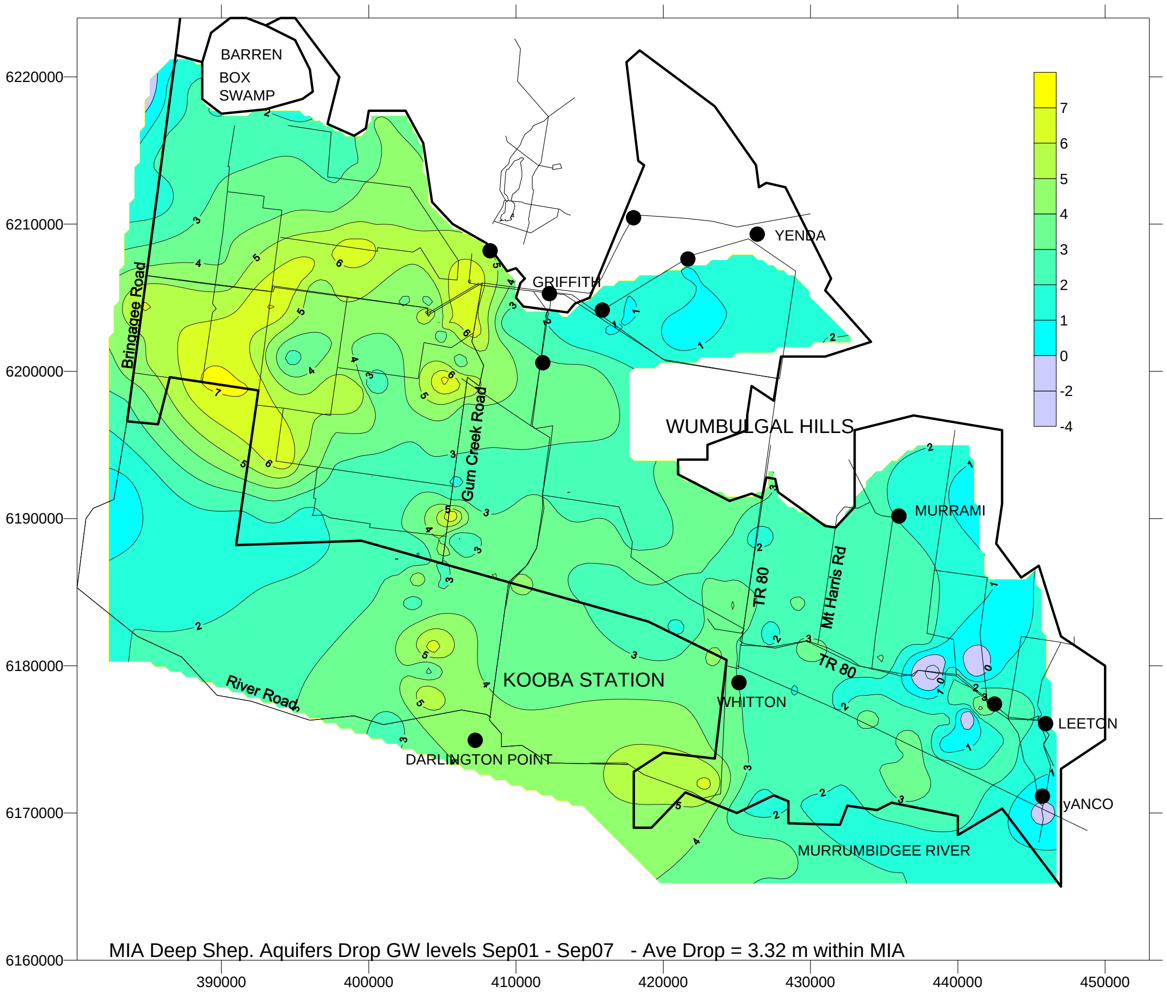
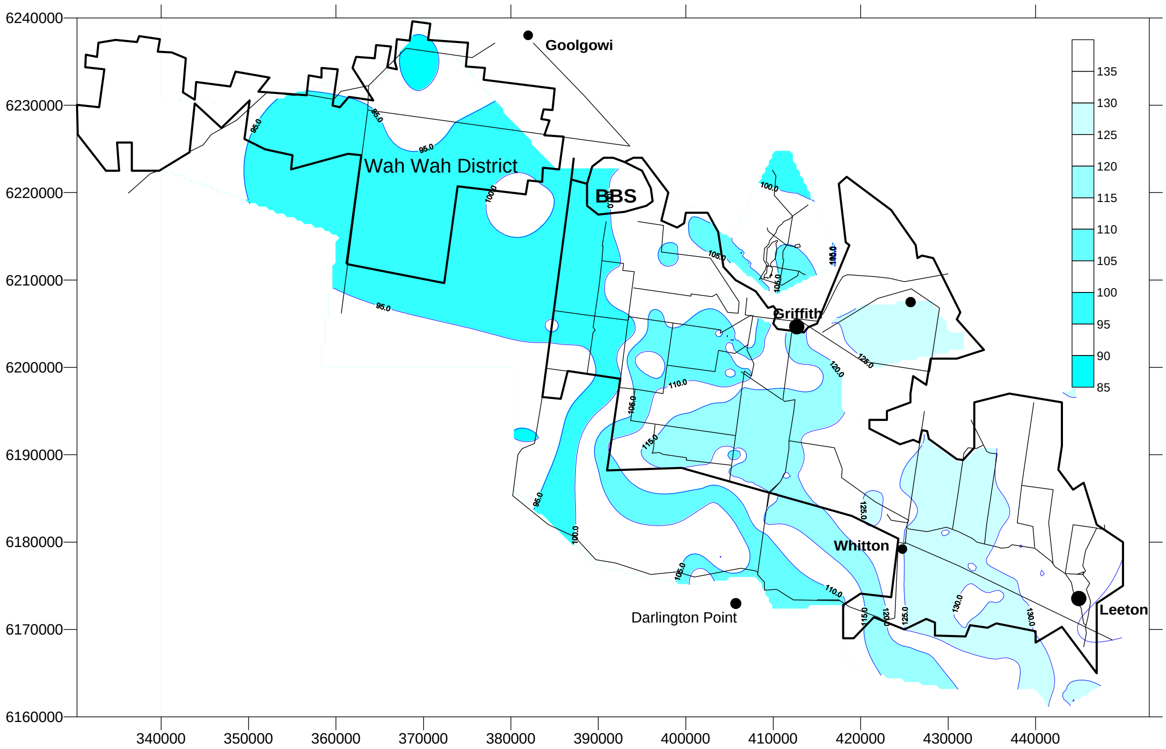


Figure 4. Depth to average pressure level in deep Shepparton aquifers of the MIA.



Map 5: Drop (m) in deep Shepparton groundwater levels in the MIA, Sep01 to Sep07



Map 6: AHD contours of deep Shepparton Formation groundwater pressure levels in the MIA, Sep 2006

Map 6 shows the AHD contours of the MIA, extending towards the Wah Wah Irrigation District ([5]). The gradients are generally from east to west, but near the southern boundary there are also gradients from the Yanco area towards and beneath the Murrumbidgee River, from the south-west Yanco and south Mirrool areas into Kooba station, and from Benerembah in a westerly direction. There is no evidence from this map that the Barren Box Storage area has any influence on groundwater conditions.

The pattern shown has not changed significantly in the last 40 years. The effect of the flow to adjacent areas is discussed at section 5.

3.3. Calivil Formation Aquifers

Map 7 shows ground water levels below surface for the Calivil Formation (depth 70-130 metres, less towards the northern parts of the MIA) for winter 2007. Whilst this is not an AHD contour map, it is evident that gradients exist from all directions towards the main groundwater bore pumpers area west of Darlington Point towards Carrathool. The deepest pressure depth is now about 42 metres, whereas it was about 20 metres in the 1970's (less near Carrathool).

Beneath the MIA the aquifer pressure depths range from about 12 metres towards the north to 20 metres in the south. The drop in pressure levels from 2001 to 2007 (in m) are shown at Map 8. The drop beneath the MIA varies from 2 to 6 metres, with one apparent anomaly in Benerembah (perhaps due to a pump no longer being used).

Figure 5 shows the average behaviour of Calivil groundwater levels beneath the MIA from 1996. The annual variation is very large (>2m) compared to that of the shallower groundwater systems ([6]). The variation is caused by large volume groundwater pumping and partial recovery in the non-irrigation season. The average has dropped more than the averages for the shallower

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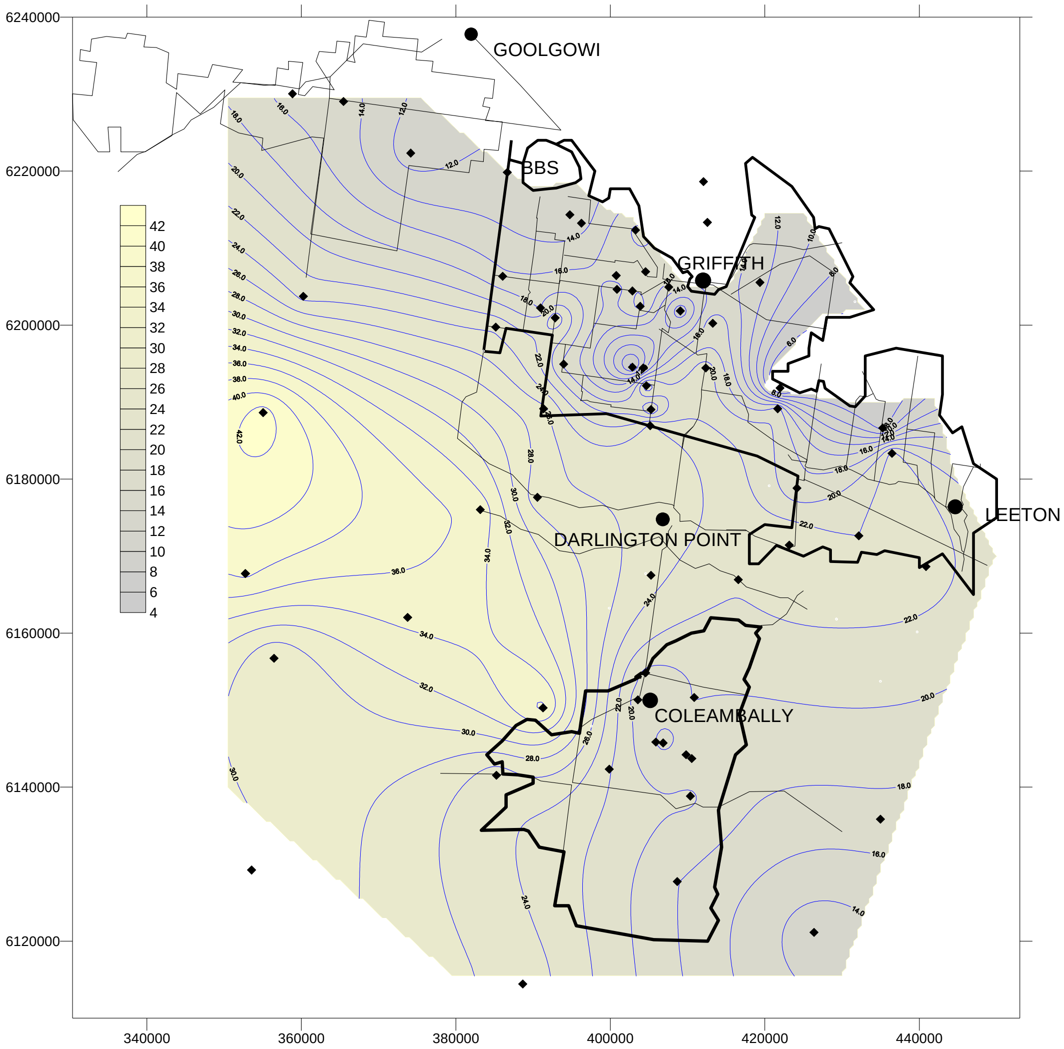
[5] The accuracy of contours towards the west is less accurate due to the limited number of piezometers available. The contouring method used provided contours anyway.
[6] The storativity of the deeper (confined) aquifers is much less so it takes less volume of groundwater to change the level by say one metre compared to the watertable aquifers.

systems, indicating deep leakage gradients from shallow to deep aquifers have increased over the period. This had an effect on the groundwater balance, see section 6.



Map 7: Depth of pressure level in Calivil Formation beneath the MIA and adjacent areas, August/September 2007. Piezometer locations used for this map are also shown.

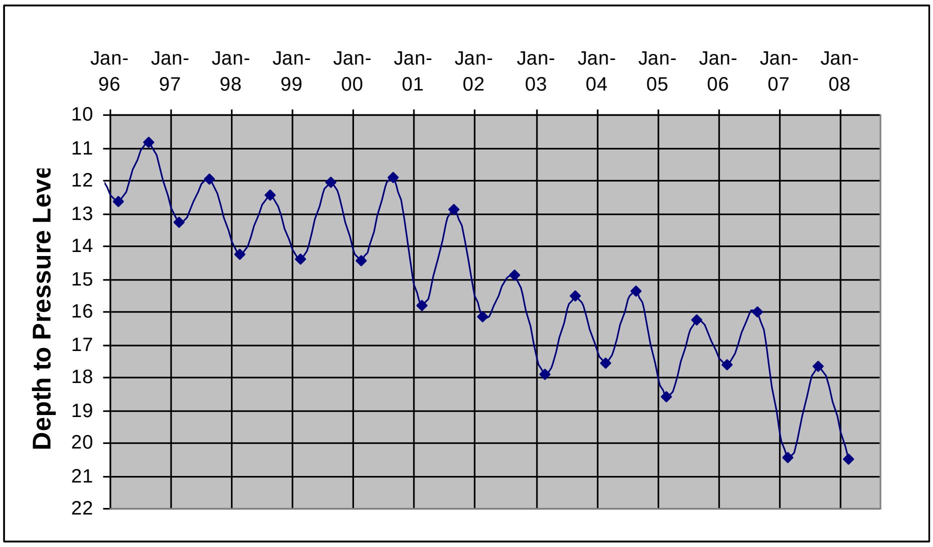
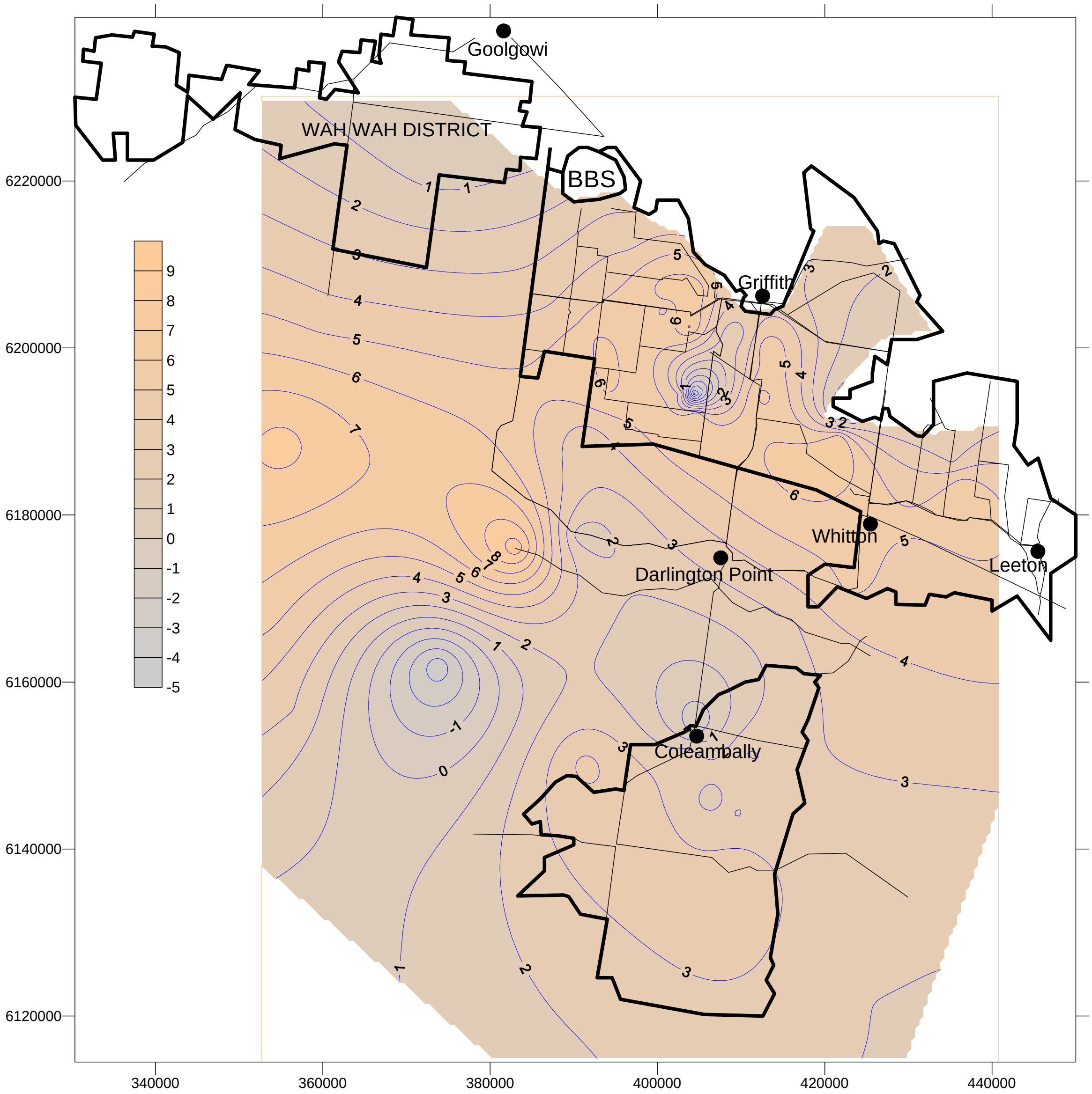


Figure 5. Depth to average Calivil Formation pressure level beneath the MIA, 1996 to 2008



Map 8. Drop in groundwater pressure depths of the Calivil Formation 2001 to 2007, averaged for March and September readings.

