MURRAY IRRIGATION LIMITED

# GROUNDWATER TRENDS AND BALANCES

# 1990 – 2004

***(Preliminary Study - Draft)***

# GROUNDWATER TRENDS AND BALANCES 1990 TO 2005

## Contents



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# SUMMARY

A study was conducted to examine whether average groundwater depth behaviour of irrigated districts and sub-districts in the Murray Valley could be explained as a function of the various contributing recharge and discharge factors. To this end average groundwater depths of shallow and deep aquifers were calculated and compared with irrigation delivery data, the areas of rice, climatic data, groundwater pumping data, and other contributing factors such as channel seepage, lateral flow, tree uptake and groundwater evaporation where appropriate. The period considered was 1990 to 2004.

Correlation matrices of groundwater depth and contributing factors were assessed. Rainfall preceeding the observation dates (August, Feb/March) was sometimes well correlated, but for many subdistricts it is weak. Water use factors or rice areas also showed variable relationships. It appears there are many inter-relationships which cause that single factors cannot easily explain groundwater behaviour in isolation.

Optimisation of multipliers to all known variable factors (deep leakage, lateral groundwater flow, rainfall, and irrigation) found that a good prediction of the observed groundwater trend is possible in all areas selected ([1]). Figure S1 is an example of the fit obtained, for Berriquin North, using the stepswise method of optimisation ([2]). The trend is explained in terms of rates and volumes of the above groundwater balance factors. The standard deviation of the difference between observed and predicted varied from 0.08m to 0.16m, which is considered acceptable.

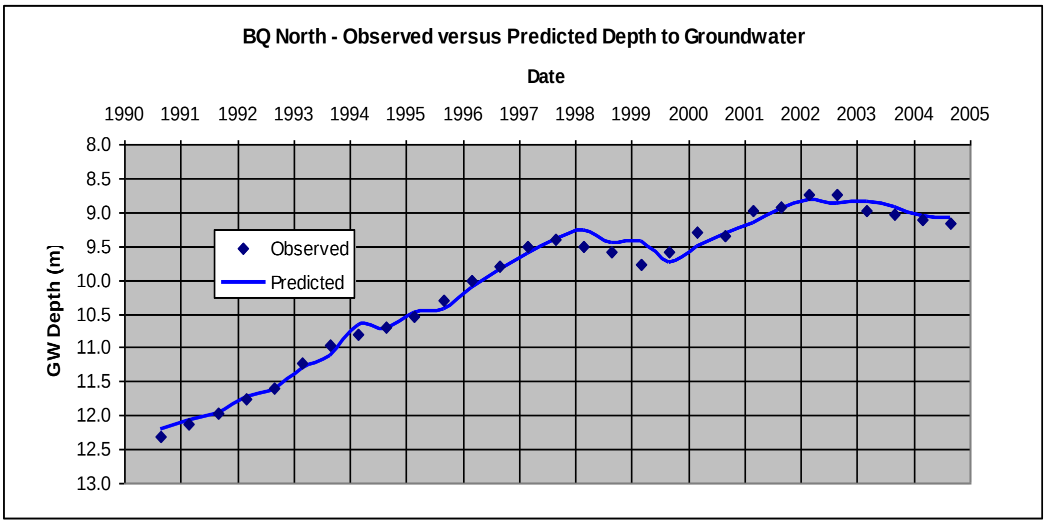


*Figure S1. Observed and predicted groundwater depths in BQ North using optimisation of groundwater recharge and discharge factors.*

Figure S1 involves two aspects, the trend over the full period, and the seasonal variation every six months. The main trend prediction using the integrated method of

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[1] Berriquin North, Central and South, Denimein, Wakool pumped and "other", and Deniboota. The Berriquin District was split in three parts, North, Central and South, to separate different land uses and the area where most shallow groundwater pumping occurs.

[2] Two methods are described in the report. Basically, the stepswise method optimises from one date to the next (six months later). The integrated method optimises for the whole period at once.

optimisation was found to be very good. The correlation coefficient between observed rises and falls and predicted rises and falls was in the order of R=0.7 for most districts, but less for Denimein.

The contribution of each factor to the average groundwater depths prediction lines varied, but there are consistencies. Table S1 is a summary of the coefficients found to be applicable to some of the major variables. Deep leakage appears to be significant, in the order of 10-20mm/year for every 10 metres down gradient. Accessions from rainfall are significant, with the winter season usually contributing more than the summer season. Irrigation appears to contribute less to groundwater than the rainfall study. In some areas the groundwater storage factors (rising groundwater levels) has been very significant in at least part of the study period, usually up to about 2001.

*Table S1. Summary of coefficients to be applied to key groundwater balance factors for bestt estimates of groundwater behaviour in each of the component areas (*1).*

| Area | Deep Leakage | Aut/Winter Rainfall | Spr/Summer Rainfall | Rice Perc ML/ha | Water Use %/100 | GW Evap |
|---|---|---|---|---|---|---|
| **BQN** | 17.8 | -0.074 | -0.015 | -0.61 | | 0.09 |
| **BQC** | 18.2 | -0.16 | -0.052 | | -0.02 | |
| **BQS** | 12.5 | -0.039 | -0.029 | -0.072 | | |
| **DN** | 18.2 | -0.061 | -0.001 | -0.3 | | |
| **WKP** | 40 | -0.115 | -0.061 | | -0.022 | 0.11 |
| **WKO** | 20 | -0.045 | -0.029 | -1.19 | | |
| **DB** | 18.1 | -0.037 | -0.042 | -0.3 | | |

(*1) Negative = recharge, positive = discharge

It is probable that irrigation recharge has been under-estimated by the methods used. However, it is also probable that some other factors have not been adequately represented in this preliminary study, eg tree evaporation. This study has not yet been brought to finality, and some input factors require reviewing.

Groundwater pumping data were included where feasible, and groundwater evaporation was included for the areas with higher groundwater levels, namely Berriquin North and Wakool Pumped. Groundwater evaporation values found were of the order of 0.1mm/day when groundwater is at 2 metres depth, which is very plausible.

Some of the data used for this study may be updated to obtain an even better prediction. This is proposed. Whilst there are dangers attached to using statistical methods for quantifying factors such as in this study, the methodology appears to offer potential to examine several of the groundwater balance factors such as channel seepage and tree uptake a bit more closely, and to link these to the variable factors such as rainfall and irrigation recharge.

# GROUNDWATER TRENDS AND BALANCES 1990 TO 2005

## 1. Background / Introduction

The Murray Region Irrigation Districts have been irrigated since the 1930's and 40's. Rice was introduced during the 1980's. Rising groundwater levels and concern re sustainability have led to the development of Land and Water Management Plans (LWMP) during the early 1990's. Many, many studies have been carried out regarding groundwater trends, groundwater balances, channel seepage, deep aquifers, and likely accession rates from irrigation. Groundwater models have been developed.

It is generally recognised that the assessed values of the components in the groundwater balance have not been precise, despite the efforts expended. Now, in 2005, it is clear that many of the predictions have been too pessimistic and wrong. To a large degree this has been caused by much drier weather conditions and a lack of irrigation supplies in the last few years. The extent by which the various components in the groundwater balance have been inaccurate or changing has not been studied in detail so far ([3]).

Despite the falling groundwater levels, Murray Irrigation has continued collection of groundwater data as part of the performance monitoring requirements of the LWMP. Groundwater conditions have been reported as maps and the area within 2 metres from the surface (MIL Annual Reports). Several studies have been carried out to analyse the effect of rainfall and flooding on groundwater change. For instance, a Standard Precipitation Index was used by CSIRO and compared with net recharge during winter. This method was found to be of limited value in the Murray Region (Khan et al, 2001). A GIS approach to analysis for the Wakool Region found that flooding in some years had a significant effect (Wang et al, 2003). A relationship between rainfall and groundwater change in winter was also found for that area. For the other districts such correlations have not yet resulted in an explanation of groundwater behaviour.

Correlations between rainfall, the areas of rice, and groundwater gradients to deep (Calivil) aquifers has been used by van der Lely for the Murrumbidgee and Coleambally Irrigation areas to estimate groundwater depth in shallow aquifers for either March or September (eg. MI Annual Groundwater reports 1999-2004). It was found that about 90% of the variation in groundwater depth could be explained by these factors. This prompted the idea to carry out a similar study for the Murray Region. The irrigation intensity of the Murray Districts and crops grown however varies significantly from the more northerly regions and it was uncertain whether that approach could produce similar results.

Groundwater level change in a subdistrict from one date to the next involves all factors in the groundwater balance, with each factor contributing a different amount to the change. Murray Irrigation in March 2005 agreed to a limited study by the author. The objective is to examine whether the groundwater behaviour in the four LWMP areas of the Murray Valley (Berriquin, Denimein, Wakool and Cadell) could

[3] As far as the author of this report is aware.

be explained by the variation in the main groundwater balance components - rainfall, deep leakage, groundwater pumping and water use / rice areas. This study is an attempt to quantify the contribution of each variable factor mentioned, but also considers the other factors mentioned in LWMP documentation, such as channel seepage, uptake by trees, lateral groundwater flow, and groundwater evaporation (via capillary rise).

Relevant data were provided by MIL and DIPNR to the author or were obtained from LWMP reports. Some data points were estimated for this preliminary study ([4]). This report describes the context, the methods used and the results obtained.

# 2. Principles, Data and Methods

## 2.1. Principles

The groundwater rise or fall between two successive dates represents net recharge or discharge. The volume of change may be measured by differences from contoured maps. An effective porosity of 5% was assumed for this study. The annual variation in changes between successive periods is probably mostly caused by variations in accessions, such as from rainfall or irrigation. Over a longer period factors such as leakage to deep aquifers may also change as the gradient for downward flow changes. Pumping of groundwater of course can have a major impact and this would varyy seasonally and over time. Channel seepage may be fairly constant unless effective works are carried out.

If all volumes were accurately known the groundwater levels can be predicted quite precisely. However, this is not true, and there are many constraints. Data are not perfect, there is spatial variation which is difficult to acount for. Between two groundwater monitoring dates a lot of factors are variable in time. All that can be expected in analysis is an estimate, based on estimated coefficients applying to the variables such as rainfall, the area of rice, or water use. This is the aim of this study, to find the best estimates of coefficients which after application to the key variables produce estimated volumes of recharge and discharge, which added up together closely match the change in groundwater storage between two dates.

Some factors apply to the August groundwater level assessment, and some factors apply to the Feb/March groundwater level assessment. For a longer period, such as 1990 to 2004, the coefficients found are assumed to be the same between years, although the factor itself may change. For instance, winter rainfall each year is to be multiplied by the same coefficient to get the variable rainfall (net) recharge each year. Table 2.1 shows the key factors, the variables they are based on, and the multipliers to be found to get a groundwater balance with observed groundwater changes.

[4] This mainly involves some water use data about 1990, and some groundwater pumping data. It may also be possible to get a split out of autumn water use each year. Further, some groundwater balance input factors may be reviewed, eg channel seepage values and tree uptake.

Some other factors are not variables, for instance channel seepage in areas with not too shallow groundwater may be input as a constant unless it is known to have changed.

*Table 2.1. Key factors, thevariables they are based on, and the multipliers to be found to get a groundwater balance with observed groundwater changes.*

| Factor | Known Variable | Unknown Multiplier | Result |
|---|---|---|---|
| Groundwater depth | None | None | Observed change between dates. |
| Deep Leakage | Gradient deep to shallow aquifer | Standardised deep leakage | mm/year leakage |
| Rainfall accessions | Rainfall or a derivative | % that becomes accessions | mm of accessions |
| Rice Percolation | Rice area each year | ML/ha percolation | Volume of rice accessions |
| Other Irrigation accessions | Water Use | % of water use that becomes accessions | ML of irrigation accessions |
| Lateral groundwater flow | Lateral gradient between areas | Standardised Lateral GW flow | ML of Lat GW Flow |
| Groundwater evaporation | Relative capillary rise rate applying for each GW depth | Multiplier to the standard rate when GW at say 2 metres depth | mm/year of groundwater evaporation |

The method used to get the optimal coefficients in the third column of Table 2.1 is described at section 2.3. It is noted that there is an implicit assumption that the multipliers correspond to a linear model of estimation. This may not always be the case, for instance with rainfall accessions the relationship is likely to be very complex. The possibility of non-linearity is beyond the scope of this study.

## 2.2. Data

The data provided by MIL for the four LWMP areas include the following:

- Shallow piezometer readings March and September
- Deliveries of water 1994 to 2004
- Rice areas 1994 to 2004
- Groundwater pumping volumes as far as available
- Maps outlining the district boundaries
- Deep piezometer groundwater levels (from DIPNR).
- Rainfall and evaporation data (monthly) Deniliquin Airport (BOM data)

It was subsequently decided by the author to extent the period of study to a longer 1990 to 2004 period. Some of the earlier water use data could be obtained from the LWMP plan documents. Rice areas of before 1995 were estimated as a proportion of water use as found for later years. This proportion was quite consistent. Tubewell drainage volumes in Berriquin were derived from LWMP documents. Some of the groundwater use data for Berriquin had to be estimated. The Wakool pumping volumes were available for the later years, but the earlier data have been estimated. The shallow piezometer data was excellent, and DIPNR Deniliquin (Mohammed Alamgir) very kindly provided some gaps in the deep piezometer data.

Other data used in this study have been derived from LWMP documentation, eg likely channel seepage volumes, uptake by trees, lateral groundwater flow. The latter data would have applied to the early 1990's conditions, and may have changed since.

It needs to be stated here that it is possible to improve the dataset used with a limited effort, and this may improve the results of this draft report. Nevertheless, it is believed that the main conclusions are unlikely to be influenced significantly.

The Berriquin District was split into three parts, the reason being that the central part has lighter textured soils, is used more widely for irrigation of crops other than rice, and has a significant groundwater pumping and reuse component. The district tubewells are also in this zone. The three parts are Berriquin North, mostly a rice growing zone, Berriquin Central, as mentioned, and Berriquin South, south of the central part. The south-eastern part of Berriquin was excluded from the analysis altogether.

The Wakool District was split in a WSSDS or "pumped" area and "other" area. Regarding the Cadell LWMP area, only the Deniboota District (western part) was considered.

Figure 2.2.1 shows the outline of the various component areas of the analysis.

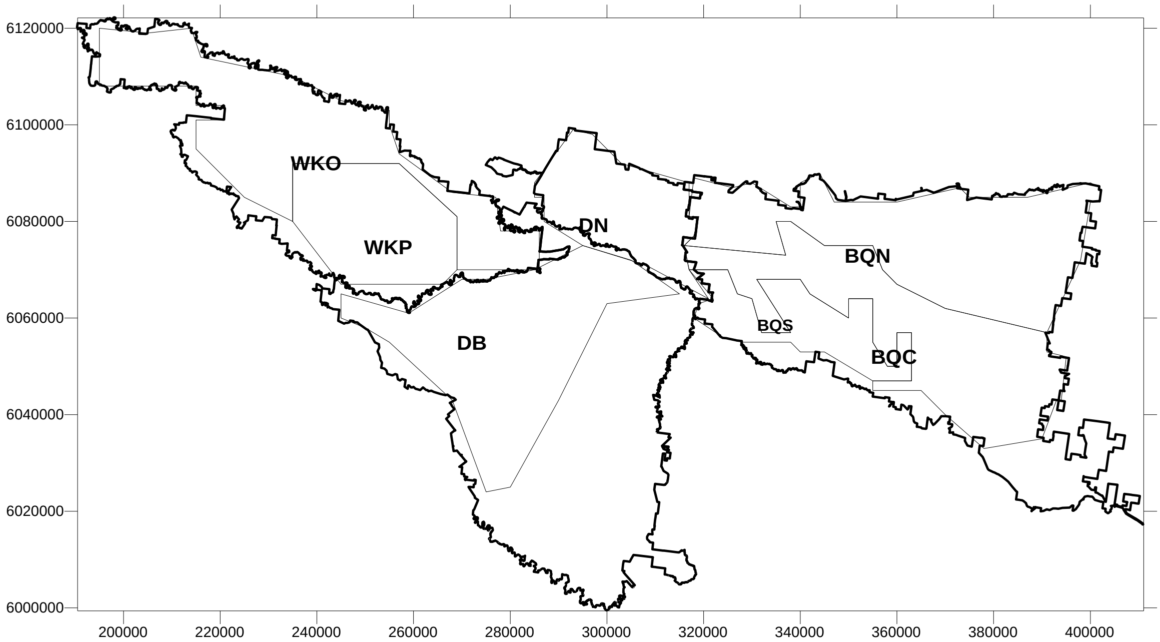


*Figure 2.2.1. Boundaries of component areas Murray Region used for analysis*

The following actions were undertaken to change the datasets into a form in which it can be used for trend analysis:

1. The shallow piezometer data were gridded for each date, and the average groundwater level determined for each date and for each area using SURFER software.
2. The deeper piezometer data was also gridded for each date, and the average groundwater depth determined for each date and component area. It is noted that the useful deep piezometer sites are limited in number and that a choice had to be made regarding the piezometer depth for the analysis ([5]).
3. The gradient for leakage to deep aquifers was deternimed for each date as the difference between average shallow and average deep aquifer depths. The actual deep leakage therefore was variable with time.
4. In some districts a lateral groundwater gradient occurs, eg in Berriquin from Central to the North. This gradient was determined as the difference between the average shallow groudwater depths. Lateral groundwater flow therefore may be variable with time. In some other districts a constant lateral groundwater flow was assumed, based on the LWMP (eg. Wakool).
5. The rainfall data was re-arranged to set up a number of datasets to find correlations with groundwater change over a six month period. For the August groundwater level, the winter rainfall, or the winter plus autumn rainfall, or the May-August rainfall, or the month with the highest rainfall (HRM) may have the highest correlation with groundwater change from March to end August. The best option may be determined by correlation analysis. For the groundwater conditions in March, either the September to February rainfall, or just the summer rainfall may be the most significant.