4. SUB-DISTRICT MONITORING.

4.1. General

Eight sub-districts are recognised. These are listed at table 3:

Table 3. List of sub-districts within the MIA for groundwater change reporting.

District	Sub-districts
Yanco IA	1. Gogeldrie / Yanco area 2. Murrami / Koonadan area
Mirrool IA	3. Kooba area 4. Yenda / Widgelli area 5. Lake Wyangan area
Benerembah ID	6. North Benerembah 7. South Benerembah
Wah Wah ID	8. Wah Wah Irrigated Area

The boundaries of the sub-districts are based on criteria of convenience and hydro-geological separation. For instance, there is an increasing likelihood of deep leakage in a southerly direction. Figure 6 shows the boundaries of these areas, except for Wah Wah.

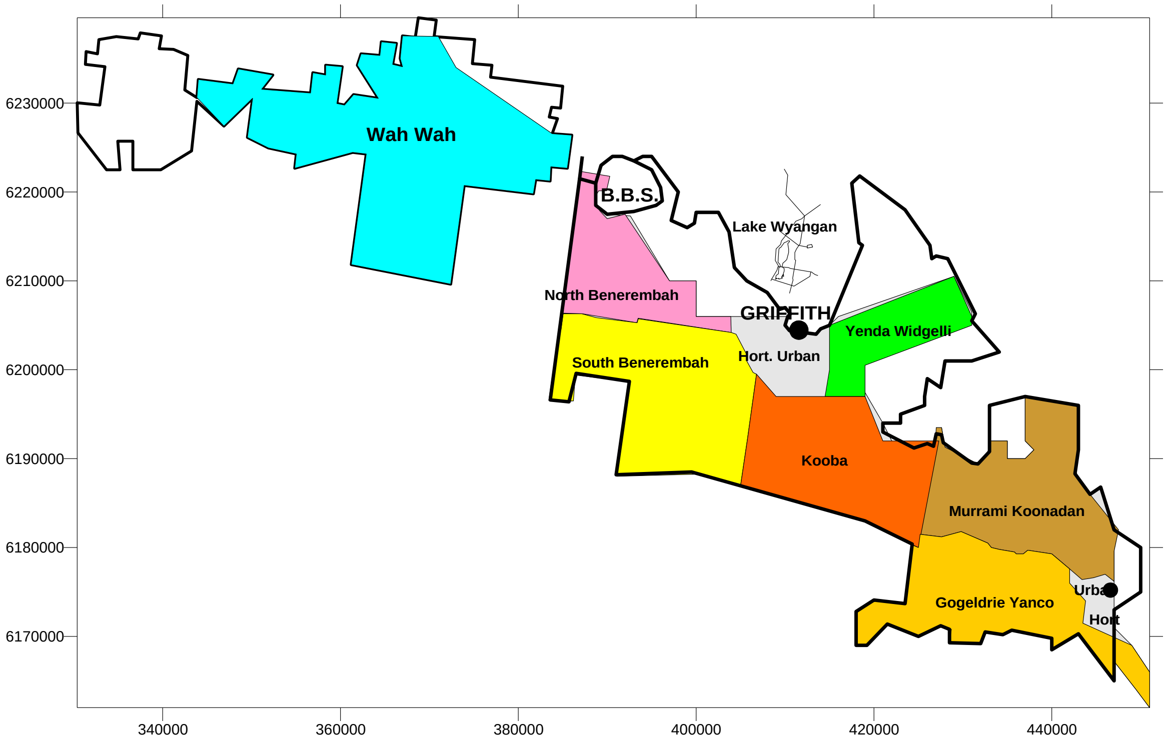


Figure 6: Sub-districts in the MIA used for ground water analysis. (Note: This map shows the sub-districts based on the outline of the extent of the shallow Shepparton groundwater zone (except Wah Wah).

There are insufficient piezometers in the Lake Wyangan sub-district to produce a contour map or produce groundwater statistics. The same applies to the shallow aquifer zone in Wah Wah. Groundwater statistics were prepared for the other sub-districts.

Bi-monthly) monitoring is carried out at about 100 piezometer sites throughout the MIA to comply with licence conditions. Individual hydrographs are available and may be consulted by interested parties to analyse the changes between seasons. It is potentially interesting information, but this part of the groundwater monitoring program has not been backed up by monitoring of local crop conditions, soil salinity, etc, at each site. Consequently, after ten years of collecting groundwater level data, it is believed that nothing more can be gained from this monitoring. It should be abandoned. CLU has agreed (Appendix B) that the results do not contribute to the overall analysis and that it can be scaled back as long as the bi-annual monitoring provides sufficient indication of the seasonal variation. This is the case. The bi-annual monitoring and calculation of averages for sub-districts based on all available piezometers has been used to provide for a much better interpretation for each sub-district discussed.

The average groundwater depths of each sub-district have been calculated from the average grid heights of the contour maps over the full area of the sub-district.

4.2. North Benerembah.

Figure 7 shows the averages found for depth to groundwater for the shallow and deep groundwater zones. The Calivil groundwater depths are only a couple of metres deeper than those of the deep Shepparton Formation North Benerembah has the largest difference between shallow and deep Shepparton aquifers. This is consistent with bore profile interpretation, which in most situations suggests that the 20-35metres zone geologically is of the Tertiary era, and the sands belong to the Calivil Formation rather than deep Shepparton. The Calivil Formation is often capped by a less permeable layer, in this case restricting leakage between the shallowest zone and the 12-35 metre zone.

Since the late 1990's the average shallow groundwater level has dropped from about 2 metres to about 4 metres depth. A small upswing is noticeable in March 2006.

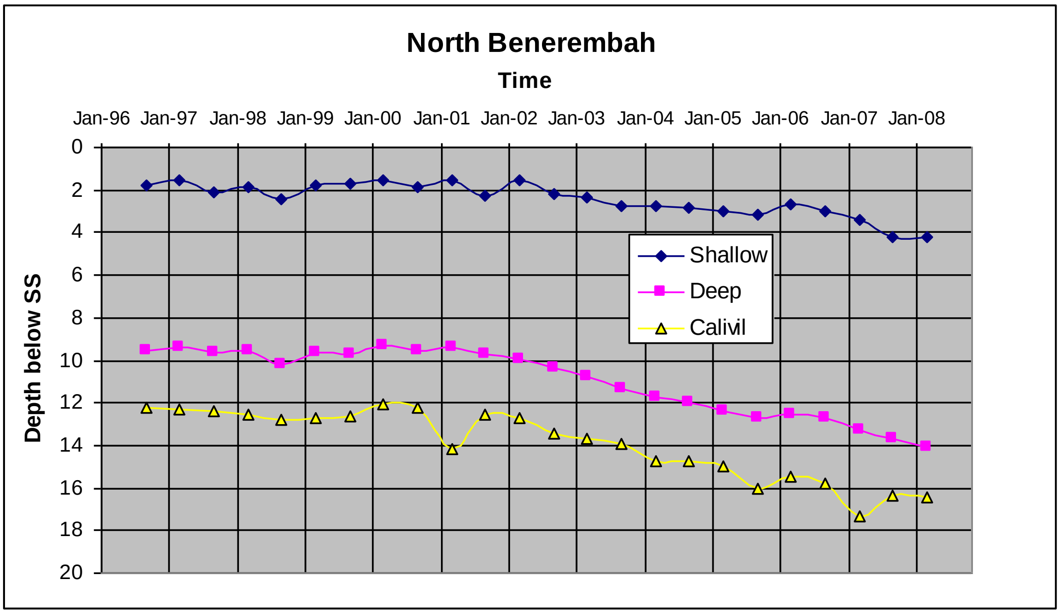


Figure 7. North Benerembah. March and September average depth to groundwater of three aquifer systems, 1996-2008.

Table 4 shows the frequency statistics for North Benerembah.

Table 4: North Benerembah. Percentages of land with groundwater within depth indicated

Shallow Aquifers	Sep-96	Sep-00	Sep-02	Sep-04	Sep-05	Sep-06	Mar-07	Sep-07	Mar-08
within 1m	12	10	1	0	0	0	0	0	0
within 2m	76	74	69	28	19	12	1	0	1
within 3m	94	93	90	75	68	72	63	12	16
within 4m	99	102	97	91	84	89	79	69	69
Deep Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1 m	0	0	0	0	0	0	0	0	0
within 2m	0	0	0	0	0	0	0	0	0
within 3m	17	13	7	0	0	0	0	0	0
within 4m	47	46	28	4	4	3	0	0	0

The proportion of North Benerembah with shallow groundwater within 2 metres has decreased from about 75% in 1996 to 1% by March 2007 and March 2008.

4.3. South Benerembah.

Figure 8 shows the average depth to groundwater for March and September and Table 5 shows the frequency statistics for South Benerembah.

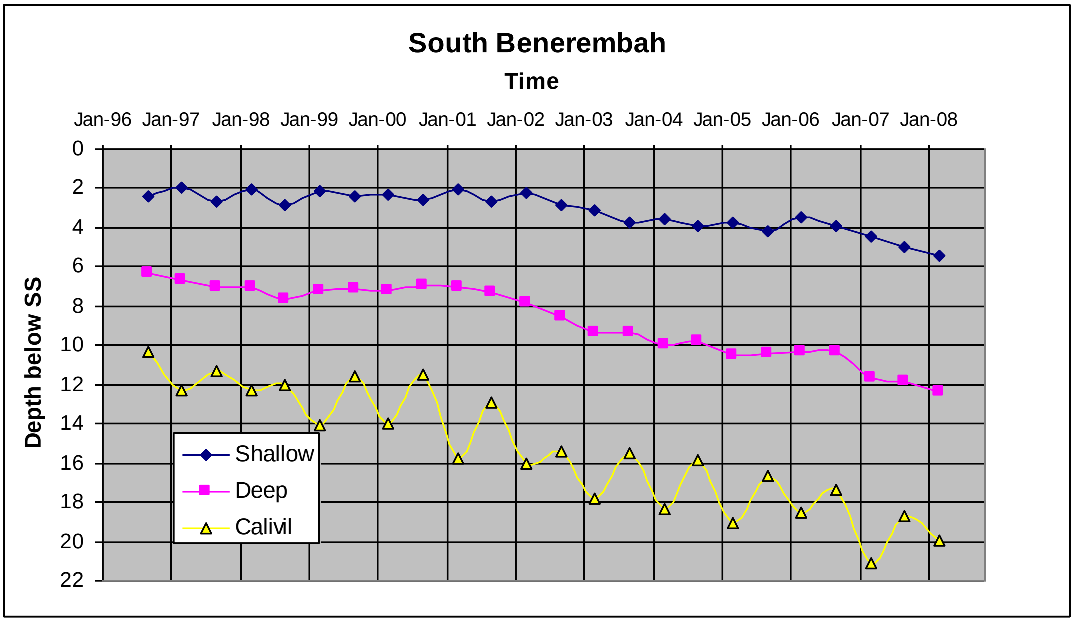


Figure 8. South Benerembah. March and September average depth to groundwater of three aquifers systems, 1996-2008

A similar comment regarding leakage between the shallowest and deeper Shepparton aquifer systems may be made for (the northern part of) South Benerembah as for North Benerembah, but the effect is less pronounced.

No land in South Benerembah presently is subjected to groundwater within 2 metres from the surface (Table 5). The proportion within 2 metres is actually a bit higher in the deeper Shepparton aquifers. This could be a feature of deep and shallow piezometer distribution and availability (consult Piezometer location maps Appendix C). Local deep groundwater pumping can produce distortions if the locations of shallow and deep aquifers are not the same. Despite this, the gradient for deep leakage appears significant, even between the shallow and deeper Shepparton Formation.

The depth to pressure levels in the Calivil Formation has also dropped, from about 12 metres in the late 1990's to about 20m at present. The Calivil levels during the end of summer are much deeper than at the end of winter.

Table 5. South Benerembah. Percentages of land with groundwater within depth indicated

Shallow Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1m	37	12	1	0	0	0	0	0	0
within 2m	68	56	39	3	5	2	0	0	0
within 3m	83	78	71	42	29	39	13	1	0
within 4m	89	88	87	69	63	68	55	31	18
Deep Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1 m	13	12	8	0	0	0	0	0	0
within 2m	34	32	23	15	8	13	10	6	2
within 3m	61	57	42	31	27	27	23	19	16
within 4m	75	71	62	49	43	45	35	33	28

4.4. Kooba Area

Figure 9 shows the average depth to groundwater for March and September since 1996 and Table 6 shows the frequency statistics for the Kooba area.

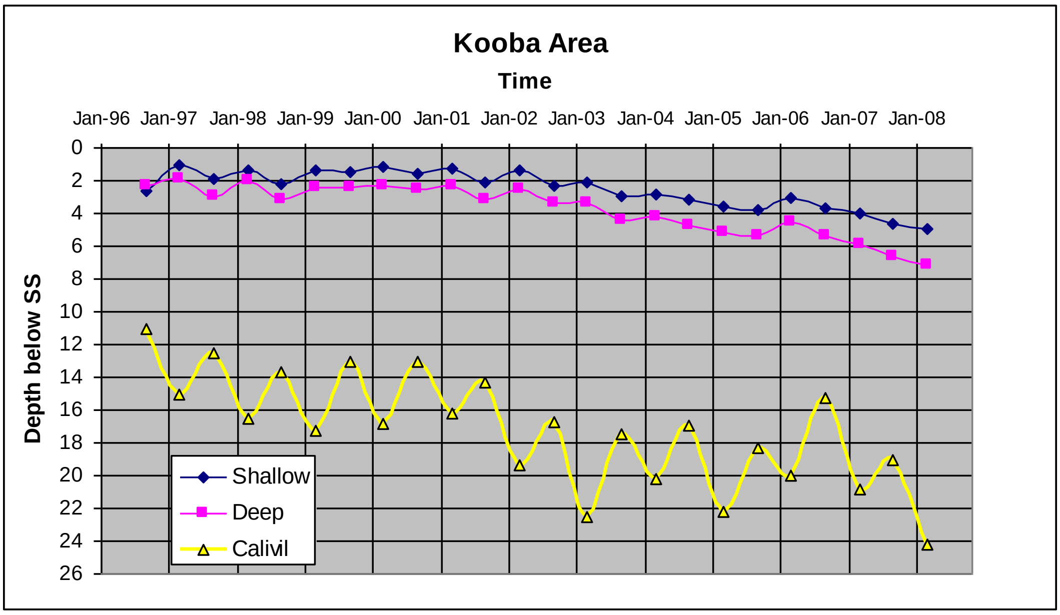


Figure 9: Kooba Area. March and September average depth to groundwater in three aquifer systems, 1996-2006.

Table 6. Kooba Area. Percentages of land with groundwater within depth indicated

Shallow Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1m	17	24	2	0	0	0	0	0	0
within 2m	87	84	44	10	3	6	1	1	1
within 3m	99	98	86	57	23	27	18	10	7
within 4m	100	100	98	87	68	75	64	34	29
Deep Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1 m	3	1	0	0	0	0	0	0	0
within 2m	53	53	11	1	0	0	0	0	0
within 3m	86	83	64	8	1	3	0	0	0
within 4m	97	93	85	49	18	18	10	1	0

The deep Shepparton Formation groundwater levels behave in parallel with the shallow zone, one to two metres apart. This aspect is quite different to South Benerembah, and more similar to the sub-districts to the east (see below). The Calivil Formation levels vary from 17 metres at the end of winter to over 21 metres at the end of summer. There is a substantial gradient for deep leakage, but the restriction for downward flow is between the deep Shepparton and Calivil Formations, unlike northern Benerembah.

4.5. Yenda / Widgelli Area.

Figure 10 shows the average depth to groundwater for March and September readings and Table 7 shows the frequency statistics for the Yenda / Bilbul area.

The area with shallow groundwater within 2 metres has reduced by a large proportion, but is still the highest of any sub-district recognised (with Murrami/Koonadan see below). The hydrographs do not vary as much between seasons as for instance in the Kooba and South Benerembah areas, because the aquifers are limited in extent and hydraulic conductivity low.

The data for this area is not as accurate because of the small number of piezometers available for monitoring.   During drilling operations (decades ago) sands were found within 20 -30 metres from the surface at only a small number of locations, hence the small number of piezometers.

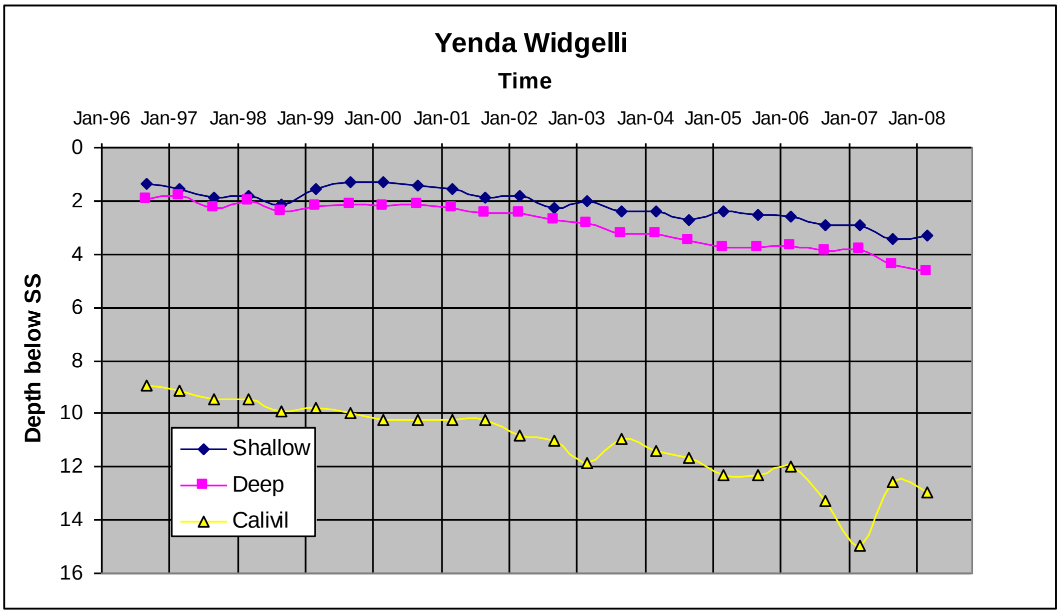


Figure 10:   Yenda / Bilbul Area.   March and September average depth to groundwater for three aquifer systems, 1996-2008.

Table 7.   Yenda / Widgelli Area. Percentages of land with groundwater within depth indicated:

Shallow Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1m	33	24	0	0	2	0	0	0	0
within 2m	97	98	39	19	36	17	16	0	2
within 3m	100	100	100	89	88	70	69	51	53
within 4m	100	100	100	100	99	99	97	94	88
Deep Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1 m	16	22	1	0	0	0	0	0	0
within 2m	74	73	60	23	19	11	16	0	1
within 3m	86	84	77	69	61	59	61	38	27
within 4m	93	90	85	80	78	75	75	70	67

Together with Murrami Koonadan, the Yenda Bilbul area has the highest proportions of land with high groundwater within 2 or 3 metres, but the “within 2m” category had dropped to only 1% by March 2008. The pressure level in the Calivil Formation has also dropped. The dip in Calivil Formation groundwater depth during March 2007 is not explained, and possibly a feature of a missing bore reading. Groundwater in the area is generally too salty for any pumping to be feasible.

4.6. Murrami /Koonadan Area

Figure 11 shows the average depth to groundwater for March and September readings and Table 8 shows the frequency statistics for the Murrami / Koonadan area.

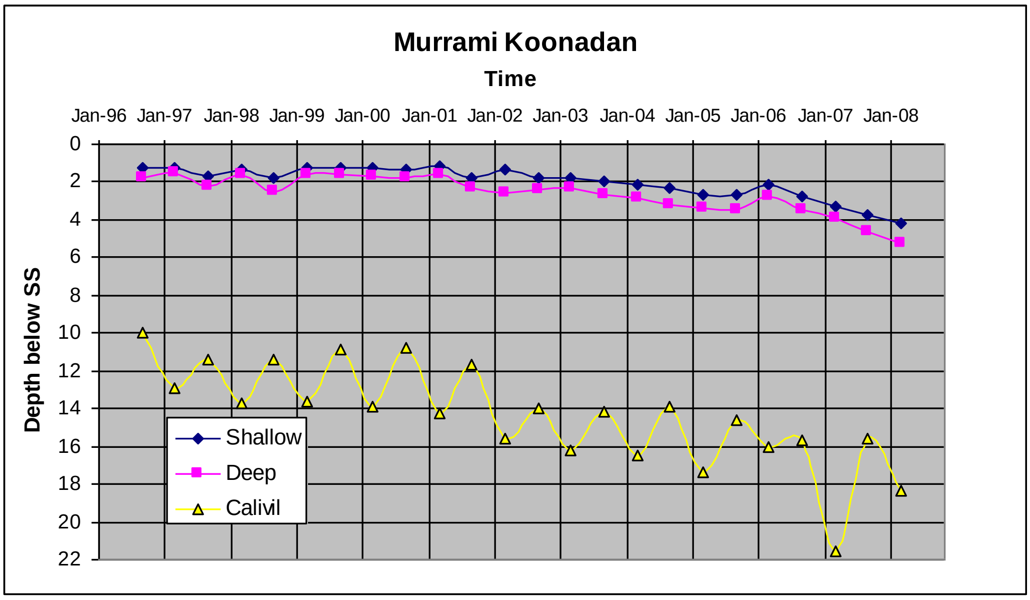


Figure 11: Murrami / Koonadan Area. March and September average depth to groundwater for three aquifer systems, 1996-2008.

Table 8: Murrami/Koonadan Area. Percentages of land with groundwater within depth indicated:

Shallow Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1m	40	44	46	2	1	0	0	0	0
within 2m	91	90	78	50	32	19	6	1	1
within 3m	99	100	96	85	78	76	78	27	17
within 4m	100	100	100	97	96	95	90	71	59
Deep Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1 m	14	18	1	0	0	0	0	0	0
within 2m	76	72	53	12	6	1	5	0	0
within 3m	99	97	82	59	50	47	26	10	4
within 4m	100	100	99	89	77	81	63	39	21

Historically, shallow groundwater levels in the Murrami/Koonadan area have been very high, reflected by very high proportions of land within 2 metres, similar to the Yenda area. Map 1 indicates that the Koonadan area presently has higher groundwater than the Murrami area. This is also where groundwater levels dropped the least from Sep 2001 to Sep 2007 (Map 3). Probable reasons are higher infiltration rates to the shallow aquifer and lesser deep leakage rates from shallow to deep aquifers. It is almost as if the Koonadan area has different groundwater behaviour from the west Murrami area, and it could be considered to vary sub-district boundaries on this feature, together with previous observations that the Koonadan area is subjected to lower groundwater salinity than the Murrami area.

4.7. Gogeldrie / Yanco Area

Figure 12 shows the average depth to groundwater for March and September readings and Table 9 shows the frequency statistics for the Gogeldrie / Yanco area.

The Gogeldrie/Yanco area is characterised by clay plains without surface evidence of prior stream activity. However, sandy aquifers of the Calivil Formation deeper down are widespread. Its position on the edge of the MIA may allow for some lateral leakage from deeper layers to adjacent areas.

It is noted that the difference in groundwater depths between shallow and deep Shepparton Formation aquifers is quite small, although still about one metre in September 2007.

Groundwater levels during the 1990's were at about 2-3 metres from the surface, with significant variation between the irrigation season and off-season. During the last five years water table levels have dropped to about 6 metres, with the deeper Shepparton groundwater levels only about one metre deeper. The trend is also reflected in the proportion of land within 2 metres, which was only 1% during September 2006 and March 2007.

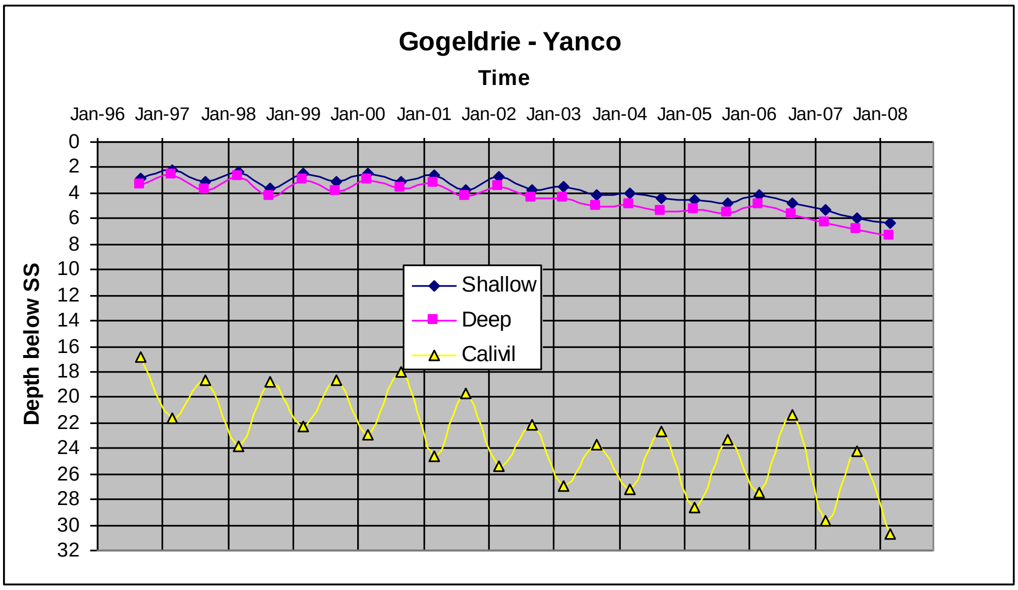


Figure 12: Gogeldrie/ Yanco Area. March and September average depth to groundwater in three aquifers systems, 1996-2008

Table 9: Gogeldrie/Yanco Area. Percentages of land with groundwater within depth indicated:

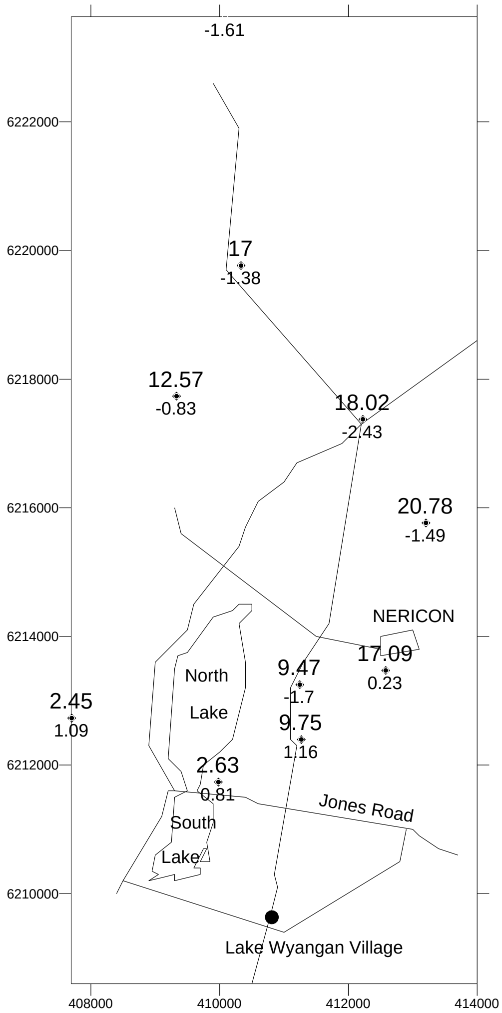
Shallow Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1m	0	1	0	1	0	0	0	0	0
within 2m	31	27	12	4	1	1	1	0	0
within 3m	62	56	44	31	20	13	9	2	1
within 4m	95	82	68	50	43	44	37	12	7
Deep Aquifers	**Sep-96**	**Sep-00**	**Sep-02**	**Sep-04**	**Sep-05**	**Sep-06**	**Mar-07**	**Sep-07**	**Mar-08**
within 1 m	1	2	0	0	0	0	0	0	0
within 2m	27	23	5	1	0	0	0	0	0
within 3m	58	48	37	13	9	7	2	1	1
within 4m	87	73	61	36	37	36	20	3	3

The Calivil aquifer average depth to groundwater has declined to almost 30 metres during March, the deepest of all sub-districts. The annual fluctuation within this aquifer is also the largest. However, the August September averages are at 22-24 metres, indicating the annual effect of groundwater pumping and recharge.

4.8. Lake Wyangan Area

Map 9 shows the location of some piezometers and the corresponding depth to groundwater September 2006. Little has changed in the Lake Wyangan sub-district. The levels in the piezometers with deeper groundwater show a very small decline over the last 10 years (about 1-1.5m). On the other hand, where groundwater is very high, groundwater has dropped (one piezometer).

There are insufficient piezometers in this area to make a meaningful analysis.



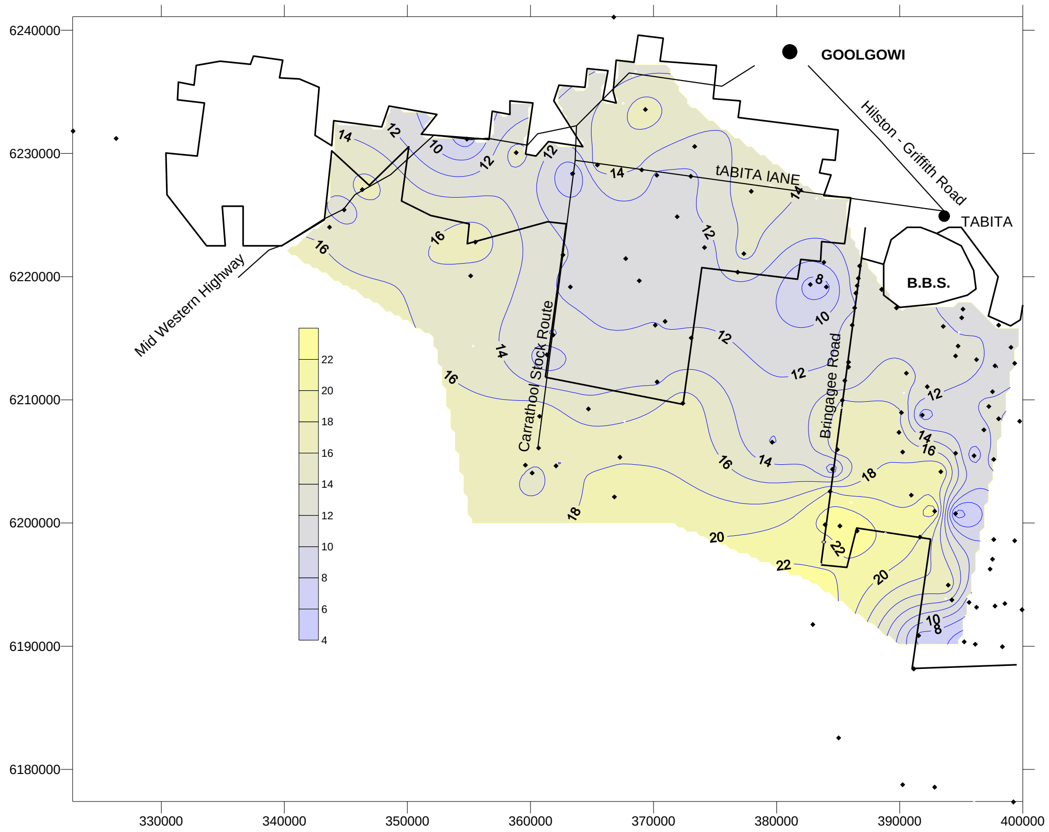
Map 9 Lake Wyangan area. Location of piezometers and depth to groundwater Sep 2007

The groundwater levels are marked above the piezometer positions and the drops (positive) are marked below. Both rises and drops have occurred over the 12 year period, without a clear pattern. Where groundwater is deeper, the levels have generally risen.

Land use has changed significantly in the Lake Wyangan area, away from irrigation farming to residential development, and from flood type irrigation systems to improved irrigation systems. Some vegetable growing and furrow irrigation of horticulture may still be occurring. There is no significant groundwater issue at present; however groundwater monitoring should continue to see whether the trend of the last 12 years is continuing.