The other data did not require further re-arrangement. For some component areas, the area of rice was estimated as a proportion of total District rice area, eg Berriquin North and Wakool "Other". The same applied for water use for eg Berriquin Central, which was assumed to be a proportion of total Berriquin water use. Groundwater maps of the shallow groundwater system are not presented in this report, they are plentiful available in other reports, eg., the MIL Annual Environmental Reports. However, Appendix 1 shows two typical groundwater maps for the deeper aquifer systems, to demonstrate that the limited data for that aquifer system resulted in a plausible assessment of average conditions for each date.

## 2.3. Methods

For either the February/March groundwater data, or the August groundwater data, it was found that the correlation with rainfall factors, or water use, or rice area factors were usually much less significant than the correlation with the previous reading six month before, or the time factor (see sections for individual component areas). The correlation with deep groundwater depth was usually poor. On basis of these observations it was concluded that regression analysis to predict groundwater levels

[5] There were only 28 piezometers covering the MIL area, with each site having about 4 piezos varying in depth from 50 to over 300 metres depth. The very deep piezometers in the Renmark Formation were excluded since they often showed different groundwater levels (higher). Piezometers of the intermediate aquifer depth range of 100 to just over 200 metres was selected by preference. At many sites 2-3 piezometers exist within this depth range, and SURFER was instructed to calculate the average level of available data. The depth range selected includes the effect of deep groundwater pumping since about 1995.

was unlikely to be a productive method. It was decided to instead use optimisation techniques using EXCEL Solver to determine coefficients to be applied to the variable factors.

Table 2.1 was prepared to show which factors were used to estimate the groundwater depths in either August or February/March.

*Table 2.1. Factors used to estimate groundwater depth in either March or August*

| **Factor** | **Type** | **BQN** | **BQC** | **BQS** | **DN** | **WKP** | **WKO** | **DB** | **Comment** |
|---|---|---|---|---|---|---|---|---|---|
| Previous Depth | | + | + | + | + | + | + | + | |
| Winter Rainfall | var | + | + | + | + | + | + | + | August only |
| Summer Rainfall | var | + | + | + | + | + | + | + | March only |
| Deep Leakage | var | + | + | + | + | + | + | + | |
| Lat. GW Flow | var | + | + | + | - | + | + | - | |
| Water Use | var | - | + | - | - | + | - | - | March only |
| Rice Area | var | + | - | + | + | - | + | + | March only |
| Channel Seepage | fixed | - | + | - | + | + | + | + | |
| Tree Uptake | fixed | - | - | - | - | - | + | + | |
| Groundwater evaporation | var | - | + | - | - | + | - | - | High WT areas |
| GW pumping | var | - | + | - | + | + | - | + | |

For channel seepage and groundwater pumping 70/30 split of the annual value was used to separate the effect on March groundwater depths and August depths. However, with tubewell drainage a 50/50 split was adopted as it would have been used all year round.

The effect of irrigation is represented by either water deliveries (use) or rice growing, as shown. No split between before 1 March and after 1 March water use was adopted, since the water use of crops other than rice is only known imprecisely, and the proportion of autumn water use is even less well known. MIL staff may provide advice in this regard to improve the analysis. Hence, so far, the effect of autumn irrigation has not been analysed in this study.

The optimisation calculations resulted in coefficients which are multiplied with the variables or fixed values, and added up together to calculate the net discharge / recharge. This value is added to the previous groundwater depth to result in an estimate of the current date groundwater depth. The assessment for each subsequent date based on the previous date and the various factors therefore results in a stepswise assessment for the whole period. The estimated and observed values were compared and the difference calculated. Optimisation occurred when the sum of squares of the differences was minimised. The standard deviation of the differences was calculated.

Positive coefficients in the assessment represented groundwater discharge, and negative values represented recharge. In some instances a constraint needed to be applied to the optimisation coefficient to ensure it was ballpark, for instance, rice percolation must have a negative effect (recharge). It can’t be postive (discharge). Interestingly, this type of adjustment was not necessary often, and where such a constraint was applied, the other coefficients re-adjusted to produce the best possible combination overall.

Where a fixed (constant) input value was used (eg channel seepage), this value could be changed in the optimisation model to see what effect it has on the other factors, and the standard error of the estimate. Hence, the methodology may be used to examine the appropriateness of some of the major factors in the groundwater balances adopted for the LWMPs. This work has not yet been carried through to finality. Further discussion regarding this is in the individual component area sections.

Instead of applying optimisation coefficients to variables and adding these as assessed (net) recharge/discharge to the observed average groundwater depth six months earlier, the assessed recharge/discharge may be added to the average groundwater depth estimated for the date six months earlier. This way a integrated array of estimated groundwater depths may be calculated over the full 15 year period. The calculated whole array can then be compared to the array of observed average values. The integrated method may or may not produce similar values for the various coefficients and volumes of recharge/discharge as the stepswise method. Both methods were applied to all component areas. The results of the integrated method may be found at Appendix 3. The stepswise method results were used to present the results for the various component areas.

The stepswise method of optimisation is based on the observed average groundwater depth six months earlier. This feature causes in situations where groundwater levels change many metres over 15 years it is possible that the main trend is represented quite well, but that the rises and falls every six months actually were estimated very poorly. In other words, the graph looks good, but the calculated net recharge / discharge may not match up at all with the value of changed groundwater depth. This aspect was analysed for all component areas by comparing observed rises and falls with the calculated rises and falls for both methods of optimisation. Results are presented in Section 5

## 3. General Trends

Groundwater conditions, irrigation practices, and groundwater reuse factors have changed quite significantly since the early 1990’s. This would have been reported in the Annual Environmental Reports of Murray Irrigation Limited. A general understanding of these is necessary to identify which factors are critical for each component area, before attempting analysis of trends based on groundwater balances.

The groundwater data will be shown at the respective component area sections. Water use data, rice areas, and groundwater pumping data are shown at Appendix 2, together with correlation matrices. Below follows a very brief description of changes which have occurred over the 1990 to 2004 period.

Appendix 1 shows two maps of groundwater conditions in the deeper (100-240m) aquifers. It shows more or less where groundwater in this aquifer has dropped the most. The greatest drop of up to 20 metres occurred from 1995 onwards in the south western parts of Berriquin, but a general drop has spread out to all areas including Berriquin North, Denimein and Cadell, with some effect as far as the WTSSDS in the Wakool area.

Shallow groundwater levels continued to rise slowly in the Berriquin North area until 2002, after which a small drop commenced. A similar scenario exists for the Cadell area. The other areas have maintained relatively constant groundwater levels with a drop after the reduction in irrigation activity due to a lack of water.

The gradient for leakage to the deep aquifer has varied over the period, and in some areas has doubled. Leakage represents the effect of deep groundwater pumping, which therefore does not have to be represented by other means in the groundwater balance for the shallow aquifer system. Groundwater pumping adds to the volume of irrigation deliveries and includes deep and shallow groundwater supplies. It has been added to the water use factor where data are known, but usually it is a small proportion of total water deliveries. Groundwater pumping for supply purposes has increased during the recent dry period.

Water use has declined since about 2001, and so have the rice areas. It would be expected that this would have had a significant effect on groundwater change. Groundwater pumping volumes for drainage, such as the tubewells in Berriquin and the WTSSDS pumps in Wakool, have also declined.

Trees may have an effect on groundwater levels by extracting groundwater. Based on groundwater balances in the LWMP documents this factor is believed to be significant in the Wakool area and possibly the Cadell area. Whilst tree planting would have taken place it is not known how this may have affected the trend.

Channel seepage is signifcant in many areas of the Murray Irrigation LWMP areas, but it is not known how much channel improvement works of the last 10 years would have changed the volumes involved. This information may still be incorporated in the study.

Groundwater evaporation may be significant in areas where groundwater is within 2 metres. In Beriquin Central and the WTSSDS area the average groundwater levels are at about 2-3 metres, hence a proportion of these landscapes would be expected to have a shallower groundwater depth. For these two areas a groundwater evaporation component was added to the groundwater balance to better simulate groundwater behaviour.

# 4. Component Areas Results

## 4.1. Berrquin North

Figure 4.1.1 shows the groundwater trend in Berriquin North. The shallow groundwater levels have kept rising until about 2002, after which they have dropped slightly ([6]). The deep piezometers peaked in 1995 after which they dropped from 16 to about 20 metres and the annual variation also increased The behaviour of these two lines therefore appears independent. The difference between the two lines represents the gradient for downward leakage, which changed from about 4.5 metres to 11 metres. Also shown is the shallow average groundwater depth in the Berriquin Central area. This line shows the trend in the gradient for lateral groundwater flow in shallow aquifers from the Central area to the North. From LWMP documentation such lateral flow may have been about 4-8000ML/year in the early 1990s. Whichever value applies, it would have reduced over the last 10-15 years.

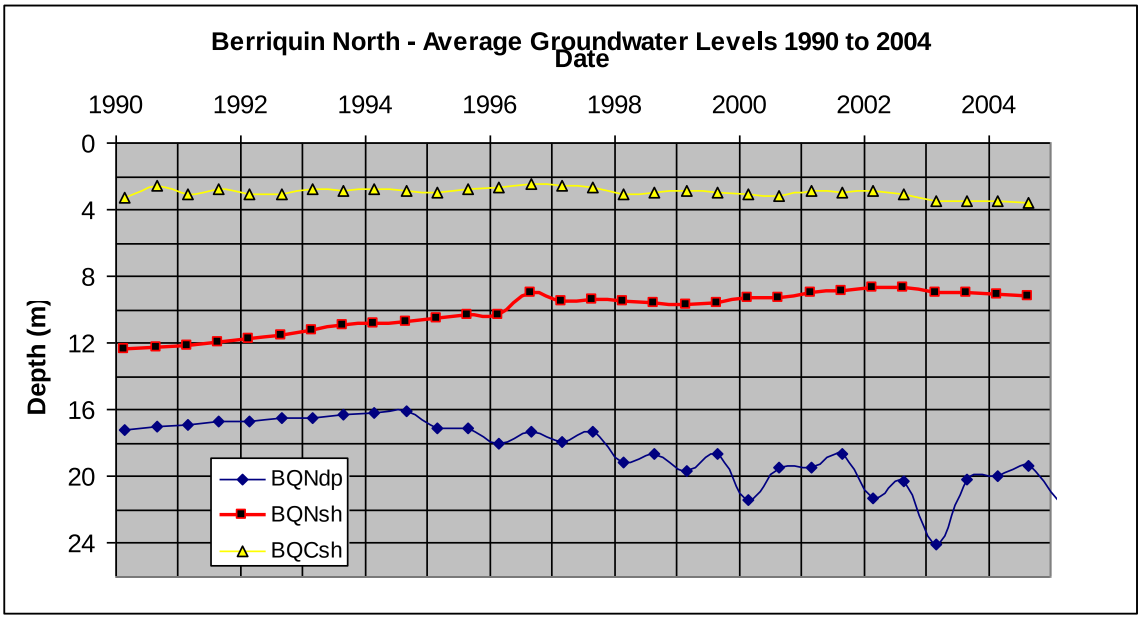


*Figure 4.1.1 Hydrographs of shallow and deep average groundwater depth in the Berriquin North area.*

The data used for the analysis is shown at Appendix 2, which also shows the correlation between the variables affecting average August groundwater depth and the correlation between the variables affecting average February/March groundwater depth.

It was found that the August groundwater depths were affected mostly by the previous level and time (R>0.9). The gradient to deeper groundwater is negatively correlated. Both systems appear believed to be virtually independent, except for a small leakage factor. The deep gradient is correlated with the amount of groundwater rise each previous 6 month period (R=-0.62). The rainfall factors used show a poor correlation with groundwater rise only, ranging from R=0.25 to R=0.37.

[6] August 1996 may be an anomalous data point as only a few piezometers were read that time.

The February groundwater depths show strong correlations with time and previous August readings, and a negative correlation with the deep gradient. The rise from August to February is more strongly influenced by water use or the rice area factor (R=0.62) than the rainfall from September to February (R=0.18).

Figure 4.1.2 shows the curve predicted from stepswise optimisation and the actual observed average groundwater depths for each date. The correspondence is striking. Since the integrated method of optimisation also shows a good simulation of the general trend, it is clear that the general trend in groundwater behaviour may be estimated by using the method employed. However, it is noted that the standard error between predicted and observed average groundwater depth is 0.13m. Of the observed rises and falls in groundwater every six months, only about 50% was accounted for by the methods used. This is further discusses at Section 5 ([7]).

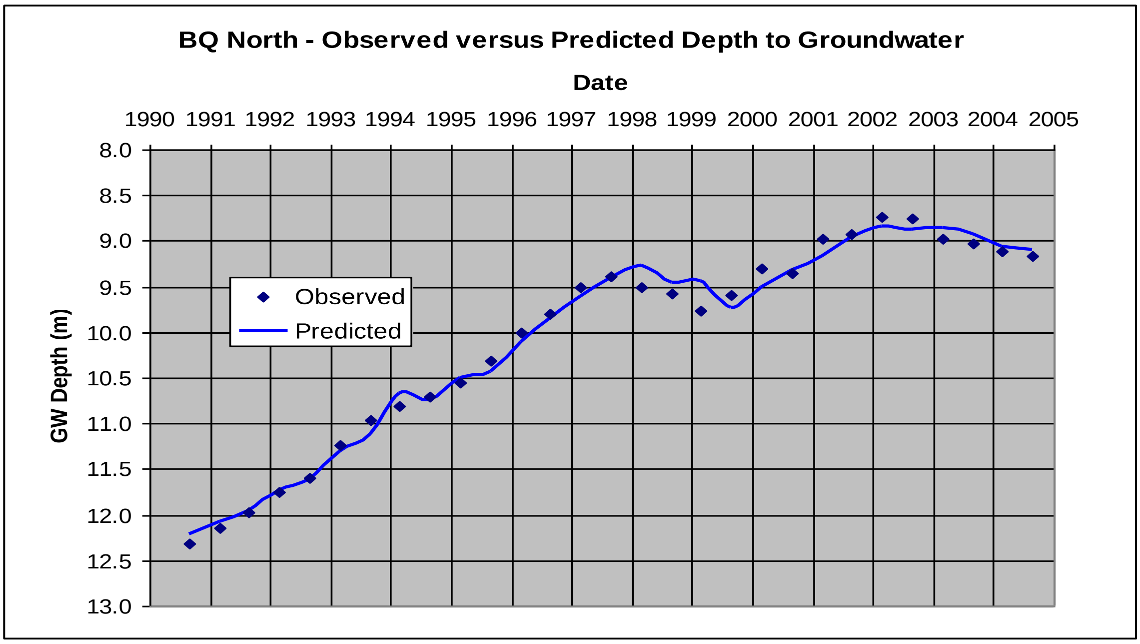


*Figure 4.1.2 BQ North. Predicted curve from optimisation and observed average groundwater depths.*

The seasonal and annual change is caused by recharge and discharge processes. The volumes of each factor corresponding to optimisation of the prediction curve of the groundwater behaviour may be found at Table 4.1.1.