4.9. Wah Wah District

Map 10 shows the depth to groundwater in the deep Shepparton aquifer for September 2007. In most of the Wah Wah Irrigation District the groundwater levels are between 10 and 14 metres below the surface, with evidence of a shallow groundwater mound in the Corynnia sub-division. There is no evidence that Barren Box Storage contributes significantly to groundwater system recharge.



Map 10. Wah Wah District. Depth to deep Shepparton groundwater levels, Sep 2007.

Map 11 shows that in most of the area there has been a drop in groundwater levels since 2001, but near Tabbita lane the drop was close to zero. The overall drop in the Wah Wah District has been about 1.3 metres since 1996, as shown in Table 10 and Figure 13 below. The difference in behaviour between these two parts of the sub-district is worthy of continued monitoring. Soils are different; hence there would be a different impact of irrigation. Perhaps near Tabbita Lane irrigation never had much of an impact in the first place, whilst it is known that a small groundwater mound developed beneath the Corynnia sub-division soon after 1990 when rice was first introduced.

Table 10: Wah Wah District. Average depth to groundwater deep Shepparton and Calivil aquifers and frequency statistics

Wah Wah	**Sep-96**	**Sep-01**	**Sep-04**	**Mar-05**	**Sep-05**	**Mar-06**	**Sep-06**	**Mar-07**	Sep-07	Mar-08
within 4m	2	0	0	0	0	0	0	0	0	0
within 6m	13	7	2	1	0	0	0	0	0	0
within 8m	27	25	16	16	7	12	11	9	0	0
within 10m	71	78	55	59	27	32	31	29	5	5
Average	12.21	11.84	12.36	12.34	12.89	12.65	12.61	13.04	13.49	13.64
Ave Calivil	15.02	14.44	14.65	16.12	15.07	15.23	16.35	15.79	15.78	16.04

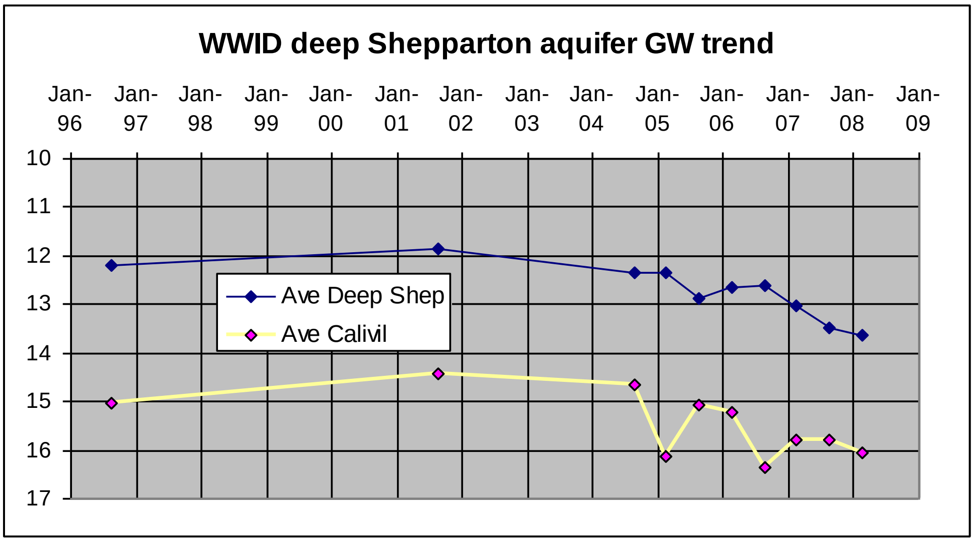
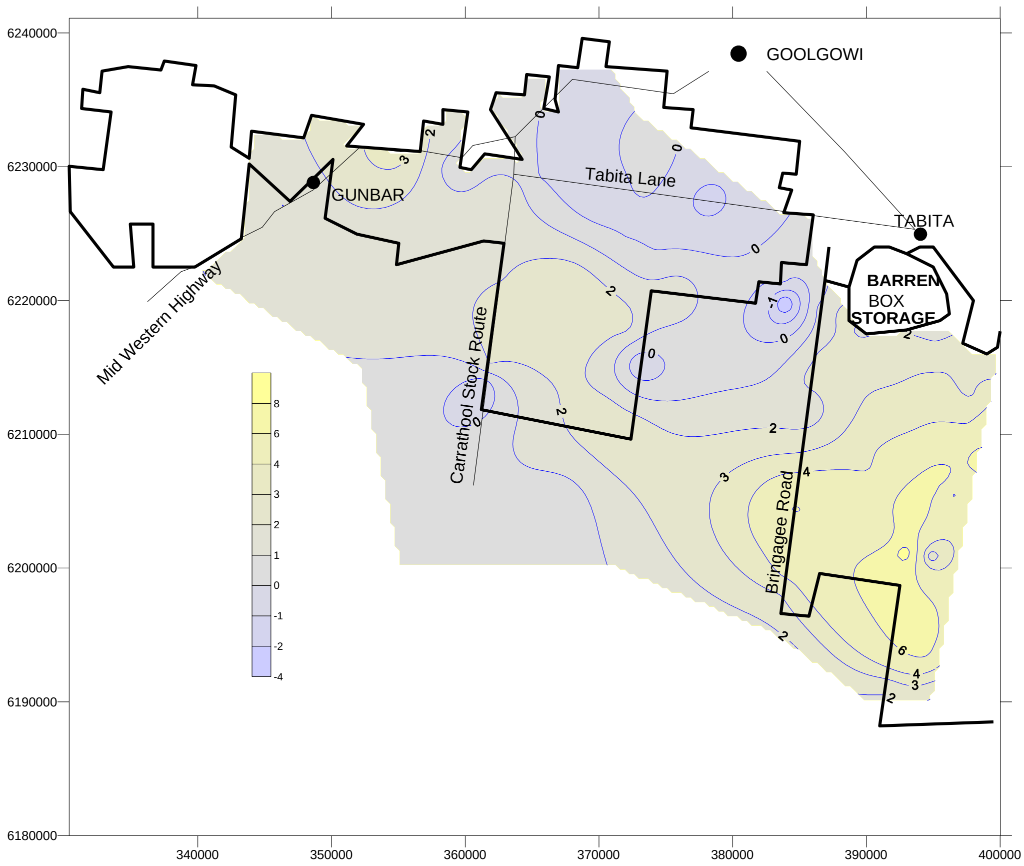


Figure 13. Trend in average groundwater depth in the Wah Wah District (Note: September averages for some of the late 1990's .



Map 11. Wah Wah Irrigation District. Drop (m/year) in groundwater levels Sep00 to Sep07, deep Shepparton Formation aquifers.

Only 5% of the area within Wah Wah has groundwater within 10 metres from the surface, and the average seems to have decreased rather than increased since 1996. The conclusion appears to be that there are few concerns with groundwater levels in the Wah Wah District at present or the foreseeable future.

5. OTHER GROUNDWATER MONITORING OUTCOMES.

5.1. Lands Adjacent to the MIA.

Map 4 (page 9) shows deep groundwater levels in the "deep" Shepparton aquifers south of the MIA. Map 5 (page 11) shows these have been declining. The information unfortunately is based on a small number of piezometers only. Nevertheless, there is no doubt the trend has been downwards.

Figure 14 shows hydrographs for five key piezometers just outside the MIA. Bore 1198 shows a seasonal fluctuation of 2-3 metres due to groundwater pumping in the vicinity up to Sep 2004, but not since. Interestingly, since September 2004 this fluctuation has almost disappeared.

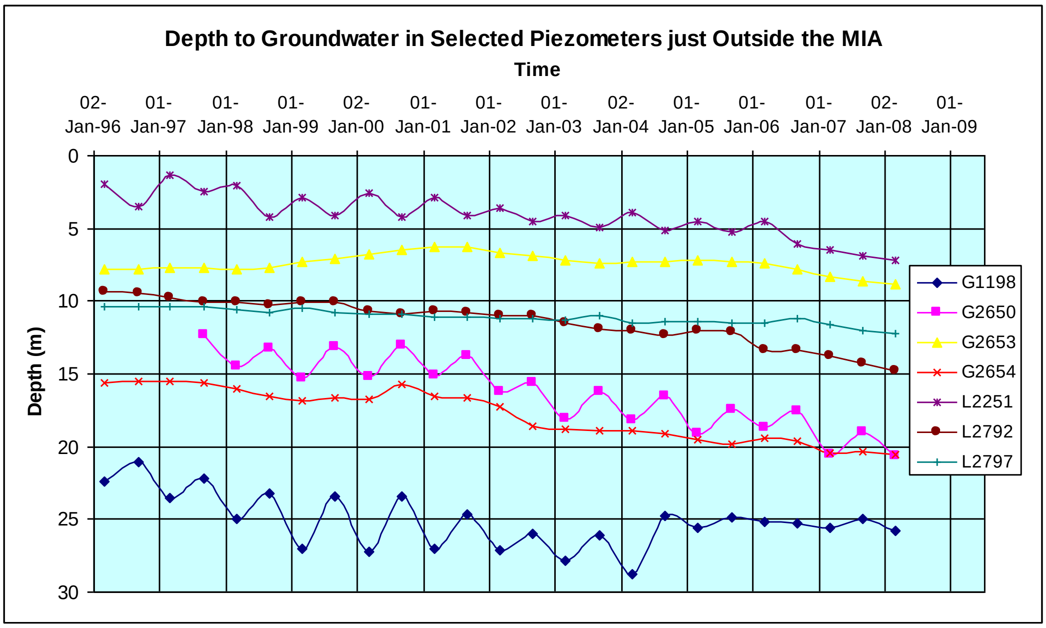


Figure 14. Behaviour of 5 piezometers just outside the MIA

G1198	South West of Benerembah on Bringagee Road+
G2653, G2654	Kooba Station
G2650	West of the Yanco area on the Whitton Darlington Point Road
L2792	South of M'gee River directly south of Whitton
L2797	South of M'gee River and south of Leeton

Groundwater levels in the Calivil Formation are also declining. The conclusion is that there is no evidence that the MIA is having an adverse impact on the adjacent areas. On the contrary, the increased leakage gradients to the adjacent areas due to groundwater pumping are having a contributory effect to increasing potential percolation from irrigation in the MIA to the groundwater system, increasing channel seepage and rice percolation rates

5.2. Lower Mirrool Creek Floodway

In respect to the Lower Mirrool Creek Floodway, Table 11 shows that most piezometers have shown small declines in groundwater levels since 1996. Bores 3345 and 3388 show the largest drops. There have been no flood events in the Lower Mirrool Creek since the early 1990's.

Table 11. Behaviour of piezometers in the Lower Mirrool Creek Floodway area west of the Mid Western Highway

Bore-ID	X-cma	Y-cma	Depth	1/09/1996	1/03/2000	1/09/2002	1/09/2004	1-Sep-06	1-Mar-07	1-Sep-07	1-Mar-08	Drop S96-S07
G3388	344820	6225460	14.5	7.07	10.35	10.71	11.33	11.81	12.07	11.95	12.13	5.06
G3389	322800	6231850	18.6	#N/A	17.02	17.16	17.31	17.42	17.45	17.29	17.33	0.31
G3391	360100	6204100	16	13.7	13.9	13.89	14.12	14.35	14.3	14.23	14.37	0.67
G3392	326300	6231250	26	17.81	17.85	17.94	18.08	18.1	18.2	17.97	18.07	0.26
G3345	343633	6224050	25	14	14.45	14.65	15.28	15.35	15.76	15.63	15.67	1.67
G3337	346300	6227100	22	16.16	16.45	16.4	17.08	17.09	17.52	17.33	17.48	1.32

5.3. Ground Water Salinity

The last time groundwater was sampled for salinity was during 2002. The results are described by a Murrumbidgee Irrigation Report (van der Lely, 2003). The licence conditions would require that groundwater be sampled again over the next twelve months or so.

Old groundwater salinity data of the 1960's and 1970's have been digitised. From data analysis it appears there is no justification to sample more often than once every five years.

5.4. Soil Salinity and Ground Water Levels

No new surveys have been carried out in respect of this subject over the last twelve months. However, the 500 soil sampling data points of the 1998 survey have been put in map form and compared with the groundwater salinity map and the groundwater maps of the groundwater reporting. Whilst such a soil salinity map is not without anomalies, the comparison allows the interpretation of areas of higher and lower soil salinity in the context of the other two factors and geo-morphology. This may be of value for the MI / CSIRO hydro-ecological study being undertaken at present.

5.5. Groundwater Contamination Incidents

No incident regarding groundwater contamination has come to the notice of Murrumbidgee Irrigation during 2004, 2005, 2006, 2007 and the first half of 2008.

6. TRENDS AND TARGETS

6.1. LWMP Target

Figure 15 shows, for the shallow aquifer zone and September data only, the changes in the areas with water tables within 2 metres from the surface since 1990. There has been a huge reduction, from over 70% in the early 1990's to 7.6% September 2005 and zero in 2007 and 2008. The Land and Water Management Plan predictions are shown as well. It is clear the predictions have become unstuck due to the reductions in water allocations forced by the drought, and now require a re-evaluation in the light of climate change.

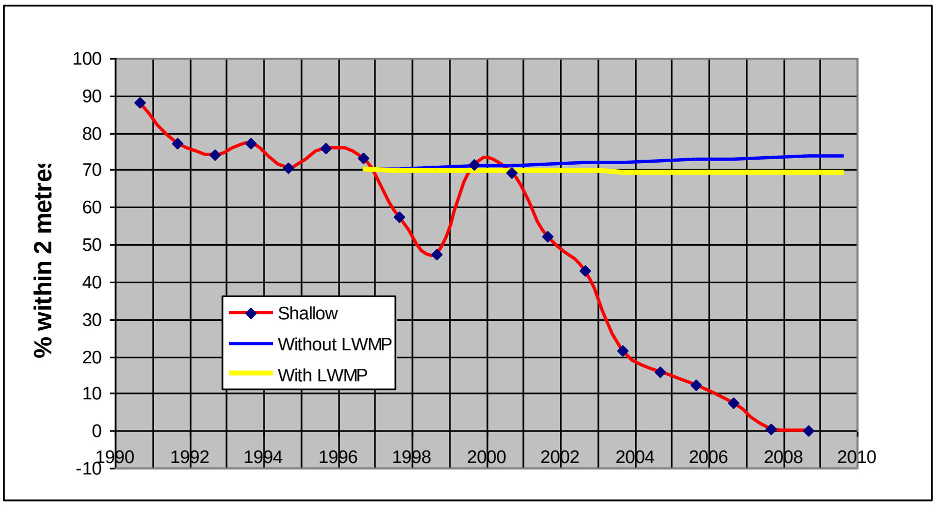


Figure 15. Percentage of the MIA shallow groundwater zone with groundwater within 2 metres from the surface as recorded since 1990 compared to LWMP expectations.

Some of the key questions for the evaluation of new LWMP targets would be what would happen with groundwater if irrigation was returned to previous intensity, or if rice was eliminated but other crops were intensified, or if rainfall as well as irrigation remained less than before. These questions are partially answered at section 6.3.

6.2. Recharge Targets

The 2006 annual groundwater report produced a comprehensive analysis of trends and estimated volumes of the various contributing recharge and discharge factors involved based on a statistically based modelling procedure involving optimisation. The principle of modelling is that each 6 months change in average groundwater depth, from September to March, and from March to September, involves a combination of recharge and discharge factors, each of which can be estimated from observable factors by multiplication with a coefficient or use of an algorithm. Table 12 is a summary of the factors involved, the observable quantity, and the coefficient or algorithm to convert the observable quantity into a volume. The methodology and the factors are discussed in more detail at Appendix D.

The coefficients were determined by optimisation of the coefficients working on the data sets compiled for the 1990 to 2008 period, covering 18 March to September periods and 18 September to March periods. The process is similar to the principles of multiple regression. The model coefficient for each factor is the same over the whole period, but the observable quantities vary ([7]). There are quite a few variables ([8]), but because of the quite large variation in many factors

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[7] For instance, winter rainfall or the rice area is different each year, but the coefficient is assumed the same between years. For irrigation and rainfall recharge the model coefficient is not assumed the same between the autumn/winter season and the spring/summer season.

[8] Nine variables, see Appendix D

over 18 years (both 6 months periods) the statistical significance of each coefficient improves to the extent that the volumes of recharge and discharge found become meaningful.