Over the period considered the groundwater storage factor has been a major feature in Berriquin North. Rainfall overall seems to be a larger factor than rice recharge ([8]). Deep leakage is a significant factor to keep the watertable rise within more acceptable rates.

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[7] This asepct of only about 50% of variation being accounted for applied to all component areas.

[8] Rice recharge represents summer irrigation recharge processes. Since non rice water use has not been considered, rice recharge in this analusis also includes a factor for crops other than rice.

It is possible to calculate the net recharge and discharge factors for each year separately. Such results allow the examination of individual factors between years. The context and merit of the results reported is further discussed at Section 8.

*Table 4.1.1 Recharge and discharge factors for annual groundwater balance Berriquin North (stepswise method).*

| BQ North | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 17.8 | 19101 | |
| Lateral GW Flow | | -12349 | From BQ Central |
| W Rainfall % | -0.074 | -9590 | |
| S Rainfall % | -0.015 | -3842 | |
| Rice Recharge ML/ha | -0.61 | -7627 | |
| Water Use Excess (%) | | 0 | not assessed |
| Channel Seepage | | -10000 | Assumed |
| Tree Uptake | | 10000 | Assumed |
| Change Storage/yr | | 15372 | Average 14 yrs |
| **Balance** | | **1065** | Unaccounted for |

## 4.2. Berriquin Central.

The Berriquin Central area has a high proportion of lighter textured prior stream soils. Land use is mostly for crops other than rice growing. There is also a large proportion of groundwater pumping and reuse. These features influence the factors to be used to predict February/March groundwater levels.

Figure 4.2.1 shows the groundwater trends in the Berriquin Central area. The shallow groundwater levels have stayed relatively the same, with some drop after about 2002. The deeper aquifer shows a drop after 1995 from about 13 metres depth to over 22 metres depth. The annual variation is pronounced. Deep leakage would have increased in proportion to the increase in gradient.

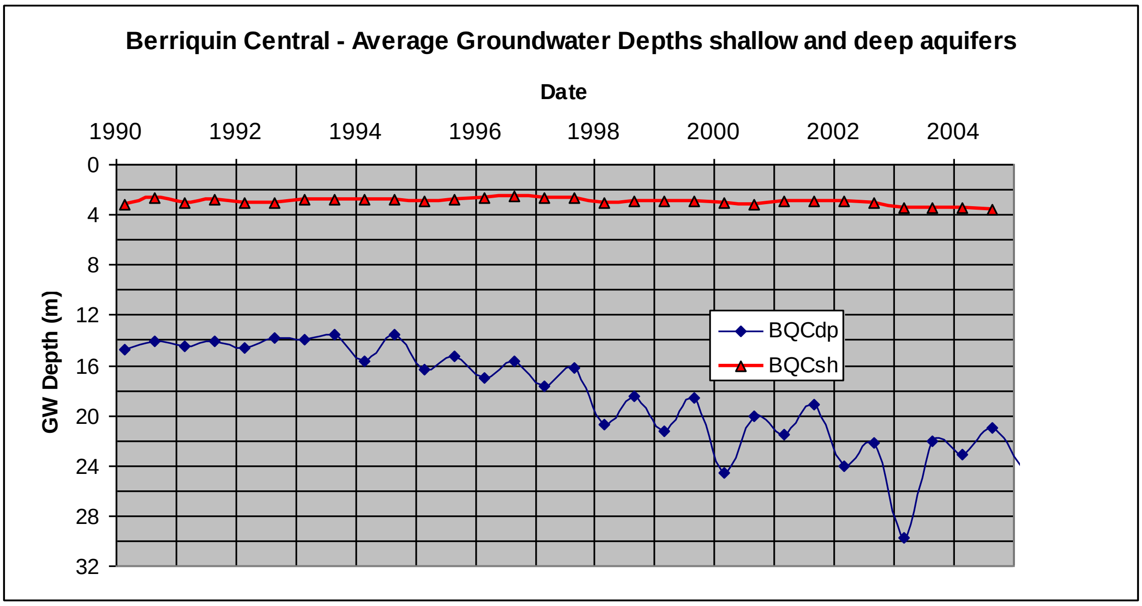



*Figure 4.2.1. Hydrographs of shallow and deep average groundwater depth in the Berriquin Central area.*

The correlation matrices of the data used to predict August and February/March groundwater levels are shown at Appendix 2. Generally, for March, summer rainfall appears to have a strong effect on the amount of groundwater rise (R=0.79). Total water use (supplies, pumping) seem to have a small effect on groundwater rise, but there is a correlation with groundwater depth in Feb/March. For August predictions, there is a correlation of groundwater rise (Feb to Aug) with several of the possible rainfall factors, with the total rainfall May to August being the highest (R=0.71).

Figure 4.2.2 shows the observed groundwater averages for August and Feb/March with the predicted line based on stepswise optimisation of the various input factors. The prediction line follows the data quite well, despite a standard error of 0.157m.

Groundwater behaviour in the Berrquin Central area is within a narrow band. Considering the relatively poor water use data and groundwater pumping data ([9]) the results are quite good. The integrated method of optimisation shows similar results.

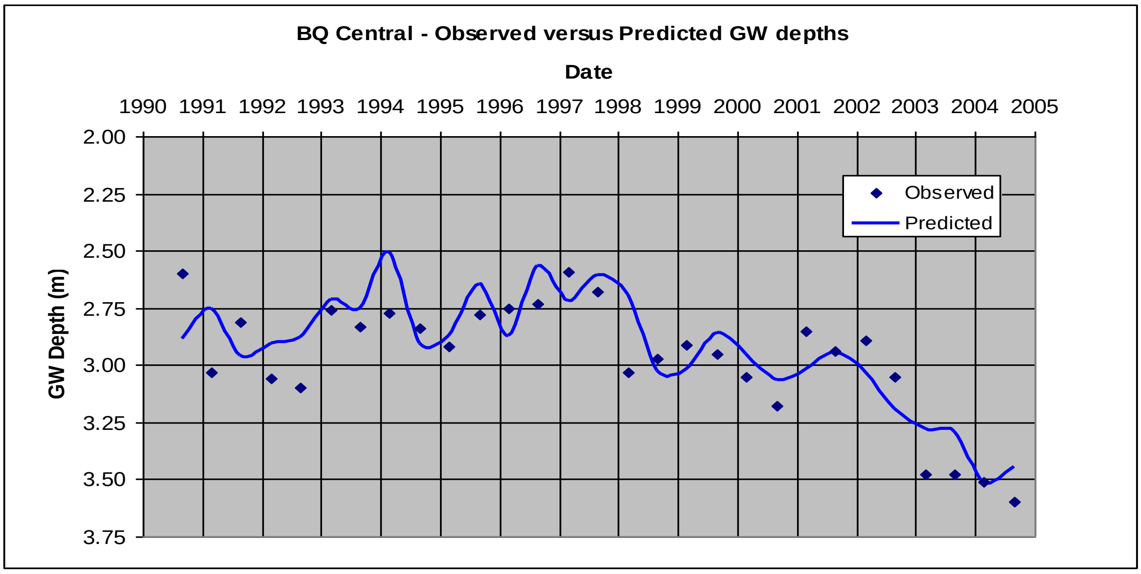



*Figure 4.2.2. Observed and Predicted shallow groundwater average depths for the Berriquin Central area.*

The various volumes resulting from optimisation to produce the stepswise prediction line are shown at Table 4.2.1.

Because groundwater levels in a proportion of Berriquin Central are regularly within 2m from the surface, a grounwater evaporation component was also included in the assessment. It amounted to about 0.09mm/day or 30mm/year over the whole area, which is quite plausible. The other factors are also plausible, although irrigation percolation at 2% may be underestimated and winter rainfall excess at 16% may be overestimated.

[9] The water use data for instance are estimated to be 50% of the total for Berriquin, and this proportion may vary from year to year. The 1990-94 data were estimated. Groundwater pumping volume records are generally held to be not accurate.

*Table 4.2.1. Volumes of recharge and discharge corresponding with groundwater behaviour in Berriquin Central*

| BQ Central | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 18.2 | 32106 | |
| Lateral GW Flow | | 5373 | To North |
| W Rainfall % | -0.164 | -24991 | |
| S Rainfall % | -0.052 | -11766 | |
| Rice Recharge ML/ha | | | Not assessed |
| Water Use Excess (%) | -0.02 | -6188 | |
| Channel Seepage ML | | -30000 | Assumed |
| GW Pumping ML | | 17689 | |
| Tree Uptake ML | | | Not assessed |
| GW Evaporation mm/day | 0.00 | 19026 | |
| Change Storage/yr | | 13 | Average 14 yrs |
| **Balance** | | **1261** | Unaccounted for |

## 4.3. Berriquin South.

The boundaries of this area as defined are shown at Figure 2.1.1. Figure 4.3.1 shows the deep and shallow groundwater behaviour. The deep groundwater has dropped a lot since 1995, whilst the shallow groundwater increased from 4.5 to about 3.2 metres by 1997, when it peaked. Since 1997/8 the groundwater levels have dropped again and were at about 5 metres in 2004. Deep groundwater pumping is a feature in this area, which has been delineated to represent mostly the areas used for rice growing ([10]).

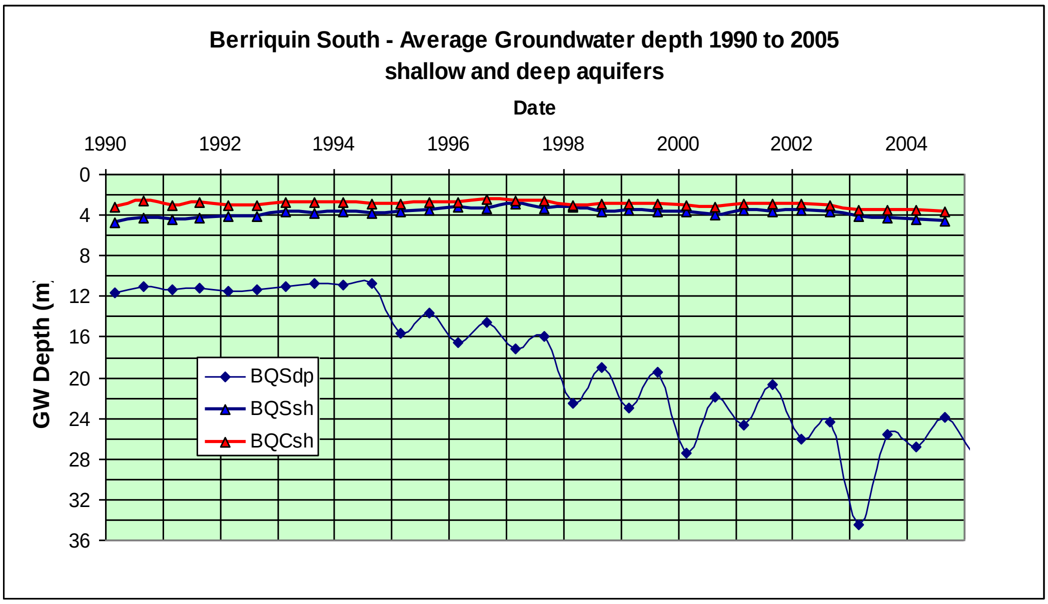



*Figure 4.3.1. Berriquin South. Shallow and deep groundwater behaviour shown together with shallow groundwater depth for the BQ Central area.*

[10] Irrigation accessions for BQS have been estimated via the rice area factor. Water use other than for rice has not been considered, but this is possible if data can be generated. It was also assumed that the rice area of BQ south is 15% of the total rice area for Berriquin as a whole.

Figure 4.3.1 also shows the shallow groundwater depth for BerriquinCentral. It is shown that lateral leakage from the central area to the south is subject to a small gradient only (abt 1m). It is likely that from the central area, in the shallow aquifer systems, more lateral flow is to the north, than the flow to the south, subject to transmissivity being about the same. Based on these observations, it is likely that shallow lateral groundwater flow from BQ central to the south is small.

The correlation matrices of the data used to predicte August and February/March groundwater levels are shown at Appendix 2. Generally, for March, summer rainfall appears to have a significant effect on the amount of groundwater rise (R=0.6). Total water use and rice areas however show a stronger correlation (R=0.70-0.77). For August predictions, there is a correlation of groundwater rise (Feb to Aug) with several of the possible rainfall factors showing R about 0.4. Figure 4.3.2 shows the observed data and the values predicted from optimisation. The integrated method gave similar results (Appendix 3).

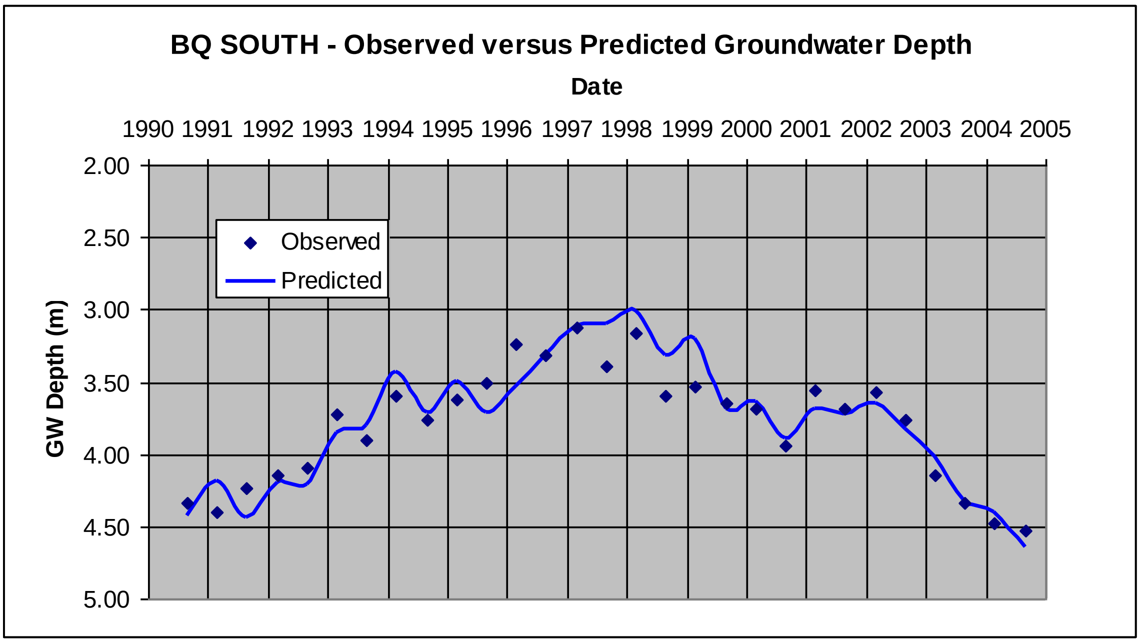



*Figure 4.3.2 BQ South. Observed average groundwater depth and predicted depths from optimisation using groundwater balance factors.*

The standard error of the prediction is 0.15m, which is acceptable considering the quality of some of the input data. The upward and downward trend has been very well reflected. Table 4.3.1 shows the optimal rates found for the factors used. Section 5 discusses the prediction of rises and falls as shown at Figure 4.3.2.

It is shown that deep leakage is a significant feature in Berriquin South, as expected. The average groundwater change is based on the beginning and end points of the whole period, therefore very small. Irrigation and rainfall accessions appear to be small, but these may be under-estimated, as suggested by the upward trend in Figure 4.3.1 during the early 1990s.