Table 12: Groundwater Recharge/Discharge factors and their use in a six monthly model

Factor	Observable Quantities	Coefficient / Algorithm	Result
Deep Leakage	Gradient Shallow to Calivil aquifer (m)	Leakage per 10 m gradient	Volume of discharge
Rainfall Recharge	Rainfall, Month or season with highest rainfall, etc.	Multiplier to convert rainfall into recharge	Volume of rainfall recharge
Irrigation recharge	Volume of water use on crops	Multiplier to convert water use into recharge	Volume of irrigation recharge
Channel Seepage	Volume of channel seepage from study, depth to average groundwater	Channel seepage varies with groundwater depth via an algorithm	Channel seepage volume for each season separately
Rice Percolation	Areas of rice, depth to average groundwater	Average rice percolation rate as ML/ha, algorithm to vary rice percolation with depth to GW	Rice percolation volume for each season separately
Groundwater evaporation	Depth to groundwater, typical groundwater evaporation curves from studies.	Algorithm and coefficients to shape groundwater evaporation curve	Groundwater evaporation volume for each season
Groundwater Pumping	Volumes measured	No coefficient needed	Groundwater pumping volume
Lateral groundwater flow	Assessed volume from gradients and typical likely transmissivity (estimated)	No coefficient used	Volume of lateral GW flow
Tree uptake	Areas of trees (estimated), typical rate of GW use	No coefficient used	Volume of Tree uptake
Effective Porosity	Not observable, but would range from 0.03 to 0.08	Effective porosity	Effective porosity in GW balance

The data compilation for a modelling process over a period as long as September 1990 to March 2008 is not without difficulty. The main inconsistency in the datasets was found to be with water use data. This data needs to be separate for rice and other crops, and the other crops water use needs to be split between September to March and after March (the dates of groundwater measurement). Only during the last four years this has been officially recorded, however for the previous years it was possible to produce meaningful (albeit less accurate) separations. Other data such as rainfall (CSIRO data used only) are also likely to produce bias when applied to the whole MIA, etc, etc. This is to be kept in mind when examining results from the model, but it may be stated that every model is subject to such or similar shortcomings. This aspect is not further discussed here.

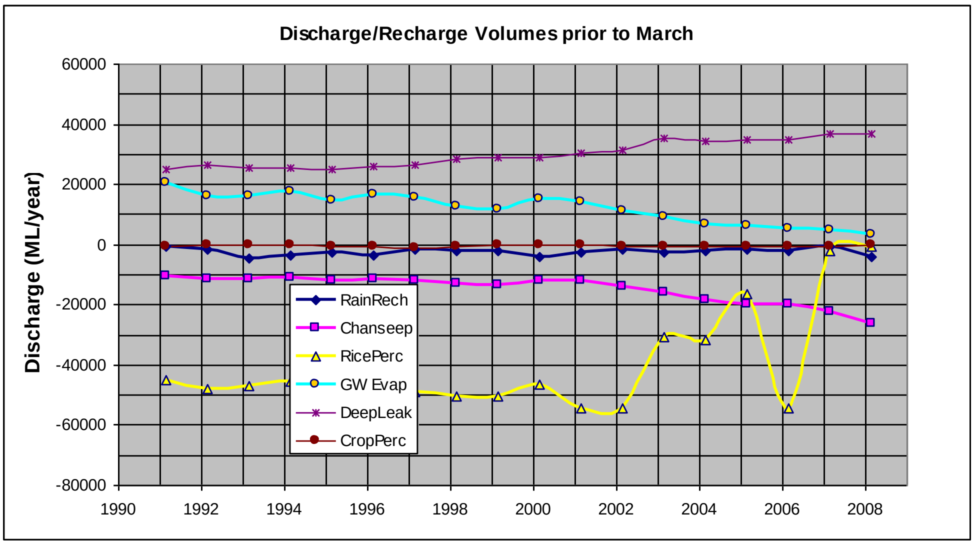

Figure 16: Modelled volumes of recharge and discharge to the MIA shallow groundwater system prior to March each year from 1990 to 2008.

For this report, the new data for September 2007 to March 2008 have been added to the model produced for the MIA. The results in terms of trends in estimated recharge and discharge volumes are shown at Figures 16 for the periods prior to March each year, and Figure 17 for the periods prior to September each year.

It is shown for the main irrigation season (Figure 16) that the estimated deep leakage has increased and would be the main discharge factor. Groundwater evaporation was very significant in the 1990's but has decreased due to deeper groundwater levels.

Of the recharge factors, the estimated rice percolation was undoubtedly the largest factor during the 1990's, but is now very small. In that regard there were no issues regarding targets in the 2007/08 season, even though the percolation rate per hectare may have increased (Appendix D).

Channel seepage has become a dominant factor in the much reduced total volumes of recharge ([9]). Both rainfall and irrigation recharge of crops other than rice has remained fairly insignificant in the spring / summer season.

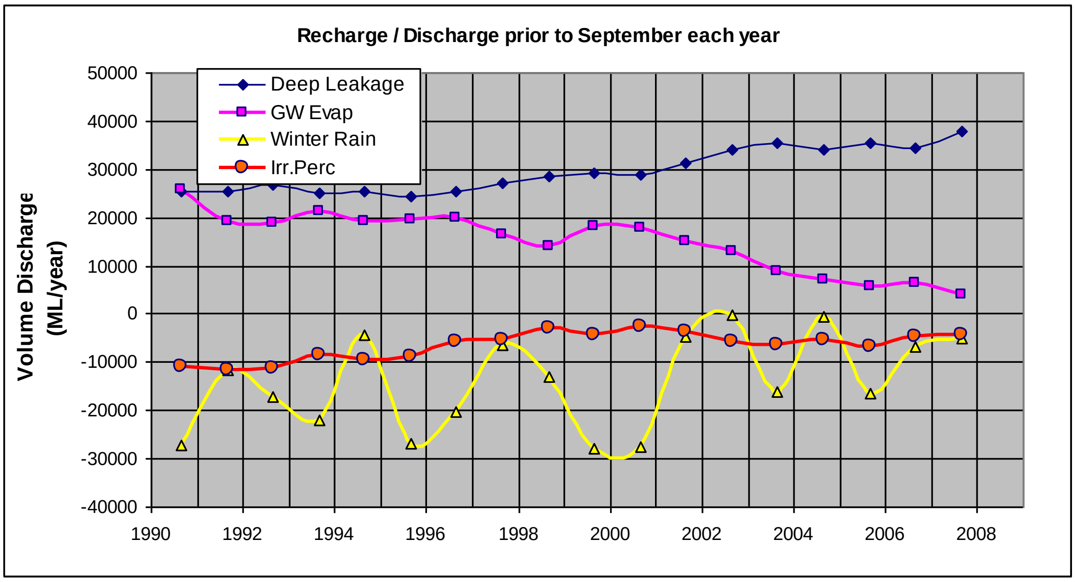

Figure 17: Modelled volumes of recharge and discharge to the MIA shallow groundwater system prior to September each year from 1990 to 2008.

For the six month periods prior to September each year the main discharge factor is deep leakage. Again it is shown that groundwater evaporation has decreased significantly over the last 8 years. Of the recharge factors winter rainfall is a significant factor, but it varies between years as would be expected. There is also an indication that autumn irrigation contributes to groundwater recharge. Some channel seepage over the March to May period would also occur each year ([10]). This factor is not shown at Figure 17 to avoid clutter.

No specific recharge target was specified in the LWMP, except the aim was "…to reduce the area with groundwater within 2 metres to below 70%". This has certainly been achieved. The model has also provided insight into the most significant factors involved, and their annual variation. The model coefficients and the volumes of (annual) groundwater recharge / discharge for 2007/08 relative to the long terms average (1990-2008) is shown at Table 13.

The MIA LWMP assessed the annual recharge and discharge to be in the order of 96,000ML, which is of the same order as the total in Table 13. The model coefficients show 38 mm/year deep leakage when the downward gradient is 10m (it has been in excess of this most of the time), a 1.7ML/ha average rice percolation when groundwater is at 1.5 metres, and groundwater evaporation of 76mm/year when groundwater is at 1.0 metres. The channel seepage component

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[9] Although it may be over-estimated for 2006/07 and 2007/08 as there are indications the channel system was not filled (or was running at less full levels) for the full season in all parts of the MIA.
[10] But perhaps less in 2006/07 and 2007/07 since the channel system was not full all the time, especially 2007/08.

could not be assessed using the methodology used, it was estimated to be 15,000 ML/year over the area considered when groundwater is at 1.5 metres depth, and then varied upwards as the groundwater increased. The total volumes involved in this factor (>32,000ML) during 2007/08 may have been more than half of all the recharge in large area farms of the MIA (43,500ML), unless the channels were not filled all the time, or the 15,000 ML baseline estimate was wrong in the first place ([11]).

Table 13. Volumes of recharge and discharge estimated from optimisation model for the MIA and sub-districts (shallow groundwater zone).

MIA GROUNDWATER BALANCE			ANNUAL TOTALS	
Variable	**Value**	**Unit**	**ML90-08**	**ML 07-08**
Leakage	38.5	mm/10m head	62686	73371
Rain Rech Winter	-0.173	part of Rain Factor	-11534	-4903
Rain Rech OctFeb	-0.016	part of Rain factor	-2864	-5014
Rice Percolation	-1.732	ML/ha (wt at 1.5m)	-36995	-575
Oct-Feb Irrigation	-0.001	part of water use	-126	-24
Autumn Irrigation	-0.091	part of water use	-5665	-789
Lateral GW Flow	2000	ML/yr	2000	1870
Channel seepage	-15000	ML/year (wt at 1.5m)	-21452	-32193
Tree GW Uptake	3000	ML/year	3000	3000
GW Evaporation	75.8	mm/yr WT at 1m	22381	7571
Porosity	0.04	Annual Total Discharge	90068	85812
Power GW Evap	1.74	Annual Total Recharge	-78635	-43497
Power ChanSeep	0.70	Average Depth WT	2.58	3.26
Power Rice Percolation	0.75			

Constant	Value
Area (ha)	130000
ChanSeep % in Summer	0.70
Chanseep% in Autumn	0.30

Optimisation Statistics	
St.Dev	0.090
Sum.Sqrs	0.281

There is a question as to whether deep leakage at 39mm for every 10 metres of head difference between deep and shallow aquifers is too high an estimate ([12]), however, if it was less, most recharge factors would have to be less as well, or groundwater evaporation should be a higher estimate.

It is possible that the 9% assessment of autumn irrigation ending up as recharge is too high. The estimate of groundwater evaporation, at 76mm/year when groundwater is at 1 metres depth, seems more reasonable, considering that the potential maximum 1mm/day groundwater evaporation only occurs when it does not rain, it does not apply to rice fields and fields when they are irrigated, and is not achieved when the surface soil is dried out, which would be the case during most of the summer months.

The assumed channel seepage value of 15,000 ML (when groundwater is at 1.5m, Table 13 shows 21,400 ML average for the 18 year period) may be less than believed by those studying the subject, however it is noted that this rate of seepage applies over the area of the shallow groundwater zone only, or about 75% of the total area of large area farm land in the MIA.

The higher coefficients for autumn irrigation and autumn and winter rainfall relative to spring / summer irrigation and rainfall should be noted. The coefficient for irrigation recharge is applied directly to water use data, so 9.1% of autumn irrigation would have resulted in recharge, but less than 1% of summer irrigation. Together it amounted to less than 1000ML over the year, or 15% of the long term average (about 5,500ML), all if the values obtained are credible.

With rainfall recharge the model coefficients are not applied to the rainfall itself, but to a separately modelled quantity of “rainfall excess” which may have resulted in percolation (consult Appendix

[11] The LWMP channel seepage estimate was 20,000 ML/year, hence 15,000 for the more limited area appears reasonable.
[12] The author believes this is quite possible. The model outcomes cannot be assumed to be correct in every sense.

D). Here it was found that the 4900ML of autumn rainfall recharge is less than half the long term average, but the 5000ML summer rainfall recharge is almost double the long terms average. The conclusion seems to be that non rice irrigation in spring and summer is not a large contributor to groundwater in the MIA with its heavy clay soils in the large area farming lands.

The combined rainfall and irrigation recharge during 2007/08 was about 25% of the total recharge this year (43,500ML), which is more than the long term average.

Values for tree uptake of groundwater and lateral groundwater flow are small nominal estimates by the author mainly for cosmetic reasons, and do not affect the remainder of the groundwater balance.

The reliability of the model estimates depend on the credibility of optimisation modelling, which is a statistical technique which may involve multiple solutions to the same data set. Potential errors due to this aspect were reduced by setting constraints on each coefficient/factor within credible limits and repeating the process many times. The end result was a very close fit between observed average groundwater depths for the MIA and the various sub-districts individually and the groundwater depths estimated from modelling (standard deviation 0.09m over 18 years). This is shown at Figure 18 in the next section. It is healthy to remain sceptical regarding the credibility of any result found, but until a better, more credible, methodology is found the author believes this analysis is contributing significantly to the understanding of this complex subject.

The same process as for the MIA shallow groundwater zone was repeated for the various sub-districts. The results were somewhat less pleasing, which is probably due to a less accurate data set for factors such as water use (another split up based on areas), but nevertheless, the individual average annual volumes calculated for each factor produced totals which are not dissimilar to the MIA as a whole. Deep leakage was found to be less in sub-districts such as Murrami-Koonadan, North Benerembah and Yenda-Widgelli than for the more southerly sub-districts, as expected.

6.3. Predicted Groundwater Trends

Figure 18 shows, for the shallow groundwater system and for large area farming areas mostly, the observed data of average groundwater depths in the MIA versus the predicted values based on modelling, from 1990 to 2008.

Similar prediction could be made for individual sub-districts, but this has not been carried out.

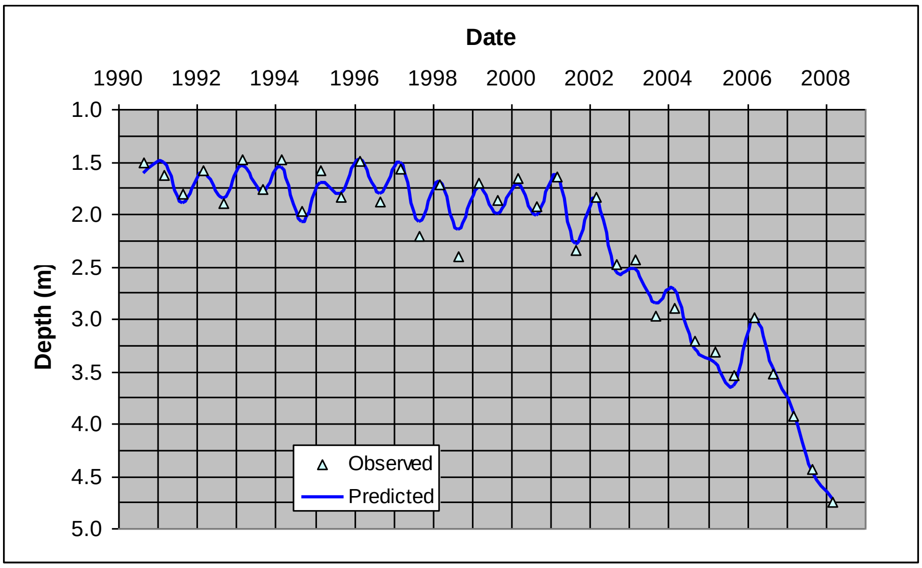

Figure 18. Observed versus calculated average groundwater depths in the shallow groundwater zone of the MIA, 1990 to 2008

There was an increase in rice growing during 2005/06, but during 2006/07 most of the about 5,000 ha of rice was dewatered before harvest, and during 2007/08 only about 300 ha of rice was grown. Other crop watering also declined but not to the same extent. The combined effect resulted in the continued decline of the average groundwater levels, as discussed.

The match for the new data is considered to be extremely good. The standard deviation of the differences over the full period was 0.09 metres. The problem with September 1997 and 1998 differences is not understood but probably relates to inaccuracies in autumn water use volume assessment. Figure 18 is the main reason for confidence that the methodology has credibility. On this basis, the model coefficients were used to extend the graph for three scenarios:

1. Rice areas remain small (about 5000ha), but all other factors are restored to 1990's conditions.
2. Rice areas and all other factors are restored to 1990's conditions.
3. Rice areas recover to 2/3rd of previous conditions, rainfall recharge stays at 2/3rd of previous, but other irrigation is restored to 1990's values.

Figures 19, 20 and 21 correspond to these three scenarios.

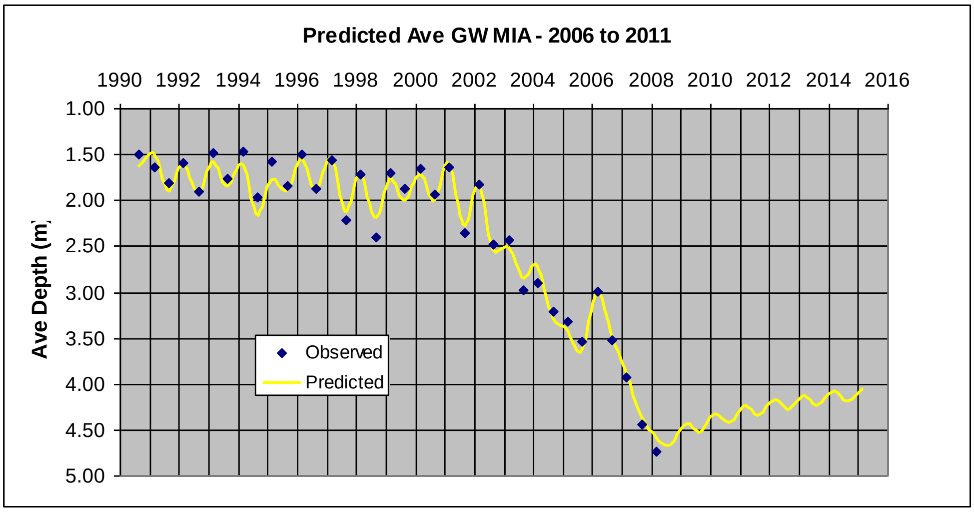

Figure 19. MIA Scenario 1 predicted outcome of future average groundwater depths in the MIA. Rice areas remain low (6,000ha/year), but other factors return to 1990's situation.

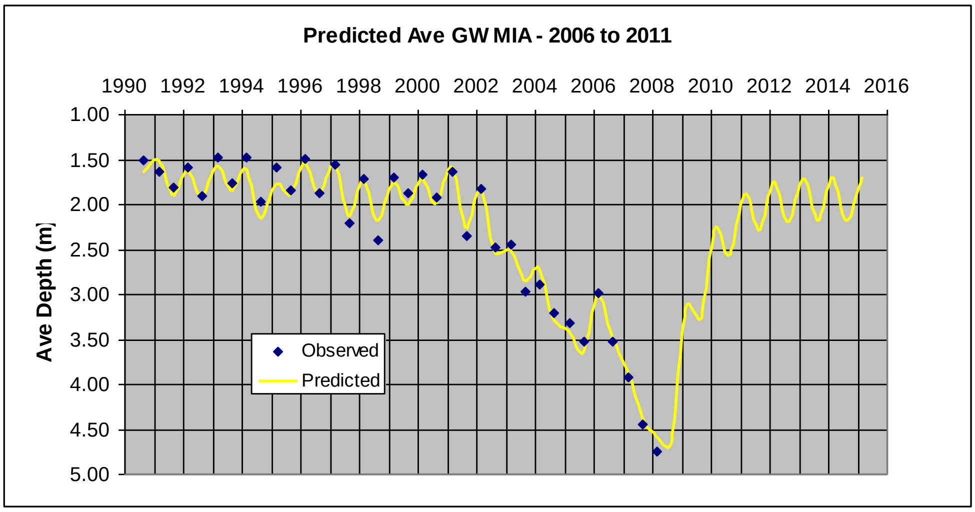

Figure 20: Scenario 2: Rice areas and all other factors restored to 1990's situation for the MIA – Effect on average groundwater depth.

It is shown that a return to the 1990's situation (Figure 20) would see groundwater levels recover within about four years. On the other hand, groundwater would only recover partially if rice areas do not return to previous intensity (hydraulic loading) but if other irrigation activity returns to normal (or even increases to some extent).

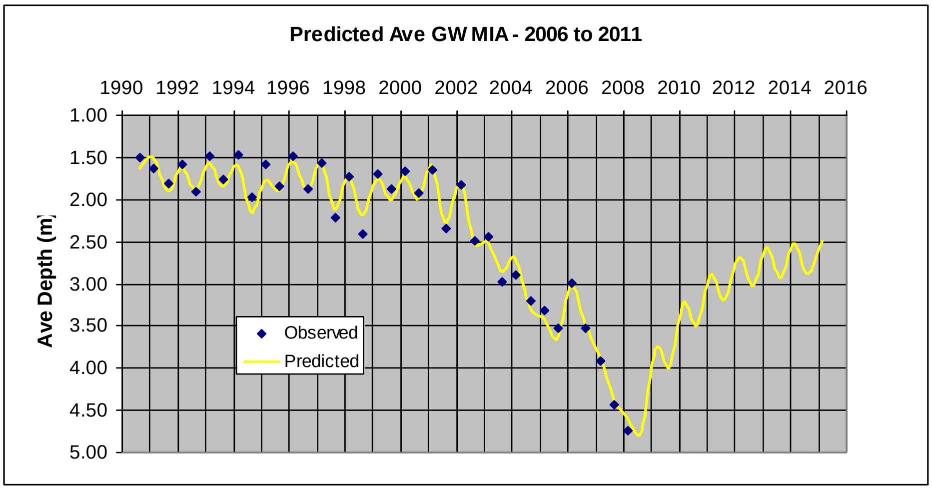

Figure 21: MIA Scenario 3, with rice areas 2/3rd of 1990's, rainfall accessions 60% of previous, but other irrigation restored to 1990's situation.

The sharp rise in watertables of Figures 20 and 21 would significantly be caused by increased percolation from rice areas. The model results suggest that with an average watertable at 4.5 metres in the first year the rice percolation would be above 10 ML/ha! Even if this is considered too high an estimate, rice water usages over 18-20 ML/ha may be expected once again on quite a few farms if the distribution of rice across the landscape is the same as before.

The above predictions concern groundwater levels. The behaviour of soil salinity is not necessarily parallel, as experience has shown. Rice has a beneficial effect in terms of salinity management, particularly when carried out as a rotation. Deeper groundwater levels than experienced in the MIA in the past (1.0-1.5m range), combined with a variety of alternative irrigation methods may still bring about salting processes. It is also not known whether the recent drop in groundwater levels has resulted in a decline or increase of soil salinity, although, for depressed areas previously subjected to very high groundwater it is believed an improvement would have taken place. It is not impossible that in some other areas there has been an increase, since a significant part of groundwater discharge is in the form of capillary rise and evaporation. Only a new survey similar to that carried out in the 1990's will be able to show what the outcome has been of the recent changes.

The analysis cannot be further improved without a better water use dataset. It was assumed the application of water is even across the landscape ([13]), which is not the case. More intensive areas of irrigation are developing in between drier areas, or groups of farms which have sold water. The future improvement of this type of analysis is with a spatially distributed dataset. Lists of farms with their individual water use for different crops already exist. The opportunity for inexpensive analysis as in this report is with the provision of coordinates to each farm entity (which should be easy), and overlaying this with the groundwater information, to allow analysis of "hotspots", probably most suitably in a GIS environment, but SURFER as at present may be sufficient ([14]).

The next step up would be the use of more comprehensive modelling involving groundwater flow between areas. This is being pursued at present by MI and the CSIRO. The author believes that in the MIA the volumes involved in groundwater flow are very small relative to what goes in and out vertically at each location, and, to keep costs down, the suggested intermediate step may be worthwhile to consider until there is certainty the integrated modelling approach will produce the results desired.

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[13] Otherwise, where a limited number of piezometers is present, they individually would be affected unevenly, and this would have an effect on the accuracy of contour mapping.
[14] The Murray Region has already gone through an exercise of this nature with its GIS system and it would be useful to contact them before embarking on this approach.

7. DISCUSSION

The author believes that after 13 years of monitoring under the same licence conditions a review should be conducted and implemented. Some comment is offered in this respect.

It appears obvious that the type of analysis as reported this year would be excessive if carried out on an annual basis. The assessment of groundwater balance, recharge and discharge factors and prediction of trends should not be part of reporting each year. Perhaps once every five years would be sufficient. This does not mean that some work can be carried out at any time address specific issues if the model can deliver the answers sought. Of course, if there are large gaps between reporting dates, the methodology previously used may have become lost, or new personnel does not know how to use it any more. Some kind of balance is needed here.

The reporting of bi-monthly groundwater levels is not valuable unless supported by additional monitoring, such as the crops grown nearby, soil salinity changes, and even the irrigation activity carried out at the site. Such sites should be located within irrigated fields rather than along road or channel reserves. The Department of Water and Energy, Corporate Licensing Unit, has already agreed with this conclusion (2007 comments).

The number of piezometers monitored varies between districts, sub-districts, and even within sub-districts, and is much higher in the Yanco Irrigation Area than elsewhere. The network's lowest density of piezometers is in the Wah Wah area, the Lake Wyangan area, and the Yenda area. This report concluded that over the last 13 years there have been no adverse impacts of irrigation on groundwater levels in the Wah Wah area or the Lake Wyangan area, although it is rising slowly in the latter. A consequential tentative conclusion would be that there is no need for a large investment in piezometers in these two areas unless there are reasons that this scenario is about to change, which is not the case at present. The present numbers are sufficient.

If the current trends of water shortages in the Murray Darling Basin and transfer of irrigation volumes to environmental flow objectives, and reduced rainfall due to climate change continue or become a reality, scenarios in groundwater behaviour close to that presented in Figures 18 and 20 are likely to become the most likely outcome. Groundwater levels will not return to their former highs. Whilst the author of this report is not in a position to make forecasts of this nature, there are strong indications that the scenario of Figure 19 in terms of rice growing areas is unlikely to ever return (or exceeded). When this is combined with the conclusion of this report that the impact of irrigation other than rice in large area farms on groundwater levels is relatively much smaller, the conclusion would be that groundwater levels in the future will remain lower than in the past. This has consequences in terms of the salinity risk and the need to maintain the extensive monitoring system available at present.

During the early 1990's the number of piezometers monitored was reduced significantly. It then returned to a larger number for the IC licence conditions to ensure that the newly privatised irrigation companies carried out their responsibility correctly. Later, the abundance of data became a bonus for research into groundwater behaviour, supporting the development of regional and smaller scale models (which is still in progress). The question to be asked is whether a research effort of this nature is sufficient incentive in itself to maintain an extensive monitoring network, unless the threat of irrigation practices on sustainability is sufficiently clear, and the research is capable of coming up with appropriate solutions.

The monitoring system exists and it would be a shame to just abandon the investment made by previous managers. However the follow up in terms of analysis and reporting should be honestly questioned. The aim should be to come up with some very simple key performance indicators, simple to analyse and report, requiring no more than an answer to the question as to whether a new threat or potential should be investigated more closely. A set of tables with a frequency distribution and some averages for a reviewed list of sub-districts could be the basis of this minimum requirement. The number of groundwater maps required each year could be reduced to no more than one or two.

8. CONCLUSIONS

Murrumbidgee Irrigation has complied with the requirements of the Environmental Conditions of the Works Licence and monitored over 850 piezometers six-monthly as required, and a sub-set of over 100 piezometers bi-monthly.

Groundwater levels in all aquifer systems recognised have declined from 2000 to March 2008.

The areas with shallow groundwater within 2 metres from the surface have reached an all-time low during March 2008, when less than 1% of the MIA had this condition.

Analysis of bi-monthly monitoring data has not resulted in an improved understanding of the groundwater system or irrigation practices, similar to that found in previous years reports. It was therefore omitted from this report.

The terms of reference of this report require discussion of the following targets and sustainability performance indicators:

- LWMP targets have been met
- Target for accessions to and extractions from the groundwater system (net accessions). Accessions have been significantly less than average during 2007/08.
- Area and distribution targets for watertable levels within 2 metres from the surface. The proportions are at an all-time low.
- Pressure level in deep aquifer target. The pressure levels are at an all-time low, and questions regarding sustainability of current groundwater pumping rates exist.

It was concluded there are no groundwater management issues coming forth from the 2007/08 data set.

The potential for channel seepage in large area farm channels may have increased significantly as groundwater dropped, and the volumes involved now may comprise more than half of the total accessions in such areas, compared to the 1990's, when it was only about 20%, or 3% of river diversions (note: this does not mean it has become economic to do something about it).

Predictions of groundwater trends for three scenarios of irrigation and rainfall returning to previous levels have been considered. Groundwater levels would recover wholly or partially dependent on the degree of irrigation intensity returning to normal. There is a big question mark whether the latter scenario will ever occur again.

Groundwater conditions in the Wah Wah Irrigation District and the Lake Wyangan area have not deteriorated significantly over the last 13 years, and the lack of a sufficient piezometer network in these areas has not had a negative impact on the level of analysis required / possible.

9. Recommendations

1. It is recommended that bi-monthly monitoring be abandoned. Dependent on the current CSIRO hydro-ecological study, an integrated soil salinity / groundwater / land use monitoring system may be considered, initially at a few sites only.
2. It is recommended that future reporting puts a focus on the production of frequency statistics on ground water conditions and averages for the MIA and sub-districts regarding the shallow groundwater zone, and averages only for the deeper aquifers.
3. It is recommended that it is considered to reduce the number of piezometers used for monitoring in the Yanco Irrigation Area, but not the other areas.
4. It is recommended, where not already done, a GPS be used to more accurately define piezometer locations.
5. It is recommended that water use data continue to be collected, with a split up by crop type, a split up by seasons (before and after 1 March), and a split up by sub-district. The latter data would be much improved if data was extractable from the GIS, after entry for each farm, each crop, and each month of the year, with coordinates attached to each farm entity.
6. It is recommended that LWMP targets regarding groundwater be reviewed.
7. It is recommended that the Lake Wyangan sub-district be deleted from the listing of sub-districts to be analysed. There is insufficient information to carry out a meaningful analysis on an annual basis, and the few piezometers present do provide a rough guide concerning the long term trend in groundwater conditions anyway.

References

1. DLWC (1998) "Environmental Management Conditions". IC5 License. Leeton, NSW
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APPENDIX “A’

Murrumbidgee Irrigation
Consultancy Brief
Groundwater monitoring report for the 2007/2008 season

1. PROJECT BACKGROUND

As part of the Irrigation Corporation Water Management Works Licence (the Licence), Murrumbidgee Irrigation is required to provide an annual groundwater monitoring report to the Department of Natural Resources.

The Company carries out a bi-monthly and a six-monthly groundwater monitoring program, the results of which form the basis of the groundwater monitoring report.

2. DESIRED OUTCOMES

The desired outcome of the project is a thorough understanding of the changes in groundwater and groundwater salinity levels in the MIA & D over the past 12 months.

3. TERMS OF REFERENCE

The following provides the terms of reference:

3.1 Undertake analysis of groundwater monitoring data as detailed in the Company’s Water Management Works Licence. The requirements of the licence are as follows:

The licensee must:

- “report annually the results of its groundwater monitoring and analysis as required by this licence and the LWMP, against the benchmark conditions and targets nominated in the LWMP and explain groundwater level, salinity and quality variations from those benchmarks and targets”
- “report annually on changes in groundwater level conditions resulting from flood releases in the Lower Mirrool Creek area of the Wah Wah I&SDD”
- “produce groundwater in agreed formats”
- “include the following information annual presentations of the results of groundwater monitoring” as shown in the following table:

Table 1: Groundwater Monitoring Reporting Schedule

No	Type	Description	Depth (metres)	Frequency
1	Map	Depth to pressure level	5-12	annual
2	Map	Depth to pressure level	12-35	annual
3	Map	Depth to pressure level	70-125	annual
4	Map	AHD of pressure level	12-35	annual
5	Map	Change in pressure level	5-12	annual
6	Map	Change in pressure level	12-35	annual
7	Map	Change in pressure level	70-125	annual
8	Map	Salinity of groundwater	5-12	3 yearly
9	Map	Salinity of groundwater	12-35	3 yearly
10	Hydrograph	Average seasonal behaviour of 8 sub-districts ++	5-12, 12-35	annual
11	Hydrograph	Average seasonal behaviour of 8 sub-districts ++	5-12, 12-35	annual
12	Freq Table #	Groundwater depth in the 8 sub-districts ++	5-12	annual

13	Freq Table #	Groundwater depth in the 8 sub-districts ++	12-35	annual
14	Freq Table #	Groundwater salinity	12-35	3 yearly
15	Map	Piezometer sites	-	annual
16	Map	Groundwater sub-districts	-	annual

Performance indicators

The following sustainability indicators are to be addressed in the report:

- Target for accessions to and extractions from the groundwater system (net accession)
- Areas and distribution targets for watertable levels within 2 metres from the surface
- Pressure level in deep aquifer target

In addition to the requirements of the Licence, the following criteria also need to be met:

- Any comments or suggestions which DNR might have on the 2007 report need to be addressed. These will be provided as soon as the Company receives them.
- Analyse and comment on the groundwater level trend from March 2007 to September 2007 as well as September 2007 to March 2008, ie the impacts of winter rainfall and summer cropping.

3.2 Prepare a report for the Company that addresses all of the licence conditions and covers the March 2007 to September 2007 and the September 2007 to March 2008 monitoring period.

3.3 Produce groundwater contour maps as required by the above licence conditions (Table 1) in a format that is compatible with the Company's GIS (ArcGIS). The preferred format is shape files (.shp).