*Table 4.3.1. Groundwater recharge and discharge volumes corresponding with optimisation of the prediction curve of Figure 4.3.2. (stepswise method).*

| BQ South | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 12.5 | 7546 | |
| Lateral GW Flow | | -176 | From BQ Central |
| W Rainfall % | -0.039 | -1567 | |
| S Rainfall % | -0.029 | -2343 | |
| Rice Recharge ML/ha | -0.72 | -2720 | |
| Water Use Excess (%) | | | not assessed |
| Channel Seepage | | -5000 | assumed |
| Tree Uptake | | 5000 | not assessed |
| Change Storage/yr | | -349 | Average 14 yrs |
| **Balance** | | **391** | Not explained |

## 4.4. Denimein

Figure 4.4.1 shows the groundwater trends for the Denimein area. Until 1995 the levels in deep and shallow aquifers was about the same, but this changed drastically subsequently. Is would be due to local deep groundwater pumping and disspation to groundwater pumps further to the south and south east. The shallow groundwater does not seem influenced by the deep groundwater trend. The small drop after 2001 would have been mostly due to reduced irrigation applications.

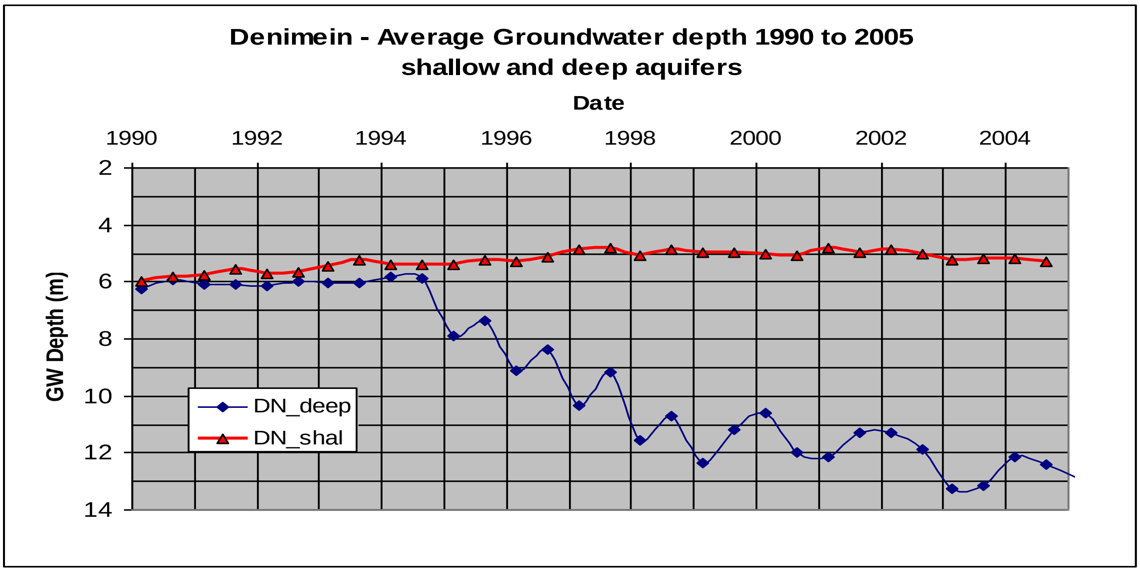



*Figure 3.4. Hydrographs of shallow and deep average groundwater depth in the Denimein District area.*

The Denimein area is used mostly for rice growing but there is a variation due to the presence of some prior stream formations and lighter textured soils. Channel seepage is reported to be high in some locations.

The correlation matrix shown at Appendix 2 confirms that there is a negative correllation between the (increasing) gradient to deep aquifers and shallow groundwater depth. In terms of groundwater rise each half year, the gradient is also negative (R=-0.6). Winter rainfall has a positive (but small) correlation with groundwater rise. It means that in most years groundwater drops from February to August despite rainfall that period ([11]). Of the factors contributing to the Feb/March groundwater levels, rainfall shows a higher correlation than the irrigation factors water use or rice area, but neither are very significant.

Figure 4.4.2 shows the observed average shallow aquifer groundwater depths, and the predictions lines from (stepswise) optimisation of the main groundwater balance factors. The standard error of the deviations was found to be 0.13m, which is good. The average annual values found for the groundwater balance factors are shown at Table 4.4.1. The integrated method of optimisation reflects the general trend quite well too, but seems to do poorly in terms of predicting six-monthly rises and falls (Appendix 3).

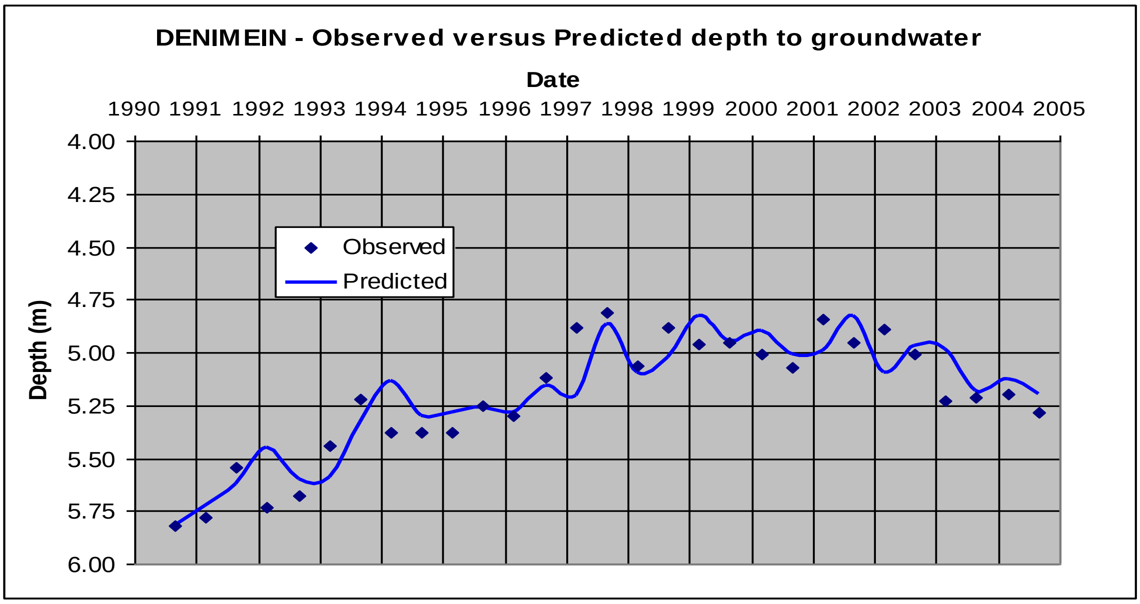



*Figure 4.4.1. Observed average groundwater depths and predicted values from optimisation of groundwater balance factors.*

*Table 4.4.1. Groundwater recharge and discharge volumes corresponding with optimisation of the prediction curve of Figure 4.4.2.(stepswise optimisation).*

| **Denimein** | **Rate** | **Annual ML** | **Comment** |
|---|---|---|---|
| Deep Leakage (mm/10m) | 18.2 | 4454 | |
| Lateral GW Flow | | | not assessed |
| W Rainfall % | -0.061 | -3692 | |
| S Rainfall % | -0.001 | -85 | |
| Rice Recharge ML/ha | -0.30 | -1251 | |
| Water Use Excess (%) | | | not assessed |
| Channel Seepage | | -3000 | Assumed |
| Groundwater Pumping | | 1239 | |
| Tree Uptake | | | not assessed |
| Change Storage/yr | | 1740 | average 14 yrs |
| **Balance** | | **-594** | Unaccounted for |

[11] This is not impossible if there is some deep leakage that period, or there is groundwater evaporation. Winter rainfall accessions in this case must be less than the discharge factors.

The volumes involved for this over 60,000ha area appear to be small. Deep leakage is of the same order as for the Berriquin District, but possibly higher than the actual value (not known). Rice percolation appears to be small as this factor also represents any recharge from other irrigation. Perhaps a factor should have been included for tree evaporation, which would out of necessity increase the recharge factors to re-establish the balance.

The unaccounted for volume of the groundwater balance is due to the methodology of stepswise estimating the groundwater depth for a date, which starts with the observed value of the previous date. The integrated method of predicting the groundwater shows unaccounted for volumes close to zero (Appendix 3).

## 4.5. Wakool Pumped Area

In the Wakool District (Figure 3.5) groundwater depths are shallower. In the WTSSDS (pumped) area it has been dropping since 1997, but in the rest of Wakool it has remained more the same. The deep aquifer pressure has dropped from 1995 to about 2003 but now seems to have stabilised ([12]). The deep pressure levels have been above the shallow groundwater levels in Wakool “Other” only during the early 1990’s.

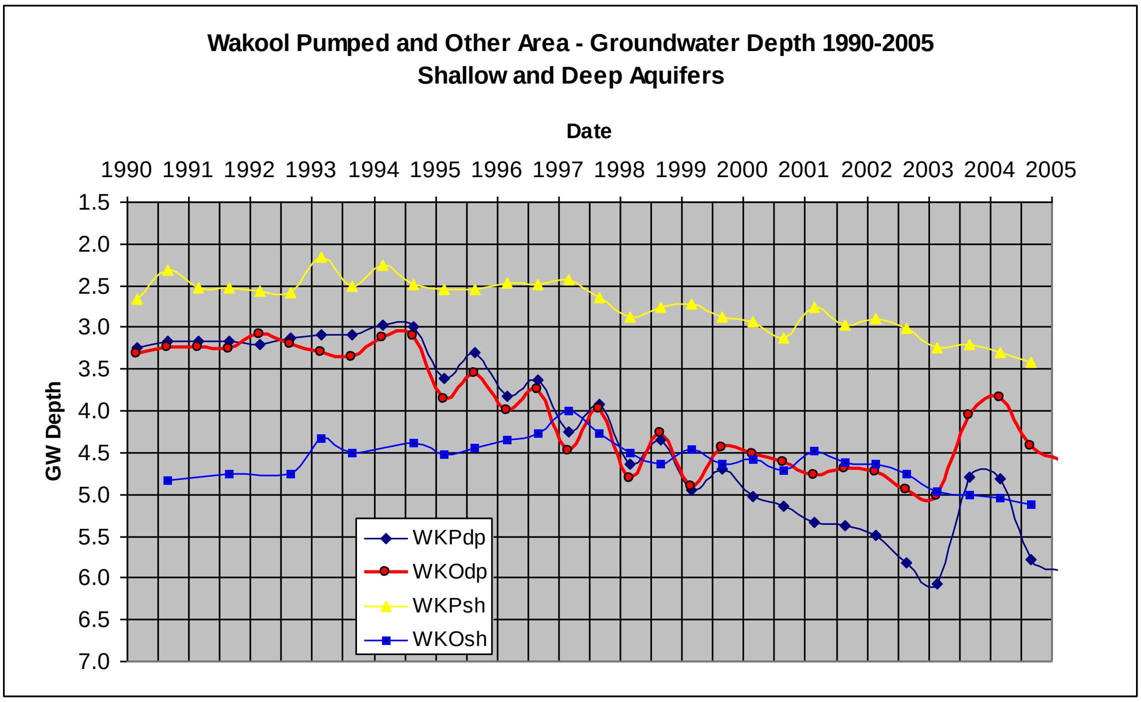



*Figure 4.5.1 Hydrographs of shallow and deep average groundwater depth in the Wakool ( pumped (WKP) and”other”(WKO)) sub-districts.*

The August shallow groundwater levels in the Wakool “pumped” area are influenced by autumn and winter rainfall factors (Appendix 2, R=about 0.6). The spring and summer rainfall has an effect on the Feb/March groundwater depths, with water use and rice areas apparently having less effect on the variation in the rise from August to

[12] The upswing of 2004 has not been explained.

March. The rate of pumping shows an effect on the depth to groundwater in both August and March, but very little on the rate of rise up to either date.

Figure 4.5.2 shows the observed groundwater depths, and the values derived from stepswise optimisation of the main contributing factors. In this area groundwater evaporation was included in the contributing factors list. The standard deviation between predicted and observed values was found to be 0.14m. The integrated method of optimisation shows similar results (Appendix 3).

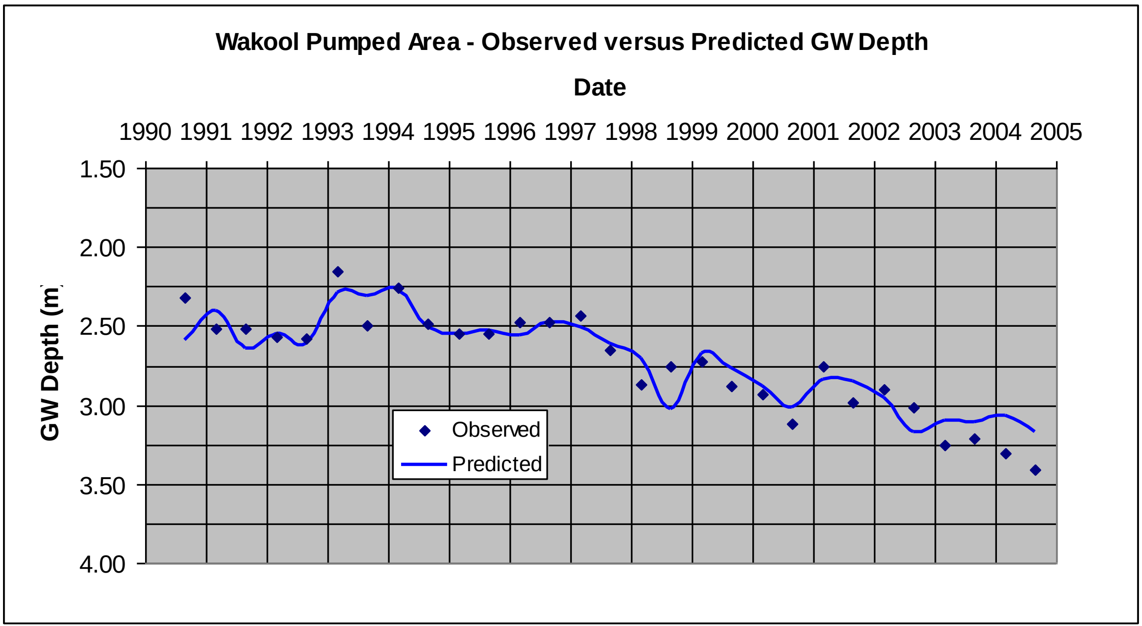



*Figure 4.5.2. Wakool pumped area. Observed average groundwater depths and predicted values from optimisation of groundwater balance factors.*

Table 4.5.1. shows the values for the groundwater balance factors used in stepswise optimisation. The (standardised) deep leakage factor appears to be very high, but it is expressed as a rate (m/year) for every 10 metres head difference between deep and shallow aquifers. Since the gradient is only about one metre, the actual volumes assessed are small. Nevertheless, it may be an over-estimation. The water use accessions at 3% may be under-estimated. It was found that channel seepage had to be reduced to about 10000ML/year relative to the estimate in the LWMP groundwater balance, otherwise it was not very well possible to get a meaningful balance using this method ([13]). Groundwater evaporation occurred at a rate of about 0.11mm/day where the groundwater is at 2 metres depth.

[13] The reduction is plausible, since for Wakool there has been an opinion that seepage losses are a simple difference between diversions and deliveries, with some small correction. This clearly is incorrect since the error in Dethridge wheel reading was not incorporated.

*Table 4.5.1. Groundwater recharge and discharge volumes corresponding with optimisation of the prediction curve of Figure 4.5.2.*

| **Wakool WTSSDS area** | **Rate** | **Annual ML** | **Comment** |
|---|---|---|---|
| Deep Leakage (mm/10m) | 40.0 | 3810 | |
| Lateral GW Flow ML | | | not assessed |
| W Rainfall (%/100) | -0.115 | -9864 | |
| S Rainfall (%/100) | -0.061 | -7680 | |
| Water Use Excess (%/100) | -0.02 | -2373 | |
| Rice Percolation (ML/ha) | | | not assessed |
| Channel Seepage (ML) | | -10000 | assumed |
| Groundwater Pumping | | 11024 | |
| Groundwater evaporation ML | | 16392 | |
| Tree Uptake (ML) | | | not assessed |
| Change Storage/yr | | -1107 | average 14 yrs |
| **Balance** | | **204** | Unaccounted for |

## 4.6. Wakool "Other"

The graphs of deep and shallow groundwater behaviour are shown at Section 4.5. There was an upward gradient in this area during the early 1990s, but at present the process may be one of (small) downward leakage again. The area is characterised by many streams passing through, many with adjacent native tree vegetation. Groundwater is believed to move laterally through shallow aquifers to these areas in non-flood periods, which represents a method of groundwater discharge by tree uptake and evaporation. On the other hand, this process may be limited, since groundwater in many locations is saline.

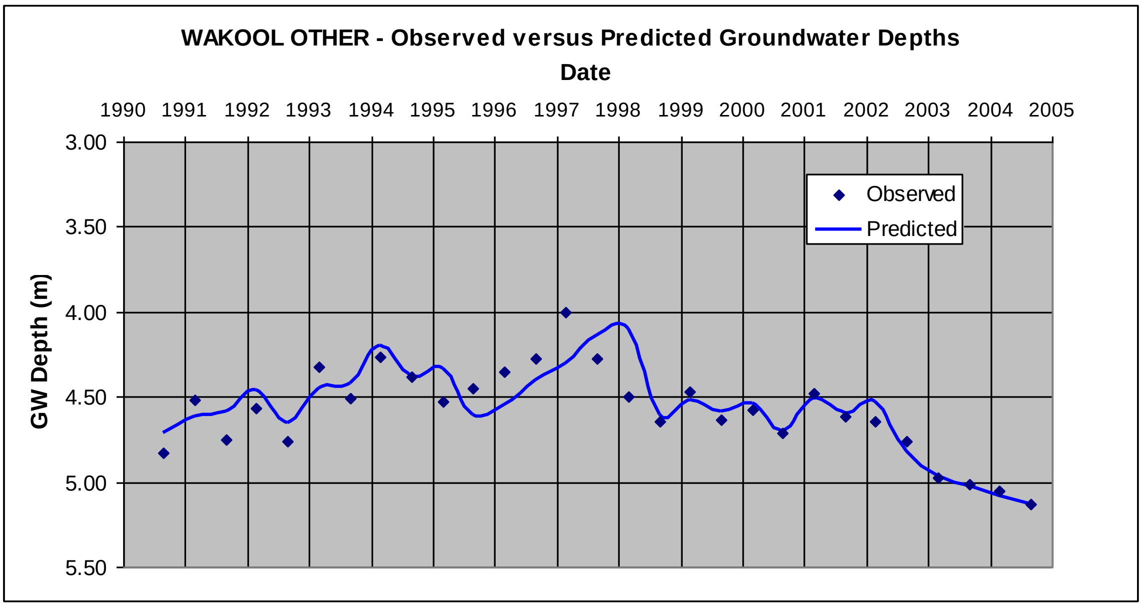



*Figure 4.6.1. Wakool "Other" area. Observed average groundwater depths and predicted values from optimisation of groundwater balance factors.*

The main irrigation source which is believed to contribute to groundwater accessions is rice growing. The correlation matrix of Appendix 2 indicates the correlation coefficient of groundwater rise over the six months to March is R=-0.6.

Spring/summer rainfall shows a weaker correlation. As far as August groundwater levels are concerned, none of the possible rainfall statistics prior to August showed a significant correlation. Shahbaz (2003) reported that flooding may also be a factor, not examined in this study.

Figure 4.6.1 shows the observed groundwater depths and the predicted values from the stepswise optimisation procedure.

The standard error between observed and predicted was 0.13m, which is quite good. The best result was actually obtained by increasing the lateral flow to trees (or creeks lines) to even more than the 25,000 ML shown at Table 4.6.1. It is interesting to note that this type of dissipation may the only process in the Wakool "Other" area to compensate for the range of recharge factors which exist (Table 4.6.1). Groundwater evaporation has been ignored since watertable levels are not extremely high (Figure 4.6.1). Deep leakage in this area has been negative on average over the period considered.

Table 4.6.1. *Groundwater recharge and discharge volumes corresponding with optimisation of the prediction curve of Figure 4.6.2.*

| Wakool "Other" | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 20.0 | -1426 | |
| Lateral GW Flow | | 25000 | To treed areas |
| W Rainfall % | -0.045 | -5611 | |
| S Rainfall % | -0.029 | -7178 | |
| Rice Recharge ML/ha | -1.19 | -9587 | |
| Water Use Excess (%) | | 0 | not assessed |
| Channel Seepage | | | not assessed |
| Tree Uptake | | | not assessed |
| Change Storage/yr | | -2144 | Average 14 yrs |
| **Balance** | | **-945** | Unaccounted for |

The integrated method of optimisation gave similar results. The predictability of rises and falls every six months is discussed at Section 5.

## 4.7. Deniboota.

Finally, the Deniboota District groundwater trends are shown at Figure 4.7.1. The deeper groundwater depths are increasing due to pumping in the east Cadell area and beyond. The shallow groundwater levels have been increasing until about 2002.

Appendix 2 shows that the groundwater rise leading up to August is only weakly correlated to groundwater depth in August. For March groundwater conditions, the spring/summer rainfall seems to have more effect on groundwater rise (R=0.7) than either rice areas of total water use (R=0.35).

The possibility of lateral groundwater flow in shallow aquifers to Green Gulley or treed areas is not a well known factor, but has been allowed for in the optimisation, of which the stepswise method result is shown at Figure 4.7.2.

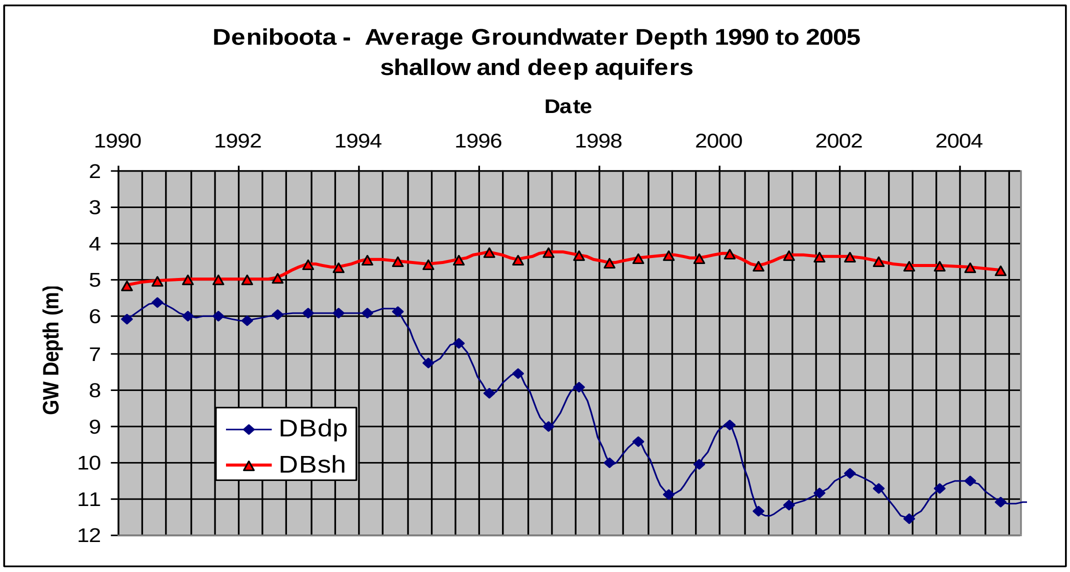



*Figure4.7.1. Hydrographs of shallow and deep average groundwater depth in the Deniboota District.*

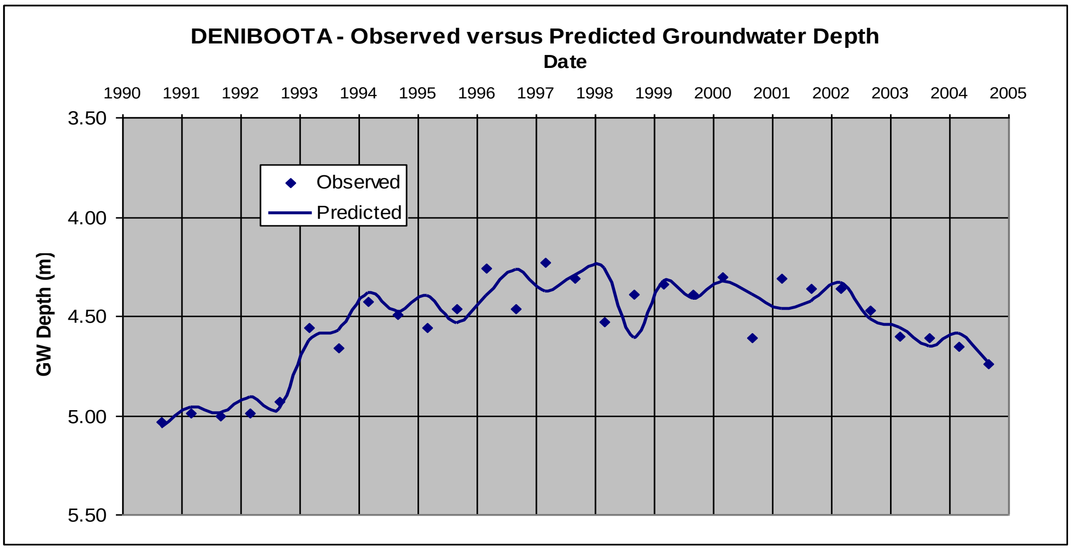



*Figure 4.7.2. Deniboota area. Observed average groundwater depths and predicted values from optimisation of groundwater balance factors.*

Table 4.7.1. shows the corresponding groundwater balance values from optimisation. The channel seepage and tree uptake are inputs based on the LWMP (but modified). The rice recharge in this result has also been increased to 0.3ML/ha to obtain a more plausible balance. Deep leakage is possitive contrary to that reported in the LWMP based on the early 1990 information. Figure 4.7.1 shows how deep leakage must have become positive. The standard deviation of the predicted and observed values was 0.11m, which is good.

Table 4.7.1. *Groundwater recharge and discharge volumes corresponding with optimisation of the prediction curve of Figure 4.7.2.*

| **Deniboota** | **Rate** | **Annual ML** | **Comment** |
|---|---|---|---|
| Deep Leakage (mm/10m) | 18.1 | 9227 | |
| Lateral GW Flow | | 4458 | Green Gulley, trees |
| W Rainfall % | -0.037 | -6434 | |
| S Rainfall % | -0.042 | -10729 | |
| Rice Recharge ML/ha | -0.30 | -2399 | |
| Water Use Excess (%) | | 0 | not assessed |
| Channel Seepage | | -10000 | not assessed |
| Tree Uptake | | 15000 | not assessed |
| Change Storage/yr | | 1907 | Average 14 yrs |
| **Balance** | | **1029** | Unaccounted for |

The results of the integrated method of optimisation may be found at Appendix 3 whilst the aspect of accuracy of predicting observed rises and falls is discussed at section 5.

# 5. Discussion

## 5.1 General

There is little doubt the type of results are of interest. Until now groundwater behaviour had not been explained in terms of the various factors in the groundwater balance. The results presented so far clearly indicate that this may be the case. The questions to be addressed therefore are whether the main trends and rises and falls have been predicted with sufficient accuracy, and whether anything can be learned from the results in terms of management.

When addressing these questions it needs to be recognised from the outset that there is scope for improvement:

1. Some of the water use data and rice area data were estimates only, and can be improved. This also applies to groundwater pumping volumes.
2. There has been no split up of water use data between the September to February period and the autumn period.
3. By using the rice water use data the volumes of irrigation for other crops may be able to be split out.
4. The boundaries of some component areas may be defined better, eg Berriquin Central.
5. There may be other independent estimates of the volumes of several factors in the groundwater, for instance channel seepage, lateral flow, deep leakage, certain types of accessions. The volumes used in this report were interpreted from LWMP documents, or “optimised” towards an optimal result. A comparison with other data which may be available has not yet been made.
6. Rainfall data were from Deniliquin airport only. Other stations could be included.
7. Several assumptions in this report may be challenged, for instance the proportion of rice in North Berriquin relative to the whole of Berriquin, the volume of water

use in WKP relative to Wakool as a whole, etc. The input data for these factors may be changed very quickly to produce (hopefully) better results.

Recognising the above, it is probably premature to draw too many conclusions and implications for management at this stage. The other factor is that the results are based on a statistical approach, with the aim of minimising the sum of squares of differences between observed and predicted values. Such an approach may be flawed, especially where some of the factors involved are not totally independent. Nevertheless, it is believed that the results obtained by the methods used are within the bounds of plausibility. If good information exists about some factors, the method presented may have potential when reviewing other, less well known groundwater balance factors. The method of this report definitely provides information regarding trends in these factors.

## 5.2. Prediction of Main Trends

The prediction of the main groundwater trends using the stepswise method of optimisation is believed to be flawed. After all, every six months the observed value for groundwater depth is the starting point for calculating the groundwater depth six months later, hence the main trend is forced. However, the integrated method of optimisation is not subject to this inherent flaw, since only the average groundwater depth of the first observation date (1990) is used, and the values for all (28) other dates are estimated / predicted from the optimisation coefficients.

Appendix 3 graphs show that the integrated method of optimisation capture the overall trends in groundwater behaviour very well, perhaps surprisingly so. Saying this, it is recognised there are some departures from the main trend, which is understandable considering the data and assumptions made ([14]). The following of the prediction line along the upward and downward trend over the 15 year period in some component areas is especially interesting.

It is believed this result was possible as the trend in certain contributing factors, such as increasing deep leakage and reducing irrigation contributions, allowed these contrary trends to be incorporated.

## 5.3. Prediction of Rises and Falls

The hydrograps of Section 4 and Appendix 3 do not show clearly to what extent the changes in groundwater depth from one date to the next have been captured by the predicted values. To examine this more closely, the observed rises and falls, and the predicted values for either method were put side by side and the correlations between the two calculated. Appendix 3 shows the results for all component areas. Figure 5.3.1 for Berriquin South and Figure 5.3.2 for Wakool Pumped are examples by which the issue may be discussed.

[14] For instance, with Berriquin North it was assumed that the proportion of rice is 50% of all Berriquin. This proportion may have varied between years. Rainfall variation spatially may have departed from that assumed (Deniliquin airport). Etc, etc…

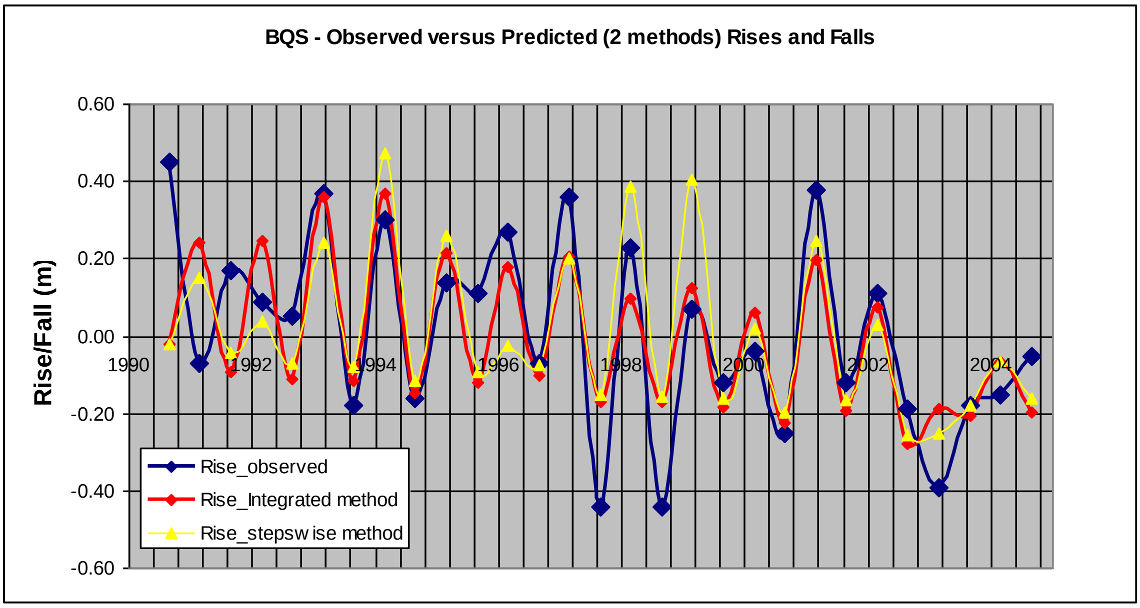



*Figure 5.3.1. Berriquin South. Observed Rises and Falls of groundwater levels versus predicted values, two methods.*

Both figures show that the general pattern of rises and falls is being simulated by both methods of prediction, the stepswise method and the integrated method. The amplitude of some of the rises and falls may have been under-estimated, however. This especially applied for Denimein (Appendix 3).