4. Indicative Project Budget

The expected cost of this project is in the vicinity of $3,000 - $4,000.

5. Project Duration

The project is anticipated to start no sooner than the 26th of May and to conclude no later than the 25th of July 2008 or four weeks after the last information is provided, whichever is later.

6. Project Deliverables

In addition to providing a report which meets all of the project terms of reference specified in this Consultancy Brief, you are required to meet the following specific requirements:

Provide:-

- A copy of the draft review report by the 4th of July 2008
- A copy of the final review report, by the 18th of July 2008, or 1 week after receiving the last comments.
- A master copy of the final report suitable for reproduction
- An electronic copy provided on disk
- An electronic copy of the groundwater contour maps suitable for use in ArcGIS.

7. Finalising the Contract

Once the tender has been received, any issues requiring clarification will be discussed and contracts will be exchanged.

8. Timing of Submissions

Please submit a quote for this.

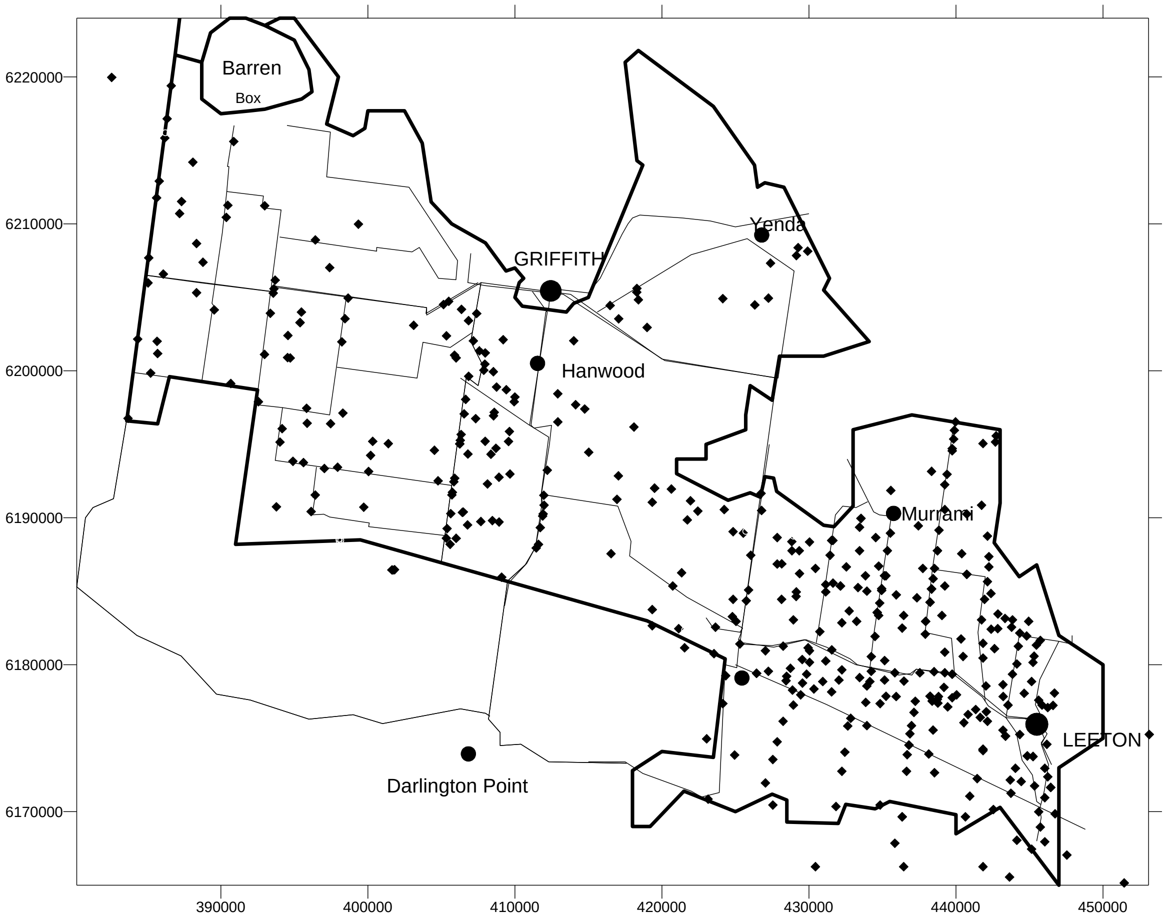
APPENDIX "B": RESPONSE TO COMMENTS BY DWE,
(Corporate Licensing Unit)

The overall comments were favourable. The specific comments by the reviewer are being responded to in tabulated form below.

No	Comment by DWE - CLU	Response
1	DWE regards the report as a very valuable component of the Annual Compliance Report and would expect this to form part of future reporting although not necessarily with the same detail on an annual basis	Agreed, detail should be much reduced after the review, with a more comprehensive report about every five years, unless prompted by a significant occurrence.
2	The discontinuity of mapping between Wah Wah and the eastern districts should be removed. As presented, there are no recognisable common locations on either map, no obvious overlap of bore information and a lack of information to assess the groundwater behaviour associated with Barren Box Storage.	Agreed. Separate maps still produced, but Wah Wah map extended eastwards to Benerembah. Effect Barren Box Storage referred to in report.
3.	Maps should more clearly indicate the limits of any of the three groundwater systems by features such as rock outcrops and absence of lateral connectivity. Doing so would give a better definition of why certain areas have no coverage and/or where coverage should be improved.	This is difficult to be achieved without significant additional effort and cost. The outline of the irrigated part of large area farm land in the MIA/WWID is shown. This excludes rock outcrops. The areas without piezometer coverage within these areas has been discussed (no sands). See also Appendix C.
4	Areas of apparent inadequate coverage are between Barren Box and Griffith, North of Griffith, between Yenda and Murrami, and parts of WWID. MI should propose how these gaps will be dealt with and/or clarify the lack of continuity of groundwater systems.	These are areas without sands in the respective aquifer systems, or part of hill slopes. The boundary of the irrigated areas is indicated on the maps, and the extent of sub-districts as defined is where piezometers exist. Many of the not covered areas were drilled in the past but no piezometer was left in the hole. Groundwater monitoring is not feasible in these areas.
5	The deep piezos in Wah Wah may have to be surveyed subject to advice from DWE regional hydro-geologist (CLU to pursue).	Noted
6	Responsibility of and scope of, assessment of deep pressure levels within and beyond MI's area of operation could be reviewed and re-defined (CLU to pursue).	Noted. The 2008 report concludes there have been no impacts of irrigation on adjacent lands to the south and west. The area between Wah Wah and Benerembah is private land. One piezometer along the Outfall Drain shows high groundwater but Barren Box Storage has had no effect on groundwater systems to the west.
7	Bi-monthly monitoring of sub-sets of 60 piezometers will be reviewed as suggested. It is suggested that only enough frequent monitoring may be required to ascertain that the bi-annual variation is a fair representation of a normal cyclical pattern. Etc, etc. Knowledge gained would be more likely of benefit to MI and the LWMP than DWE.	Agreed.
8	Figure 3a and Map 3. Should refer to the same baseline as other comparisons in the report. However, as time goes on an additional secondary presentation could be added (eg last five years). Map 3 would be preferred as a change in metres rather than m/year. M/year would be relevant to a selected period with a consistent climate and/or irrigation intensity trend but not for a longer period with significant variability.	Figure 3 (2007 report) shows the averages over the whole reference period including March and September readings. This trend has been analysed for variation in recharge and discharge characteristics. Map 3 (2007 report) shows the change from 2000 to 2007. The latter map has been changed to a total metres change for the 2008 report as requested. However the period Sep 2001 to Sep 2007 was used rather than the full 1996 to 2007 period. The choice was made after examining Figure 3 and believed to be more meaningful based on the comment by CLU.

9	It would be useful to background the groundwater contours against high, low, and no irrigation intensity. In MI context this would probably be horticulture, large area farms and mainly dryland.	It is agreed it would be useful, however mapping this feature is complex and potentially confusing. The old distinction of horticulture and LAF has become blurred as the horticultural areas have doubled and extend unevenly into large area farm land. If all farms had a coordinate in the database individual farm water use per hectare could be mapped and compared to the groundwater levels and changes. This has been adopted as a possibly useful recommendation in the 2008 report.
10	It is suggested that MI further investigate the occurrence of distinct areas with a lack of shallow groundwater recovery: (1) West of Barren Box Storage and along Tabita Lane, (2) Wyangan area, and (3) just east of Leeton. In this regard, the conclusion of Chapter 7 that There are no groundwater management issues" is not supported.	"Recovery" is interpreted as "drop" in groundwater. Area 1 showed rises during the 1990's but a 2-3 metres drop since 2001. Overall the change in groundwater levels since irrigation began is minimal. Area 2 has shown a slow increase but after 40 years is still mainly deep (section 4.8). Regarding area 3 (and Yenda/Widgelli), the much smaller drop in groundwater levels compared to the rest of the MIA is interpreted as a lack of deep leakage. Interestingly, the Yenda/Widgelli area has groundwater with high salinity, unlike the Koonadan area, which is mostly quite fresh. Groundwater EC maps are in the 2003 reference report. Overall, in none of the three areas there is evidence of an emerging groundwater issue.
11	The conclusion on Calivil groundwater behaviour in the Yenda (section 4.5) area may not be correct. Both Yenda and Murrami Calivil levels fall strongly and uncharacteristically while the Kooba and Gogeldrie pressure levels remain stable and do not appear to provide extra gradient for accelerated lateral dissipation. It is almost as if deep pumping has started up in the former two areas.	It looked a bit this way in 2007, but with the 2008 data the original trend has been re-established. What caused the dip in 2007 is not clear. It could be an anomaly in the data, or changes in pumping further south. It was not groundwater pumping in the Yenda area itself as groundwater is saline.
12	Groundwater salinity (section 5.3). DWE is likely to agree that a lesser frequency would be acceptable (CLU to follow up with MI's own review).	Agreed.
13.	Table 12: Are the volumes shown the totals for 6 months? If so, they could be added up for a 12 months period?	Totals shown were for 12 months. The 2008 report is more elaborate.
14	Section 6.2, channel seepage. The comment on increased channel seepage should be clarified. Also, the volumes indicated are in the same order of magnitude of the volumes in Table 12, which suggests that Table 12 in incomplete without this significant component added in.	It is agreed that channel seepage volumes should have been added as a significant component. It has become a significant component as other recharge volumes reduced by large proportions in recent times. This 2008 report is a stand alone version (rather than referring to a previous report for explanations) and allows better examination as to how volumes were derived from modelling.
15	Rice Targets (Section 6.3). The discussion (unless misunderstood) seems to be rather simplistic. Could one conclude that rice should be grown along Tabita Lane?	Whilst there has been little change along Tabita Lane, groundwater is (and always has been) deep, and therefore this area would not pass the criteria discussed (clay soils, high groundwater levels, small deep leakage gradient). The soil criterion for rice needs to be passed first (Tabita Lane would not), but after that, smaller percolation is expected in areas with high groundwater and little deep leakage.

APPENDIX “C”   Piezometer Locations

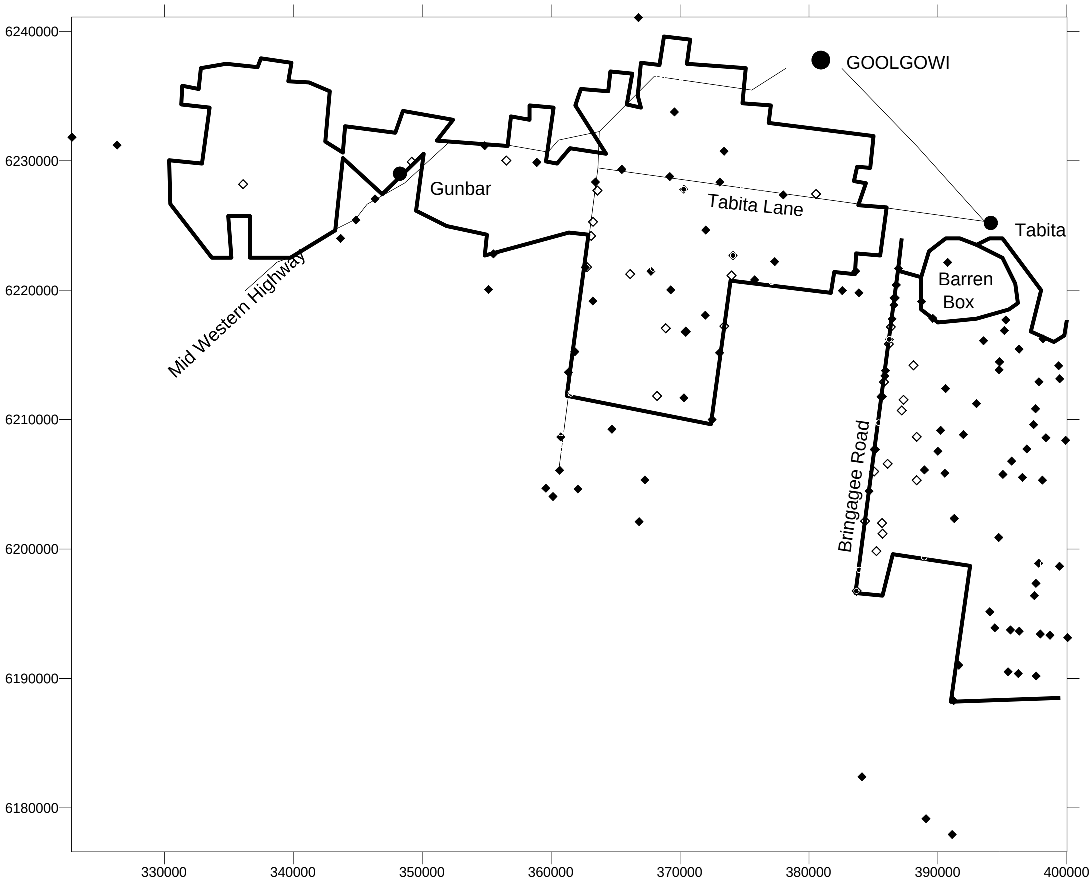


Available Shallow Piezometers in the MIA as per September 2007. Piezometers which did not produce a reading on this date were excluded.

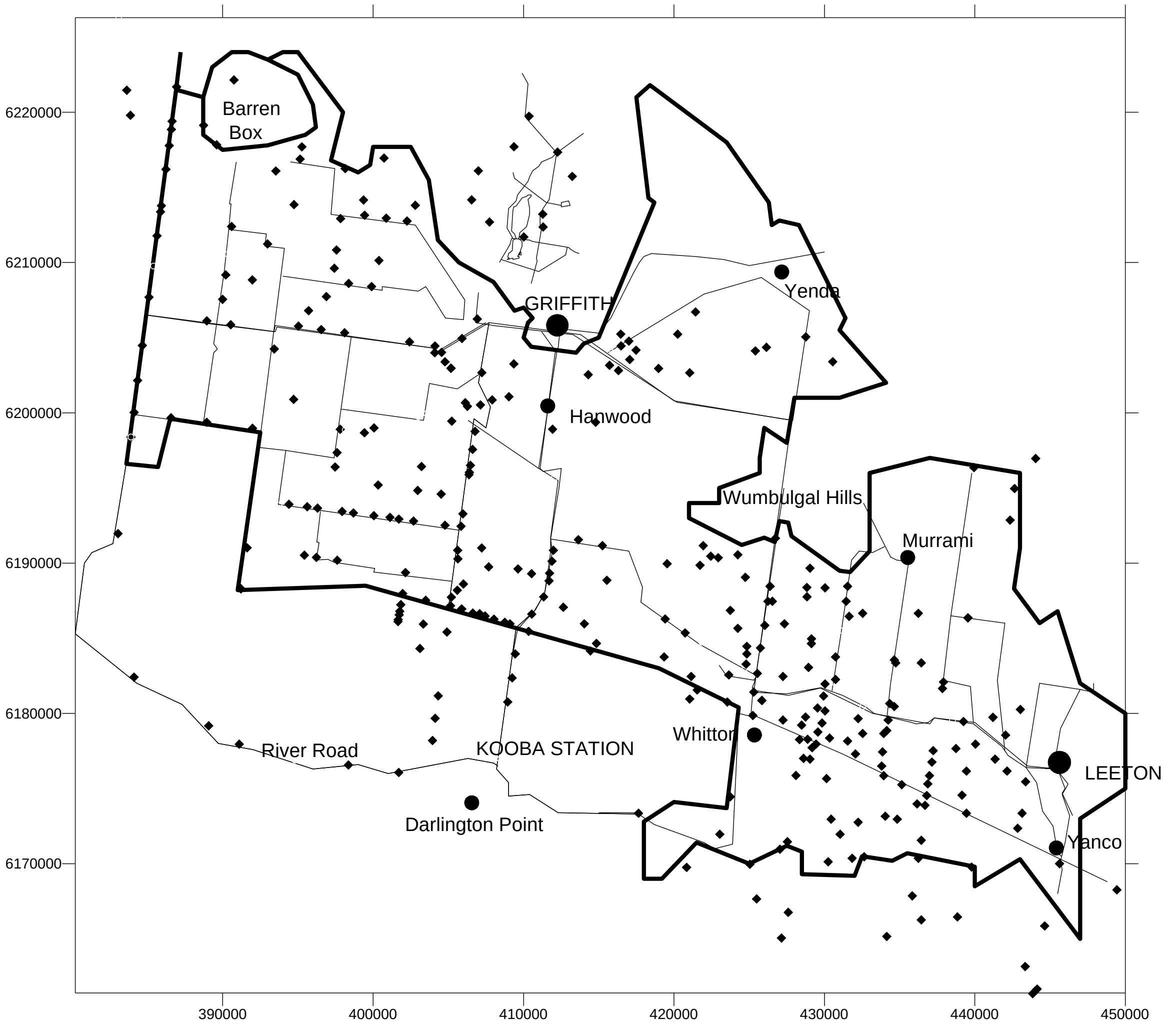
The heavy outline of the MIA is not the official boundary, rather it represents where irrigation activity takes place (except Lake Wyangan and Wah Wah). Where within this boundary no piezometers are located, these are the approximate areas where there are no shallow aquifers, due to clay soils to depth, or hill slopes.