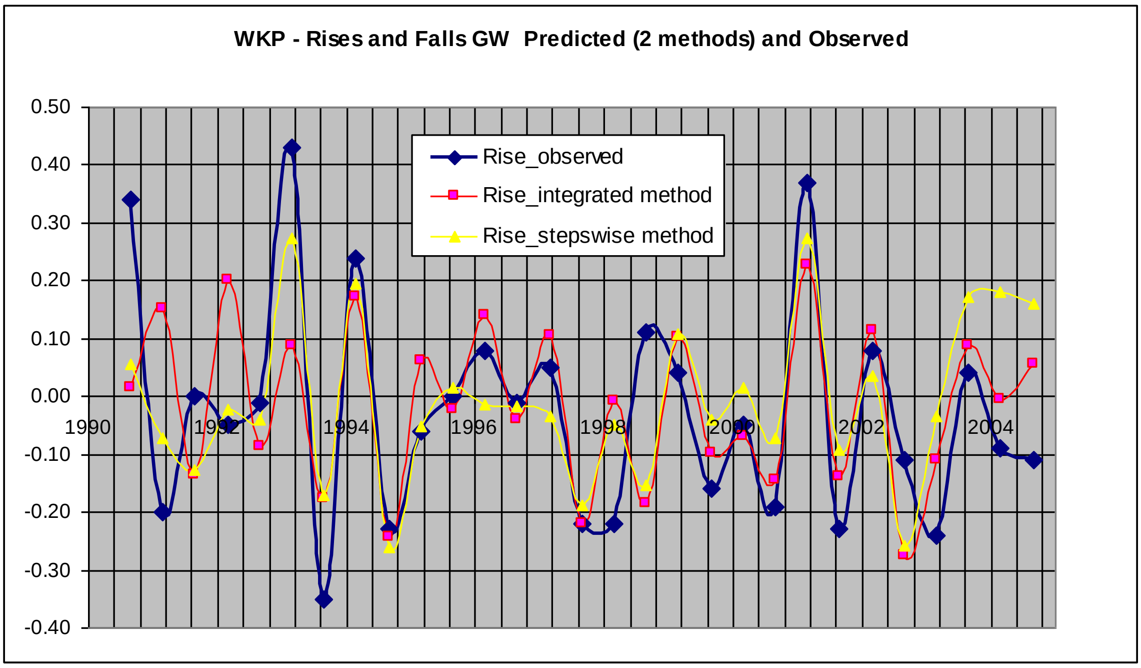



*Figure 5.3.2. Wakool – Pumped area. Observed rises and falls in groundwater level versus predicted values, two methods.*

The general correlation between observed and predicted was calculated for all component areas, with results in Table 5.3.1., which also summarises the standard deviations of differences between observed and predicted groundwater depths (based on 6 months intervals, 15 years).

*Table 5.3.1. Correlation coefficients of observed average groundwater rises and falls versus predicted values, and standard deviations of differences between average observed and predicted groundwater depths, two methods.*

| Area | R Integrated method | R Stepswise method | St Dev. Int. method | St Dev.Steps-wise method |
|---|---|---|---|---|
| BQN | 0.50 | 0.60 | 0.156 | 0.127 |
| BQC | 0.71 | 0.74 | 0.126 | 0.155 |
| BQS | 0.72 | 0.69 | 0.119 | 0.157 |
| DN | 0.46 | 0.485 | 0.110 | 0.129 |
| WKP | 0.57 | 0.71 | 0.136 | 0.143 |
| WKO | 0.56 | 0.67 | 0.102 | 0.135 |
| DB | 0.70 | 0.70 | 0.075 | 0.111 |

From these results it is concluded that the correlations are significant at the 1% level, but the results are not fantastic in terms of their predictive values. Figures 5.3.1 and 5.3.2 seem to confirm such a conclusion. The correlations for the stepswise method in most component areas apears to be better, suggesting this method is better at predicting the direction and magnitude of the rise or fall.

Regarding the standard deviations of the predicted average groundwater depths, they vary from 0.075m to 0.16m, which is considered to be a good result.

## 5.4. Estimation of Groundwater Balance Factors

The main factors found using the stepswise method of optimisation are summarised in table 5.4.1. The deep leakage factors ([15]) are all in the same order, and appear somewhat high. It is probable that groundwater modeling results have shown generally lower values. The coefficients on winter and summer rainfall appear plausible, with some looking a little high, and others perhaps low. The average rice percolation factors are believed to be under-estimates, since this factor also includes a factor for the recharge from crops other than rice. The same comment applies to the water use percolation factor in BQ Central and Wakool ‘pumped” area. The groundwater evaporation factor is entirely plausible. On the other hand, in some component areas the effect of tree uptake of groundwater may have been overlooked or under-estimated.

*Table 5.1. Summary of coefficients to be applied to key groundwater balance factors to derive best estimates of groundwater behaviour in each of the component areas.*

| Area | Deep Leakage | Aut/Winter Rainfall | Spr/Summer Rainfall | Rice Perc ML/ha | Water Use %/100 | GW Evap |
|---|---|---|---|---|---|---|
| **BQN** | 17.8 | -0.074 | -0.015 | -0.61 | | 0.09 |
| **BQC** | 18.2 | -0.16 | -0.052 | | -0.02 | |
| **BQS** | 12.5 | -0.039 | -0.029 | -0.072 | | |
| **DN** | 18.2 | -0.061 | -0.001 | -0.3 | | |
| **WKP** | 40 | -0.115 | -0.061 | | -0.022 | 0.11 |
| **WKO** | 20 | -0.045 | -0.029 | -1.19 | | |
| **DB** | 18.1 | -0.037 | -0.042 | -0.3 | | |

[15] Expressed as mm/year leakage for every 10 metres gradient between shallow and deep aquifers

The alternative coefficients found using the “integrated” optimisation procedure may be found at Appendix 3. The rates are different to a degree, but of the same order. It is also noted that the standard deviation of the results were about the same, sometimes better. Generally, however, the integrated method may have led to an under-estimation of the seasonal effects.

## 5.5 Management Implications

Since the coefficients applying to rice areas and/or water use to derive irrigation accessions were all found to be low, the present results cannot lead to the conclusion that irrigation management is the major factor in groundwater behaviour and change. Rather, rainfall factors and hydrological factors appear to be of more significance. Of course, irrigation is superimposed on a natural process, and it appears from this study that small changes in some of the key factors can lead to a gradual change for the better or for the worse. In that regard, irrigation has led to a substantial change increasing groundwater levels. This process has temporarily halted, but may be on-going in the long term.. However, deep leakage seems to have become more significant as deep gradients increased, and this is helping with sustainability. Where the equilibrium will end has not been finally determined. It would be premature to draw conclusions regarding this aspect on basis of this preliminary report.

Improvements in irrigation practices, or reductions in channel seepage, or other measures implemented from 1995 to 2004 for the LWMP, may have led to reduced recharge. These possible improvements have not been captured by this study so far. Assumptions in that regard however could be made and entered in the optimisation, to see whether this would result in an improvement in the standard deviation between observed and predicted average groundwater depths.

## 5.6. Further Work

The results of this report are believed to be interesting, and they brreak new ground in that, for the first time in the Murray Irrigation Districts, groundwater balance factors are linked with groundwater change in a quantitative way. On this basis it is considered useful to address the shortcomings in data outlined at Sections 2 and 5.1, and run the optimisation procedures again. The work should be accompanied by a review of some key groundwater input values, eg channel seepage, tree uptake and lateral groudwater flow. It is quite possible that this additional work will result in small changes only to the coefficients already found. Nevertheless, the confidence in the results would be increased significantly.

Whereas statistical methods are potentially dangerous, when combined with information from other sources the methods outlined may result in increased knowledge regarding the factors being studied. It needs to be kept in mind that almost any other methods to estimate factors in the groundwater balance is subject to similar uncertainty, and often possibly worse.

# 6. Conclusions

The change in average groundwater depth in a defined area is caused by the sum of recharge and discharge of contributing factors. As such, average groundwater depth is a useful performance monitoring indicator which Murray Irrigation should consider.

The average groundwater depth of shallow and deep aquifers in a district area may be determined from contoured information, and trends graphically examined. This also provides changes in the gradients for leakage from one aquifer system to another.

The trend line in shallow groundwater behaviour and the seasonal variation may be examined by optimisation techniques to obtain coefficients on all known variable and constant groundwater recharge and discharge factors. The outcome is a groundwater balance for each observation period (6 months) and the whole period (1990-2004).

The standard deviation between observed average groundwater depths and predicted values from optimisation was in the order of 0.08 to 0.16m.

Two methods of predictting by optimisation exist. Firstly, the stepswise method, whereby the groundwater depth for each date is based on the groundwater depth for the previous date and the various recharge and discharge factor. Secondly, the integrated method, whereby the groundwater depth for all dates may be estimated by using the first observation date only and predicting the value of each date from the predicted value for the previous date.

Both the stepswise and integrated methods of estimating average groundwater depth from groundwater balance factors may have merit, each serving a purpose. No conclusion has been drawn at this stage as to the preferred method. The stepswise method seems to predict the seasonality of rise and falls slightly better (Table 5.3.1). The integrated method has fewer flaws when estimating the main trend.

The rises and falls in groundwater levels every six months as predicted by the stepswise method of optimisation resulted in a correlation coefficient of about 0.7 for most component areas (excepting Denimein).

Autumn and winter rainfall has a small correlation with groundwater rise in many of the component study areas. Monthly spring/summer rainfall appears to be better correlated with groundwater depth in Feb/March than water use or the area of rice. The study seems to result in the observation that deep leakage is a significant factor in the groundwater balance, with leakage rates perhaps in the order of 15-20mm/year where the gradient between shallow and deep aquifers is 10 metres. Deep leakage has increased significantly in most component areas, in proportion to the rate deep groundwater pumping is lowering the deep pressure levels.

The irrigation factors (rice area, water use) appear to represent a small component in the groundwater balance, less than the combined rainfall effects during spring/summer and autumn/winter. The irrigation contribution may have been underestimated by the methods used to date. A possible explanation is that some groundwater balance factors have not been represented properly in this preliminary study.

In some districts increasing storage of groundwater (groundwater rise) has been a major factor in the groundwater balance. This trend has halted since 2002, but could start again when irrigation deliveries come back to normal.

Groundwater evaporation seems to have a significant effect in the Berriquin Central area and the Wakool – pumped area. The rate of groundwater evaporation was estimated to be in the order of 0.1mm/day where groundwater is at 2 metres depth.

Lateral groundwater flow is a factor in the Berriquin District, from the central area to the North and South, but mostly to the North.

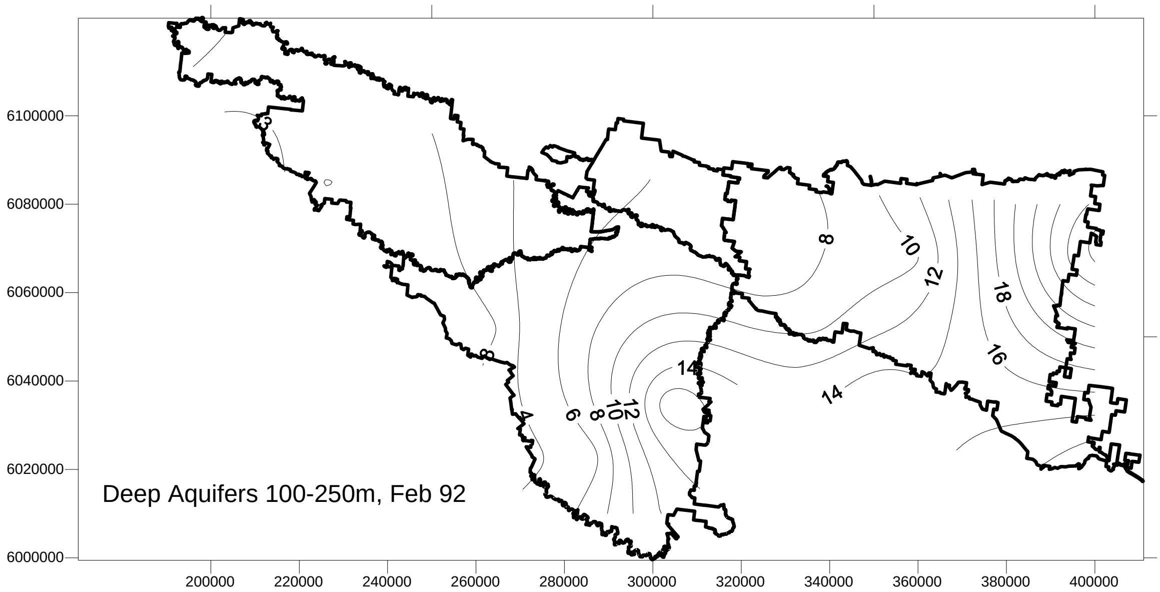
The effect of channel seepage is important, and perhaps needs to be considered more closely in further study. No information re possible improvements in this factor over the 1990-2004 period have been incorporated so far.

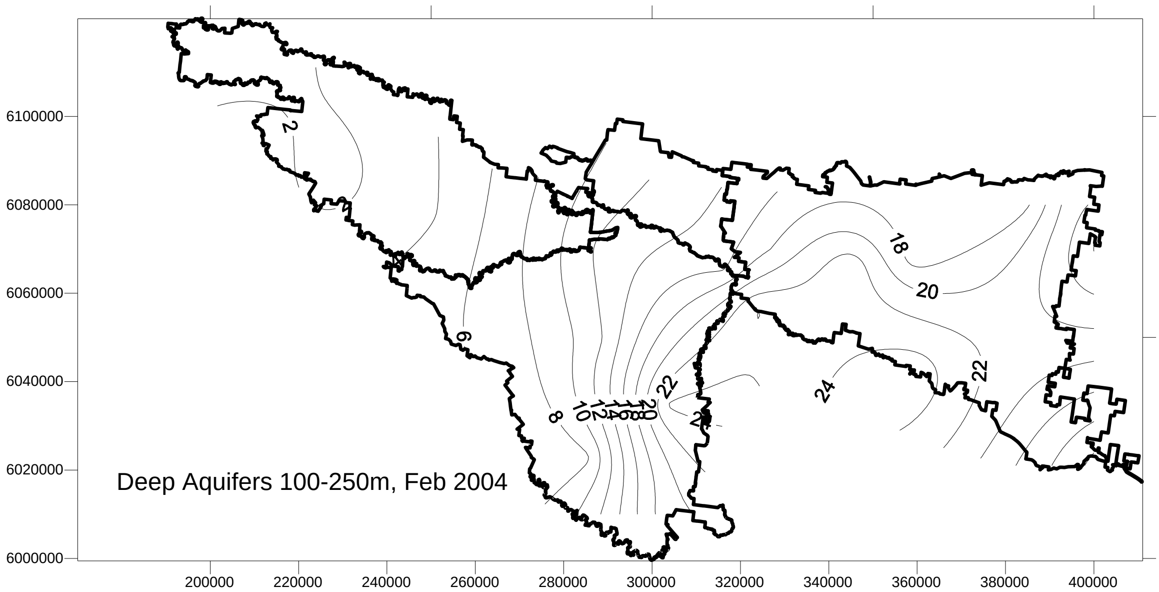
The effect of trees on lowering groundwater seems to be confirmed for the Wakool "Other" district and the Deniboota District. It should be more closely considered as an input factor for the other districts since if ignored, some of the (irrigation + rainfall) recharge factors may be significantly under-estimated.

## 7. References

| | | |
|---|---|---|
| MIL | 2001 | Berriquin LWMP Updated version. |
| MIL | 2001 | Denimein LWMP Updated version. |
| MIL | 2001 | Cadell LWMP Updated version. |
| MIL | 2001 | Wakool LWMP Updated version. |
| Wang et al | 2003 | Quantifying Impact of Rainfall on Shallow Groundwater Tble in the Wakool Area, NSW CSIRO Griffith |
| Khan, S et al | 2000 | Assessing the Impact of Rainfall Variability on Watertables in Irrigation Areas. CSIRO, Griffith |
| Wang etal | 2003 | Impact of Flooding on Shallow Groundwater Levels in the Wakool Irrigation District |

# APPENDIX 1.
# Deep Aquifer Groundwater maps 1993 and 2004.




Note: The above deep groundwater maps are based on 28 piezometer sites with data. Most sites have multiple piezometers to different depth. Another choice of piezometers would have resulted in different looking maps. The purpose of this was to characterise the typical average level of deep groundwater in each component area. The above maps show there are no major anomalies in this regard.

# APPENDIX 2.
## DATA and CORRELATION MATRICES.

<u>Note re abbreviations in this Appendix</u>

- BQNsh_feb, WKdp_aug, etc = shallow and deep average GW depth in february or August
- Rise = GW rise during suix months preceeding the date.
- Deep Grad = gradient (m) from shallow to deep aquifers
- Rain M-A = Rainfall March to August, HRM M-A = rainfall in highest rainfall month March to August, Winter = winter rainfall, WinRech = derivative of rainfall excluding the lowest farction (eg first 50mm is ignored). Rain S-F = Rainfall Sept to Feb.,
- WU is total water use (deliveries) to the irrigation district. In the model this was reduced to the proportion appropriate for the sub-district.
- Coloured data = estimated. Some 1990 to 1994 WU data and rise area data were also estimated.
- Yellow colour in correlation matrices = to highlight the correlation GW rise and other factors
- Groundwater pumping. These data are not shown

# BERRIQUIN NORTH

**AUGUST GROUNDWATER LEVEL PREDICTION**

| | | | | | | | | 50 |
|---|---|---|---|---|---|---|---|---|
| BQNsh_aug | Date | BQNsh_feb | Rise | DeepGrad | Rain_M-A | HRM_AW | Winter | WinRech |
| 12.32 | 1990.65 | 12.42 | 0.10 | 4.75 | 257 | 87 | 134 | 84 |
| 11.98 | 1991.65 | 12.14 | 0.16 | 4.72 | 146 | 62 | 119 | 69 |
| 11.59 | 1992.65 | 11.75 | 0.16 | 4.91 | 184 | 60 | 96 | 46 |
| 10.97 | 1993.65 | 11.23 | 0.26 | 5.31 | 172 | 62 | 85 | 35 |
| 10.71 | 1994.65 | 10.8 | 0.09 | 5.35 | 140 | 66 | 59 | 9 |
| 10.31 | 1995.65 | 10.55 | 0.24 | 6.68 | 227 | 78 | 116 | 66 |
| 9.80 | 1996.65 | 10.2 | 0.40 | 7.79 | 206 | 55 | 151 | 101 |
| 9.39 | 1997.65 | 9.5 | 0.11 | 8.22 | 158 | 49 | 71 | 21 |
| 9.58 | 1998.65 | 9.5 | -0.08 | 9.36 | 183 | 66 | 108 | 58 |
| 9.60 | 1999.65 | 9.77 | 0.17 | 9.49 | 265 | 107 | 98 | 48 |
| 9.36 | 2000.65 | 9.3 | -0.05 | 11.11 | 158 | 39 | 80 | 30 |
| 8.92 | 2001.65 | 8.97 | 0.05 | 10.12 | 137 | 37 | 94 | 44 |
| 8.75 | 2002.65 | 8.73 | -0.02 | 12.07 | 72 | 25 | 23 | 0 |
| 9.03 | 2003.65 | 8.97 | -0.06 | 13.11 | 211 | 70 | 156 | 106 |
| 9.17 | 2004.65 | 9.11 | -0.06 | 10.50 | 138 | 45 | 105 | 55 |
| | | St Dev | 0.169 | | | | | |

| | *BQNsh_aug* | *Date* | *BQNsh_feb* | *Rise* | *DeepGrad* | *Rain_M-A* | *HRM_AW* | *Winter* | *WinRech* |
|---|---|---|---|---|---|---|---|---|---|
| BQNsh_aug | 1.000 | | | | | | | | |
| Date | -0.936 | 1.000 | | | | | | | |
| BQNsh_feb | 0.995 | -0.953 | 1.000 | | | | | | |
| Rise | 0.435 | -0.600 | 0.525 | 1.000 | | | | | |
| DeepGrad | -0.908 | 0.955 | -0.929 | -0.623 | 1.000 | | | | |
| Rain_M-A | 0.334 | -0.327 | 0.358 | 0.376 | -0.248 | 1.000 | | | |
| HRM_AW | 0.445 | -0.413 | 0.457 | 0.323 | -0.375 | 0.881 | 1.000 | | |
| Winter | 0.241 | -0.152 | 0.257 | 0.258 | -0.096 | 0.685 | 0.477 | 1.000 | |
| WinRech | 0.197 | -0.100 | 0.213 | 0.236 | -0.022 | 0.639 | 0.427 | 0.983 | 1.000 |

**FEBRUARY LEVEL PREDICTION**

| BQNsh_feb | Date | Previous BQNsh_aug | DeepGrad | Rise | Rain S-F | HRM SF | Rice area | WU |
|---|---|---|---|---|---|---|---|---|
| 12.14 | 1991.15 | 12.32 | 4.71 | 0.18 | 88 | 25 | 31048 | 710000 |
| 11.75 | 1992.15 | 11.98 | 4.82 | 0.23 | 111 | 24 | 32360 | 740000 |
| 11.23 | 1993.15 | 11.59 | 5.10 | 0.36 | 396 | 107 | 24489 | 560000 |
| 10.80 | 1994.15 | 10.97 | 5.36 | 0.17 | 358 | 81 | 30173 | 690000 |
| 10.55 | 1995.15 | 10.71 | 5.95 | 0.16 | 148 | 58 | 30921 | 732,908 |
| 10.20 | 1996.15 | 10.31 | 7.18 | 0.11 | 135 | 30 | 32154 | 714,219 |
| 9.50 | 1997.15 | 9.80 | 8.38 | 0.30 | 171 | 46 | 36264 | 818,902 |
| 9.50 | 1998.15 | 9.39 | 8.80 | -0.11 | 165 | 31 | 24951 | 600,353 |
| 9.77 | 1999.15 | 9.58 | 9.49 | -0.19 | 202 | 63 | 27595 | 649,883 |
| 9.30 | 2000.15 | 9.60 | 10.60 | 0.30 | 212 | 54 | 20140 | 406,928 |
| 8.97 | 2001.15 | 9.36 | 10.29 | 0.39 | 307 | 92 | 33748 | 698,117 |
| 8.73 | 2002.15 | 8.92 | 11.18 | 0.19 | 168 | 55 | 27276 | 707,617 |
| 8.97 | 2003.15 | 8.75 | 13.30 | -0.22 | 84 | 26 | 568 | 263,256 |
| 9.11 | 2004.15 | 9.03 | 11.00 | -0.08 | 197 | 66 | 500 | 150,000 |

| | *BQNsh_feb* | *Date* | *BQNsh_aug* | *DeepGrad* | *Rise* | *Rain S-F* | *HRM SF* | *Rice* | *WU* |
|---|---|---|---|---|---|---|---|---|---|
| BQNsh_feb | 1.000 | | | | | | | | |
| Date | -0.944 | 1.000 | | | | | | | |
| BQNsh_aug | 0.986 | -0.956 | 1.000 | | | | | | |
| DeepGrad | -0.924 | 0.967 | -0.941 | 1.000 | | | | | |
| Rise | 0.283 | -0.412 | 0.436 | -0.433 | 1.000 | | | | |
| Rain S-F | 0.005 | -0.074 | 0.079 | -0.184 | 0.434 | 1.000 | | | |
| HRM SF | -0.110 | 0.086 | -0.035 | -0.052 | 0.403 | 0.928 | 1.000 | | |
| Rice | 0.413 | -0.635 | 0.490 | -0.621 | 0.599 | 0.144 | 0.057 | 1.000 | |
| WU | 0.402 | -0.620 | 0.460 | -0.592 | 0.487 | 0.026 | -0.044 | 0.969 | 1.000 |

# BERRIQUIN CENTRAL

**AUGUST GROUNDWATER LEVEL PREDICTION**

| BQCsh_aug | Year | Previous BQCsh_feb | Rise | BQCdp_aug | Rain Mar-Aug | HRM AW | Winter | 100 WinRech | MayAug |
|---|---|---|---|---|---|---|---|---|---|
| 2.6 | 1990.65 | 3.24 | 0.64 | 14.11 | 257 | 87 | 134 | 34 | 221.6 |
| 2.81 | 1991.65 | 3.03 | 0.22 | 14.02 | 146 | 62 | 119 | 19 | 124.6 |
| 3.1 | 1992.65 | 3.055 | -0.04 | 13.82 | 184 | 60 | 96 | 0 | 155.6 |
| 2.83 | 1993.65 | 2.76 | -0.07 | 13.54 | 172 | 62 | 85 | 0 | 109.4 |
| 2.84 | 1994.65 | 2.77 | -0.07 | 13.48 | 140 | 66 | 59 | 0 | 68.4 |
| 2.78 | 1995.65 | 2.92 | 0.14 | 15.29 | 227 | 78 | 116 | 16 | 193.8 |
| 2.46 | 1996.65 | 2.7 | 0.24 | 15.68 | 206 | 55 | 151 | 51 | 169.8 |
| 2.68 | 1997.65 | 2.59 | -0.09 | 16.14 | 158 | 49 | 71 | 0 | 106.6 |
| 2.97 | 1998.65 | 3.03 | 0.06 | 18.46 | 183 | 66 | 108 | 8 | 115.2 |
| 2.95 | 1999.65 | 2.91 | -0.04 | 18.6 | 265 | 107 | 98 | 0 | 144 |
| 3.18 | 2000.65 | 3.05 | -0.13 | 20.02 | 158 | 39 | 80 | 0 | 119 |
| 2.94 | 2001.65 | 2.855 | -0.09 | 19.13 | 137 | 37 | 94 | 0 | 101.4 |
| 3.05 | 2002.65 | 2.89 | -0.16 | 22.14 | 72 | 25 | 23 | 0 | 38.8 |
| 3.48 | 2003.65 | 3.48 | 0.00 | 22.06 | 211 | 70 | 156 | 56 | 180.6 |
| 3.6 | 2004.65 | 3.51 | -0.09 | 21.04 | 138 | 45 | 105 | 5 | 133.6 |

| | *BQCsh_aug* | *Year* | *BQCsh_feb* | *Rise* | *BQCdp_aug* | *Rain M-A* | *HRM AW* | *Winter* | *WinRech* | *MayAug* |
|---|---|---|---|---|---|---|---|---|---|---|
| BQCsh_aug | 1.000 | | | | | | | | | |
| Year | 0.686 | 1.000 | | | | | | | | |
| BQCsh_feb | 0.743 | 0.322 | 1.000 | | | | | | | |
| Rise | -0.527 | -0.601 | 0.176 | 1.000 | | | | | | |
| BQCdp_aug | 0.692 | 0.947 | 0.447 | -0.450 | 1.000 | | | | | |
| Rain Mar-aug | -0.266 | -0.327 | 0.151 | 0.583 | -0.282 | 1.000 | | | | |
| HRM AW | -0.240 | -0.413 | 0.111 | 0.494 | -0.377 | 0.881 | 1.000 | | | |
| Winter | -0.053 | -0.152 | 0.433 | 0.627 | -0.112 | 0.685 | 0.477 | 1.000 | | |
| WinRech | -0.114 | -0.045 | 0.345 | 0.606 | 0.040 | 0.451 | 0.258 | 0.819 | 1.000 | |
| MayAug | -0.122 | -0.302 | 0.419 | 0.712 | -0.225 | 0.844 | 0.608 | 0.852 | 0.652 | 1.000 |

**FEBRUARY LEVEL PREDICTION**

| BQCsh_feb | Date | previous BQCsh_aug | Rise | BQCdp_feb | Rain S-F | HighN-F | 0 SumRech | TWU |
|---|---|---|---|---|---|---|---|---|
| 3.03 | 1991.15 | 2.60 | -0.43 | 14.46 | 88 | 25 | 88 | 570000 |
| 3.06 | 1992.15 | 2.81 | -0.25 | 14.60 | 111 | 24 | 111 | 700000 |
| 2.76 | 1993.15 | 3.10 | 0.34 | 13.90 | 396 | 107 | 396 | 747908 |
| 2.77 | 1994.15 | 2.83 | 0.06 | 15.69 | 358 | 81 | 358 | 729219 |
| 2.92 | 1995.15 | 2.84 | -0.08 | 16.35 | 148 | 58 | 148 | 833902 |
| 2.70 | 1996.15 | 2.78 | 0.08 | 17.02 | 135 | 30 | 135 | 616705 |
| 2.59 | 1997.15 | 2.46 | -0.13 | 17.69 | 171 | 46 | 171 | 660518 |
| 3.03 | 1998.15 | 2.68 | -0.35 | 20.75 | 165 | 31 | 165 | 426167 |
| 2.91 | 1999.15 | 2.97 | 0.06 | 21.28 | 202 | 63 | 202 | 709453 |
| 3.05 | 2000.15 | 2.95 | -0.10 | 24.50 | 212 | 54 | 212 | 722354 |
| 2.86 | 2001.15 | 3.18 | 0.33 | 21.45 | 307 | 92 | 307 | 292617 |
| 2.89 | 2002.15 | 2.94 | 0.05 | 24.04 | 168 | 55 | 168 | 175000 |
| 3.48 | 2003.15 | 3.05 | -0.43 | 29.77 | 84 | 26 | 84 | 0 |
| 3.51 | 2004.15 | 3.48 | -0.03 | 23.16 | 197 | 66 | 197 | 0 |
| | | Stdev | 0.227 | | | | | |

| | *BQCsh_feb* | *Date* | *BQCsh_aug* | *Rise* | *BQCdp_feb* | *Rain S-F* | *HighN-F* | *SumRech* | *TWU* |
|---|---|---|---|---|---|---|---|---|---|
| BQCsh_feb | 1.000 | | | | | | | | |
| Date | 0.503 | 1.000 | | | | | | | |
| BQCsh_aug | 0.561 | 0.591 | 1.000 | | | | | | |
| Rise | -0.493 | 0.077 | 0.444 | 1.000 | | | | | |
| BQCdp_feb | 0.605 | 0.915 | 0.439 | -0.193 | 1.000 | | | | |
| Rain S-F | -0.391 | -0.074 | 0.352 | 0.793 | -0.245 | 1.000 | | | |
| HighN-F | -0.286 | 0.086 | 0.524 | 0.860 | -0.135 | 0.928 | 1.000 | | |
| SumRech | -0.391 | -0.074 | 0.352 | 0.793 | -0.245 | 1.000 | 0.928 | 1.000 | |
| TWU | -0.839 | -0.617 | -0.722 | 0.150 | -0.644 | 0.011 | -0.059 | 0.011 | 1.000 |

# BERRIQUIN SOUTH

**AUGUST PREDICTIONS**

60

| BQSsh_aug | Date | Previous BQSsh_feb | Rise | Deep Ave | Rain_M-A | HRM_AW | Winter | 60 WinRech |
|---|---|---|---|---|---|---|---|---|
| 4.33 | 1990.65 | 4.78 | 0.45 | 11.35 | 257 | 87 | 134 | 74 |
| 4.23 | 1991.65 | 4.4 | 0.17 | 11.30 | 146 | 62 | 119 | 59 |
| 4.09 | 1992.65 | 4.14 | 0.05 | 11.39 | 184 | 60 | 96 | 36 |
| 3.9 | 1993.65 | 3.72 | -0.18 | 10.91 | 172 | 62 | 85 | 25 |
| 3.76 | 1994.65 | 3.6 | -0.16 | 10.84 | 140 | 66 | 59 | 0 |
| 3.51 | 1995.65 | 3.62 | 0.11 | 14.61 | 227 | 78 | 116 | 56 |
| 3.31 | 1996.65 | 3.24 | -0.07 | 15.55 | 206 | 55 | 151 | 91 |
| 3.39 | 1997.65 | 2.95 | -0.44 | 16.60 | 158 | 49 | 71 | 11 |
| 3.6 | 1998.65 | 3.16 | -0.44 | 20.74 | 183 | 66 | 108 | 48 |
| 3.65 | 1999.65 | 3.53 | -0.12 | 21.25 | 265 | 107 | 98 | 38 |
| 3.94 | 2000.65 | 3.69 | -0.25 | 24.69 | 158 | 39 | 80 | 20 |
| 3.68 | 2001.65 | 3.56 | -0.12 | 22.64 | 137 | 37 | 94 | 34 |
| 3.76 | 2002.65 | 3.57 | -0.19 | 25.26 | 72 | 25 | 23 | 0 |
| 4.33 | 2003.65 | 4.15 | -0.18 | 29.99 | 211 | 70 | 156 | 96 |
| 4.53 | 2004.65 | 4.48 | -0.05 | 25.29 | 138 | 45 | 105 | 45 |