The same comments apply for the MIA Deep Piezometer location map.

Regarding the Wah Wah piezometer map, it shows both the shallow and deep piezometers together. The shallow piezometers are open diamond shape, and the deep piezometers are full diamonds.



Available Deep and Shallow Piezometers Wah Wah District as per September 2007



Available Deep Shepparton Piezometers in the MIA as per September 2006.

APPENDIX D: GROUNDWATER BALANCE ASSESSMENT MODEL

D1. Principle

The average groundwater level in March or September is a function of the groundwater level six months earlier, plus the net effect of recharge and discharge processes over the period. The sum of these factors divided by the effective porosity of the groundwater system (about 3-8% in clays) equals the net change in average groundwater level. The change may vary from zero to over 0.5 metres, and varies quite a lot and involves quite large volumes of recharge and discharge. The LWMP (finalised in 2000) estimates of gross recharge each year of 96,000 ML, comprising two half yearly components.

The groundwater level change varies each 6 month season (time step) since 1990. This means every time step the volumes of recharge and discharge have a different composition, with some factors increasing and others decreasing. A groundwater balance is achieved when the recharge and discharge for a period adds up to be equal to the volume of groundwater change. This balance is needed for each of 36 six month time steps if 18 years are considered.

The factors contributing to net recharge from September to March are:

1. irrigation recharge, comprising rice accessions and other irrigation accessions
2. channel seepage,
3. rainfall recharge,
4. deep leakage, from shallow to deeper Shepparton aquifers and from these to the Calivil Formation or, by lateral dissipation, to adjacent areas.
5. capillary rise and groundwater evaporation processes
6. groundwater pumping from shallow aquifers where this is practiced
7. uptake by trees of groundwater

From March to September similar factors play a role, except they will be different in size, for instance rainfall recharge may be more significant in winter.

Each recharge or discharge factor varies between time steps dependent on what drives the individual factor. Quantification is difficult. However, for each factor there is usually an observable quantity, which after application of a coefficient or factor would produce the volume of recharge or discharge. For instance, rainfall accessions may be estimated from a rainfall quantity multiplied with a proportion. If the proportion (or coefficient) remains the same between the same season of each of the 18 years, then the quantity of recharge/discharge of each year is estimated from the observable quantity. The model approach therefore is to find the best estimates of the proportions / coefficients for each recharge and discharge factor. These best estimates may be found by optimisation, which is a statistical technique not unlike multiple regression. EXCEL Solver allows this modelling process to occur.

Some factors may be considered more or less constant between years, others are variables. For instance, shallow groundwater pumping may be considered constant, based on the records available. About 3000 ML of groundwater is pumped annually in the Gogeldrie sub-district. The effective porosity also is a constant, but it may vary between sub-districts, mostly depending on soil characteristics. On the other hand, channel seepage is not a constant, as it may vary with the average depth to groundwater in the (sub) district.

Most factors of the model, such as deep leakage, rice recharge, irrigation recharge, rainfall recharge and groundwater evaporation are variables. The model coefficients for rainfall and irrigation would be different between the spring/summer and autumn winter season.

D2: Model to Describe Groundwater Trends

Based on the discussion above, datasets have been prepared, including groundwater data, Calivil Formation groundwater data, rainfall data, rice area data and water use data. This collation was extended not only to the $MIA_{shallow}$ area, but also to the six sub-districts identified for the MIA, giving seven data sets. The data was compiled for all factors for the full 1990 – 2008 period, which was not difficult except for water use.

Water use data for all crop types and each district (Mirrool, Yanco, Benerembah) was available from 2000 to 2008, including a split up of before and after 1 March each year. A similar but less accurate set of water use data is available for the 1996 to 2000 period. Prior to 1996 total water use data is available, but a split up between sub-districts and a split up before and after 1 March is not available. To overcome this limitation, surrogate data was generated from proportions of totals found for years <u>with</u> the available information, and then applied to the years for which it was not available. Any resultant loss of accuracy in the early years mainly influences the effect of non-rice crop irrigation on March groundwater depths, and autumn irrigation on September groundwater depths.

After development of the optimisation model it was applied separately to each sub-district and the MIA as a whole. In each case it uses the average groundwater depth for the first date (September 1990), which is the start of a series of 36 time steps of six months each, to March 2008. For each successive time step, the volumes of net recharge which best describe the next date's groundwater depth need to be found. This next date's groundwater depth becomes the starting point for the next time step, and so on.

The actual field volumes, of course, are unknown. Every bit of data used is an estimate, based on what is available. For instance water deliveries are not very accurate, rainfall data are for one site (CSIRO) only, groundwater averages depend on the reliability of the piezometer sets, etc. All data therefore is subject to some error. Despite this, there is an optimal set of coefficients / multipliers applying to the variable data inputs, which will produce the best estimates of volumes of recharge and discharge for each time step, and henceforth the groundwater levels. These estimates may be compared to the observed groundwater levels, and the differences between observed and calculated values may be considered.

<u>The criterion used for optimisation is that the sum squared of the differences between observed and calculated average groundwater depths needs to be minimised</u>.

The EXCEL "Solver" software can produce optimal coefficients for each variable factor. The main problem with the technique is that several sets of statistically (close to) optimal solutions may exist. Furthermore, a statistical technique can't claim to have a sound physical basis, even though in this case all kind of physical factors have been built in. For that reason it is necessary to discriminate between the solutions, and reject those which are less likely to be applicable. This process involves the narrowing down of many of the coefficients to a narrower and more credible range. In practice this is not really difficult. Previous research work allows reasonable constraint values to be adopted in the model ([15]). Adopting such constraints ensures that the optimisation comes up with only one alternative solution, which also has the lowest possible standard error between observed and calculated values.

The result produced by the model is four fold:

1. Coefficients applicable to each factor or stand alone (eg effective porosity).
2. Observed and calculated groundwater depths for each time step
3. Volumes of recharge and/or discharge for each factor for each time step and averaged annually. The total annual recharge and discharge is also found.
4. The standard error of the estimate versus the observed values

In the follow up process, factors such as channel seepage, constraints, or algorithm coefficients may be changed and the optimisation repeated. A lower sum of squared of differences and lower

[15] For instance, it is known that rainfall recharge, irrigation recharge and rice recharge all must be positive. The proportion of recharge from rainfall or irrigation is unlikely to be more than, say 10 or 20%. Rice water use is available, so the model should produce values of that order, excluding ET. Porosity is likely to be in the 0.04 to 0.08 range, Capillary rise must be negative recharge, deep leakage cannot be excessive, etc.

standard error are indicators of the direction in which change of recharge or discharge volumes should occur.

D3: DESCRIPTION ALGORITHMS FOR RECHARGE AND DISCHARGE FACTORS

1. Deep Leakage

Downward leakage is governed by the gradient between the shallow Shepparton Formation aquifer and the Calivil Formation aquifer, and the permeability of the strata. Groundwater average depths are used for each sub-district based on gridding (Appendix D). A standardised leakage rate is adopted equal to the rate which would occur if the head difference (gradient) is 10 metres. This typical rate multiplied with the gradient allows calculation of the relative leakage rate each year from 1990 to 2006.

Deep leakage includes the leakage from the shallow to the deep Shepparton Formation aquifers and then laterally out of the sub-district under consideration.

2. Summer Rainfall

The total rainfall from October to end February seems to have the highest correlation (of all possible rainfall factor combinations) with the rise (drop) of groundwater from September to March. The model coefficient operates on this total rainfall to calculate the volume of recharge over the period.

3. Winter Rainfall

Various derivatives of rainfall from March to end August all have significant correlation with rise (drop) of groundwater from March to September (Appendix E). The rainfall of the highest rainfall month in most subdistricts seems preferred. However, a simple daily rainfall recharge model also provides a high correlation, and this was adopted for the optimisation model.

The daily rainfall recharge model uses a beginning soil moisture store for the rice area and the non rice area separately on 1 March, then adds a drying effect by subtracting ET times a crop factor (about 0.25) and adding the rainfall of the day. Recharge occurs when the soil moisture deficit becomes negative. Recharge is added up over the whole period. The annual values obtained for all years are then entered in the model and the correlation with rise (drop) in groundwater levels determined.

The actual recharge in the optimisation model is the recharge of the rainfall model multiplied with the optimised model coefficient. This latter factor is likely to be less than one (but greater than zero).

4. Rice Area Recharge.

This factor is expressed as ML/ha/season. Rice recharge is not related to rice water use directly, but is taken as a function of the rice area, multiplied with a percolation rate per hectare. A standardised percolation rate when average groundwater is at 1.5 metres depth was adopted as the model coefficient to be optimised for each sub-district.

Rice recharge may vary as groundwater levels drop, such as occurred from 2000 onwards. The typical rice recharge rate therefore needs to be multiplied with a factor related to a standardised groundwater depth (1.5 metres). This factor could be the actual average groundwater depth divided by 1.5. Since it is not certain the relationship is fully linear, a power function with a coefficient between 0.5 and 1.0 was used instead (see also channel seepage).

5. Channel Seepage.

The channel seepage volumes were derived from the LWMP documentation (proportional to the areas involved, with some adjustment (making the process for this factor somewhat arbitrary)) and varied by only small amounts to see whether there was any effect during optimisation. There was little. Of course any change in channel seepage has to be matched by increased discharge from groundwater evaporation or deep leakage.

The channel seepage value increases as groundwater depth increases. Depending on stratigraphical conditions the increase may be proportional, or it may be more like a square root of depth function. A proportional increase may be expected when there is a restrictive layer near the surface and an aquifer at say 5-10 metres. An increase equal to a square root function may be expected when there is a homogeneous clay profile, without lateral movement through an aquifer.

In most sub-districts there are areas with aquifers, and some areas without shallow or deep Shepparton aquifers. The likely scenario is therefore that the optimal increase in channel seepage function behaves as the standardised channel seepage (with groundwater at 1.5 metres depth), divided by the average groundwater depth to a power, with the power being a value between 0.5 and 1.0. Figure F1 shows the relative seepage rate with increasing groundwater depth in the model.

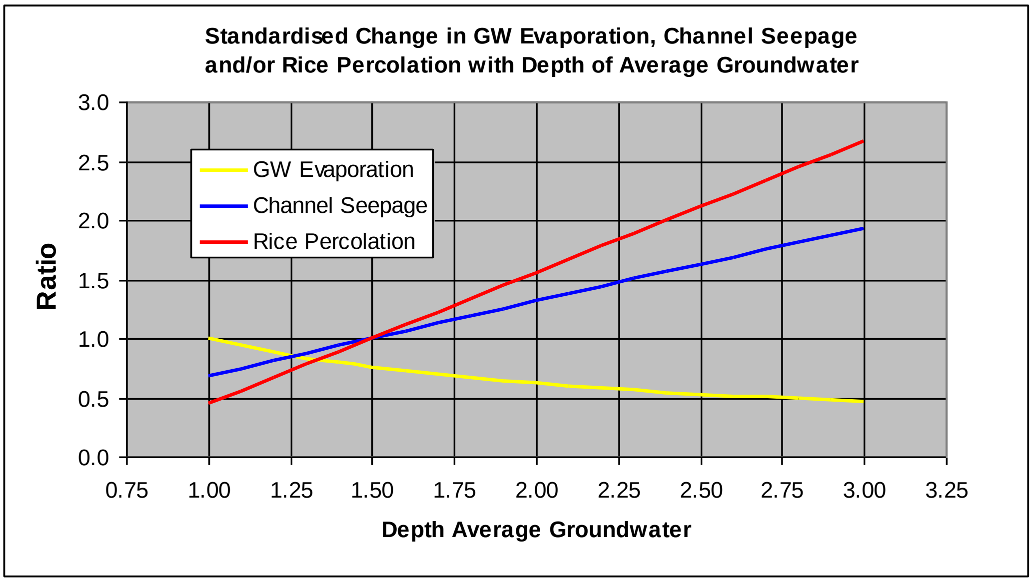


Figure D1: Relative rates of rice percolation, channel seepage and groundwater evaporation used for modeling the optimised MIA groundwater balance

6. Groundwater Evaporation

This is a complex subject. Graphs based on research describing capillary rise and groundwater evaporation are available for several soil associations. These tend to show an exponential decline of capillary rise with depth, with most of the decrease occurring as groundwater levels drop from the root zone at say 0.3 metres to about 1.2 metres depth. Below this depth the decrease is not necessarily exponential, since at very low capillary rise rates the relative proportion of moisture vapour flux increases. The curves would be different between summer and winter conditions, because in summer the soil surface dries out (unless irrigated), and a dry surface mulch develops preventing capillary rise (but not the small amount of vapour flux).

Longer time frames than one day are involved in this study, and the areas are much larger than sites. Groundwater levels vary over time and spatially. Consequently, the published research curves cannot be assumed to be valid in this situation. However, it is still likely that capillary rise / groundwater evaporation does decrease with increasing average groundwater depth.

A typical value for capillary rise as mm/year was adopted for when the average groundwater depth is at 1.0 metres. This capillary rise was divided by the actual average groundwater depth for the year in question to a power, with the optimal power value to be found by optimisation.

Figure D1 shows that the resultant groundwater evaporation with average groundwater at 2 metres is about 60% of the value when groundwater is at 1 metres and it drops to just below 50% by the time it gets to 3 metres. This may appear high, but it is noted that with an average groundwater level at 3 metres there still may be a small proportion of land in the sub-district with much higher groundwater, and that probably contributes the most. Consequently, the found values were considered to be not unrealistic.

7. Non-Rice Water Use

Both the September to end February non-rice water use, and the autumn water use were taken at face value. The optimisation model adopted a coefficient, being the proportion of water use that would result in recharge.

8. Groundwater Pumping

Shallow Groundwater pumping on a significant scale only occurs in the Yanco area (Wamoon, Stanbridge, Fivebridges). Pumping volumes have been found to be in the order of 3000 ML/year. No data was available for individual years. The pumps may have been turned off on occasion in recent times. The volumes were assumed to be constant between years. The volumes are small relative to the size of the sub-district (Gogeldrie) so no significant error is expected from this assumption.

9. Tree Water Use

The MIA only has about 1-2% of its areas still as deep rooted trees, which could be expected to remove groundwater for transpiration. It was assumed the volume is very small to insignificant, say 1-2ML/ha/year for the area involved. It was also assumed that there is no variation between years.

10. Lateral Groundwater Flow.

The shallow Shepparton aquifers are limited in extent laterally in some directions. The aquifers follow east west prior stream lines. The transmissivity where aquifers occur is not high and this transmissivity is confined to the stream beds only. Most of the lateral movement is likely to occur through the deeper Shepparton Formation aquifers, and the Calivil Formation. The volumes involved in that process are part of the deep leakage factor.

It is assumed that the lateral groundwater flow factor is small and not significant. No effort was made to vary the assumed low values in the model by changes of gradients between years.

D4. MODEL DATA AND RESULTS.

The 2006 groundwater report for MI lists all the datasets compiled for each factor and the results for each sub-district in graph and tabulated form. The results include correlation tables between factors, diagrams, recharge and discharge volumes and graphs. This detail is not included with the 2008 report as it involves many pages. Persons interested in looking at the detailed information and who like to examine the benefits and disadvantages of the model approach of this report are requested to contact the author, and, with consent of Murrumbidgee Irrigation, may develop a discussion in this regard.