SD 0.247

| | *BQSsh_aug* | *Year* | *BQSsh_feb* | *Rise* | *Deep Ave* | *Rain_M-A* | *HRM_AW* | *Winter* | *WinRech* |
|---|---|---|---|---|---|---|---|---|---|
| BQSsh_aug | 1.000 | | | | | | | | |
| Year | -0.244 | 1.000 | | | | | | | |
| BQSsh_feb | 0.913 | -0.459 | 1.000 | | | | | | |
| Rise | 0.515 | -0.624 | 0.819 | 1.000 | | | | | |
| Deep Ave | -0.018 | 0.955 | -0.241 | -0.483 | 1.000 | | | | |
| Rain_M-A | 0.091 | -0.266 | 0.253 | 0.404 | -0.149 | 1.000 | | | |
| HRM_AW | 0.159 | -0.367 | 0.293 | 0.393 | -0.282 | 0.876 | 1.000 | | |
| Winter | 0.242 | -0.190 | 0.355 | 0.406 | -0.036 | 0.711 | 0.497 | 1.000 | |
| WinRech | 0.266 | -0.100 | 0.386 | 0.437 | 0.067 | 0.633 | 0.417 | 0.967 | 1.000 |

**FEBRUARY PREDICTIONS**

| BQSsh_feb | Date | BQSsh_aug | Rise | S A-F Ave Deep | Rain S-F | HRM SF | Rice | WU |
|---|---|---|---|---|---|---|---|---|
| 4.4 | 1991.15 | 4.33 | -0.07 | 11.25 | 88 | 25 | 31048 | 710000 |
| 4.14 | 1992.15 | 4.23 | 0.09 | 11.35 | 111 | 24 | 32360 | 740000 |
| 3.72 | 1993.15 | 4.09 | 0.37 | 11.17 | 396 | 107 | 24489 | 560000 |
| 3.6 | 1994.15 | 3.9 | 0.3 | 10.84 | 358 | 81 | 30173 | 690000 |
| 3.62 | 1995.15 | 3.76 | 0.14 | 13.14 | 148 | 58 | 30921 | 732,908 |
| 3.24 | 1996.15 | 3.51 | 0.27 | 15.07 | 135 | 30 | 32154 | 714,219 |
| 2.95 | 1997.15 | 3.31 | 0.36 | 15.92 | 171 | 46 | 36264 | 818,902 |
| 3.16 | 1998.15 | 3.39 | 0.23 | 19.25 | 165 | 31 | 24951 | 600,353 |
| 3.53 | 1999.15 | 3.6 | 0.07 | 20.99 | 202 | 63 | 27595 | 649,883 |
| 3.69 | 2000.15 | 3.65 | -0.04 | 23.46 | 212 | 54 | 20140 | 406,928 |
| 3.56 | 2001.15 | 3.94 | 0.38 | 23.26 | 307 | 92 | 33748 | 698,117 |
| 3.57 | 2002.15 | 3.68 | 0.11 | 23.39 | 168 | 55 | 27276 | 707,617 |
| 4.15 | 2003.15 | 3.76 | -0.39 | 29.42 | 84 | 26 | 568 | 263,256 |
| 4.48 | 2004.15 | 4.33 | -0.15 | 26.16 | 197 | 66 | 500 | 150,000 |
| | | 4.53 | | | | | | |
| 4.78 | 1990.15 | | | | | | | |

| | *BQSsh_feb* | *Date* | *3QSsh_aug* | *Rise* | *Ave Deep* | *Rain S-F* | *HRM SF* | *Rice* | *WU* |
|---|---|---|---|---|---|---|---|---|---|
| BQSsh_feb | 1.000 | | | | | | | | |
| Date | 0.019 | 1.000 | | | | | | | |
| BQSsh_aug | 0.880 | -0.244 | 1.000 | | | | | | |
| Rise | -0.711 | -0.399 | -0.291 | 1.000 | | | | | |
| Ave Deep | 0.136 | 0.965 | -0.188 | -0.552 | 1.000 | | | | |
| Rain S-F | -0.216 | -0.074 | 0.110 | 0.596 | -0.196 | 1.000 | | | |
| HRM SF | -0.108 | 0.086 | 0.180 | 0.483 | -0.047 | 0.928 | 1.000 | | |
| Rice | -0.566 | -0.635 | -0.247 | 0.773 | -0.691 | 0.144 | 0.057 | 1.000 | |
| WU | -0.555 | -0.620 | -0.280 | 0.701 | -0.674 | 0.026 | -0.044 | 0.969 | 1.000 |

# DENIMEIN

AUGUST PREDICTIONS 70

| DNsh_aug | Date | DNsh_feb | Rise | GraddpF-A | Rain_M-A | HRM_AW | Winter | WinRech |
|---|---|---|---|---|---|---|---|---|
| 5.82 | 1990.65 | 6.00 | 0.18 | 0.17 | 257 | 87 | 134 | 64 |
| 5.54 | 1991.65 | 5.78 | 0.24 | 0.44 | 146 | 62 | 119 | 49 |
| 5.68 | 1992.65 | 5.73 | 0.05 | 0.36 | 184 | 60 | 96 | 26 |
| 5.22 | 1993.65 | 5.44 | 0.22 | 0.71 | 172 | 62 | 85 | 15 |
| 5.38 | 1994.65 | 5.38 | 0.00 | 0.47 | 140 | 66 | 59 | 0 |
| 5.25 | 1995.65 | 5.38 | 0.13 | 2.32 | 227 | 78 | 116 | 46 |
| 5.12 | 1996.65 | 5.30 | 0.18 | 3.53 | 206 | 55 | 151 | 81 |
| 4.81 | 1997.65 | 4.88 | 0.07 | 4.90 | 158 | 49 | 71 | 1 |
| 4.88 | 1998.65 | 5.06 | 0.18 | 6.17 | 183 | 66 | 108 | 38 |
| 4.95 | 1999.65 | 4.96 | 0.01 | 6.82 | 265 | 107 | 98 | 28 |
| 5.07 | 2000.65 | 5.01 | -0.06 | 6.25 | 158 | 39 | 80 | 10 |
| 4.95 | 2001.65 | 4.84 | -0.11 | 6.83 | 137 | 37 | 94 | 24 |
| 5.01 | 2002.65 | 4.89 | -0.12 | 6.63 | 72 | 25 | 23 | 0 |
| 5.21 | 2003.65 | 5.23 | 0.02 | 7.98 | 211 | 70 | 156 | 86 |
| 5.28 | 2004.65 | 5.20 | -0.08 | 7.06 | 138 | 45 | 105 | 35 |

0.147

| | *DNsh_aug* | *Date* | *DNsh_feb* | *Rise* | *GraddpF-A* | *Rain_M-A* | *HRM_AW* | *Winter* | *WinRech* |
|---|---|---|---|---|---|---|---|---|---|
| DNsh_aug | 1.000 | | | | | | | | |
| Date | -0.650 | 1.000 | | | | | | | |
| DNsh_feb | 0.946 | -0.798 | 1.000 | | | | | | |
| Rise | 0.334 | -0.749 | 0.622 | 1.000 | | | | | |
| GraddpF-A | -0.735 | 0.951 | -0.828 | -0.631 | 1.000 | | | | |
| Rain_M-A | 0.234 | -0.327 | 0.356 | 0.467 | -0.161 | 1.000 | | | |
| HRM_AW | 0.286 | -0.413 | 0.404 | 0.483 | -0.280 | 0.881 | 1.000 | | |
| Winter | 0.309 | -0.152 | 0.432 | 0.506 | -0.057 | 0.685 | 0.477 | 1.000 | |
| WinRech | 0.319 | -0.072 | 0.416 | 0.438 | 0.001 | 0.582 | 0.392 | 0.945 | 1.000 |

FEBRUARY PREDICTIONS

| DNsh_feb | Date | DNsh_aug | Rise | GraddpA-F | Rain S-F | HighN-F | Rice | WU |
|---|---|---|---|---|---|---|---|---|
| 5.78 | 1991.15 | 5.82 | 0.04 | 0.22 | 87.6 | 24.8 | 5000 | 98,000 |
| 5.73 | 1992.15 | 5.54 | -0.19 | 0.48 | 111.2 | 23.6 | 4839 | 118,000 |
| 5.44 | 1993.15 | 5.68 | 0.24 | 0.45 | 396.2 | 106.6 | 4500 | 72,000 |
| 5.38 | 1994.15 | 5.22 | -0.16 | 0.63 | 357.8 | 80.8 | 5000 | 86,000 |
| 5.38 | 1995.15 | 5.38 | 0.00 | 1.51 | 148.2 | 58.2 | 7364 | 86,247 |
| 5.30 | 1996.15 | 5.25 | -0.05 | 2.96 | 134.8 | 30.4 | 5210 | 89,379 |
| 4.88 | 1997.15 | 5.12 | 0.24 | 4.36 | 171.2 | 46.2 | 5608 | 99,166 |
| 5.06 | 1998.15 | 4.81 | -0.25 | 5.43 | 165.2 | 30.8 | 3593 | 66,057 |
| 4.96 | 1999.15 | 4.88 | -0.08 | 6.61 | 201.9 | 63.4 | 4576 | 70,786 |
| 5.01 | 2000.15 | 4.95 | -0.06 | 5.92 | 211.8 | 54.2 | 2901 | 38,700 |
| 4.84 | 2001.15 | 5.07 | 0.23 | 7.11 | 307.4 | 91.8 | 5578 | 91,392 |
| 4.89 | 2002.15 | 4.95 | 0.06 | 6.38 | 168.2 | 55 | 4078 | 77,593 |
| 5.23 | 2003.15 | 5.01 | -0.22 | 7.45 | 84.2 | 26 | 120 | 20,144 |
| 5.20 | 2004.15 | 5.21 | 0.01 | 7.45 | 197 | 66.4 | 0 | 20,000 |

| | *DNsh_feb* | *Date* | *DNsh_aug* | *Rise* | *GraddpA-F* | *Rain S-F* | *HighN-F* | *Rice* | *WU* |
|---|---|---|---|---|---|---|---|---|---|
| DNsh_feb | 1.000 | | | | | | | | |
| Date | -0.744 | 1.000 | | | | | | | |
| DNsh_aug | 0.851 | -0.754 | 1.000 | | | | | | |
| Rise | -0.260 | -0.027 | 0.285 | 1.000 | | | | | |
| GraddpA-F | -0.802 | 0.961 | -0.813 | -0.030 | 1.000 | | | | |
| Rain S-F | -0.193 | -0.074 | 0.036 | 0.418 | -0.131 | 1.000 | | | |
| HighN-F | -0.278 | 0.086 | 0.037 | 0.575 | 0.010 | 0.928 | 1.000 | | |
| Rice | 0.114 | -0.650 | 0.301 | 0.345 | -0.581 | 0.163 | 0.152 | 1.000 | |
| WU | 0.298 | -0.732 | 0.428 | 0.243 | -0.645 | 0.015 | -0.069 | 0.865 | 1.000 |

# WAKOOL PUMPED AREA

**AUGUST LEVEL PREDICTION**

| WKPsh_aug | Year | WKPsh_feb | Rise | Deep Grad | Rain_M-A | HRM_AW | Winter | MayAug | WinRech | Pumps |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 70 | |
| 2.32 | 1990.65 | 2.66 | 0.34 | 0.71 | 257 | 87 | 134 | 221.6 | 64 | 13000 |
| 2.52 | 1991.65 | 2.52 | 0.00 | 0.65 | 146 | 62 | 119 | 124.6 | 49 | 13000 |
| 2.58 | 1992.65 | 2.57 | -0.01 | 0.59 | 184 | 60 | 96 | 155.6 | 26 | 13000 |
| 2.50 | 1993.65 | 2.15 | -0.35 | 0.77 | 172 | 62 | 85 | 109.4 | 15 | 13000 |
| 2.49 | 1994.65 | 2.26 | -0.23 | 0.62 | 140 | 66 | 59 | 68.4 | 0 | 13000 |
| 2.55 | 1995.65 | 2.55 | 0.00 | 0.91 | 227 | 78 | 116 | 193.8 | 46 | 13840 |
| 2.48 | 1996.65 | 2.47 | -0.01 | 1.25 | 206 | 55 | 151 | 169.8 | 81 | 10524 |
| 2.65 | 1997.65 | 2.43 | -0.22 | 1.55 | 158 | 49 | 71 | 106.6 | 1 | 13450 |
| 2.76 | 1998.65 | 2.87 | 0.11 | 1.68 | 183 | 66 | 108 | 115.2 | 38 | 13612 |
| 2.88 | 1999.65 | 2.72 | -0.16 | 1.97 | 265 | 107 | 98 | 144 | 28 | 11206 |
| 3.12 | 2000.65 | 2.93 | -0.19 | 2.08 | 158 | 39 | 80 | 119 | 10 | 12252 |
| 2.98 | 2001.65 | 2.75 | -0.23 | 2.50 | 137 | 37 | 94 | 101.4 | 24 | 8160 |
| 3.01 | 2002.65 | 2.90 | -0.11 | 2.70 | 72 | 25 | 23 | 38.8 | 0 | 9412 |
| 3.21 | 2003.65 | 3.25 | 0.04 | 2.20 | 211 | 70 | 156 | 180.6 | 86 | 6570 |
| 3.41 | 2004.65 | 3.30 | -0.11 | 1.95 | 138 | 45 | 105 | 133.6 | 35 | 3306 |
| | | St Dev | 0.192 | | | | | | | |

Pumps are July - June and WTs are Feb and Aug. Data not corrected for seasonality

| | WKPsh_aug | Year | WKPsh_feb | Rise | Deep Grad | Rain_M-A | HRM_AW | Winter | MayAug | WinRech | Pumps |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WKPsh_aug | 1.000 | | | | | | | | | | |
| Year | 0.930 | 1.000 | | | | | | | | | |
| WKPsh_feb | 0.861 | 0.769 | 1.000 | | | | | | | | |
| Rise | -0.238 | -0.282 | 0.289 | 1.000 | | | | | | | |
| Deep Grad | 0.823 | 0.918 | 0.697 | -0.219 | 1.000 | | | | | | |
| Rain_M-A | -0.333 | -0.327 | -0.078 | 0.477 | -0.330 | 1.000 | | | | | |
| HRM_AW | -0.399 | -0.413 | -0.196 | 0.377 | -0.438 | 0.881 | 1.000 | | | | |
| Winter | -0.115 | -0.152 | 0.193 | 0.585 | -0.238 | 0.685 | 0.477 | 1.000 | | | |
| MayAug | -0.234 | -0.302 | 0.120 | 0.669 | -0.352 | 0.844 | 0.608 | 0.852 | 1.000 | | |
| WinRech | -0.074 | -0.072 | 0.284 | 0.681 | -0.126 | 0.582 | 0.392 | 0.945 | 0.788 | 1.000 | |
| Pumps | -0.804 | -0.771 | -0.745 | 0.089 | -0.622 | 0.253 | 0.326 | -0.144 | 0.041 | -0.233 | 1.000 |

**FEBRUARY LEVEL PREDICTION**

| WKPsh_feb | Date | DeepGrad | Previous WKPsh_aug | Rise | Rain S-F | HRM SF | Rice | WU | Pumps |
|---|---|---|---|---|---|---|---|---|---|
| 2.52 | 1991.15 | 0.75 | 2.32 | -0.20 | 88 | 25 | 18779 | 360000 | 13000 |
| 2.57 | 1992.15 | 0.65 | 2.52 | -0.05 | 111 | 24 | 20605 | 395000 | 13000 |
| 2.15 | 1993.15 | 0.74 | 2.58 | 0.43 | 396 | 107 | 13302 | 255000 | 13000 |
| 2.26 | 1994.15 | 0.66 | 2.50 | 0.24 | 358 | 81 | 16953 | 325000 | 13000 |
| 2.55 | 1995.15 | 0.79 | 2.49 | -0.06 | 148 | 58 | 12371 | 279,450 | 13840 |
| 2.47 | 1996.15 | 1.05 | 2.55 | 0.08 | 135 | 30 | 15389 | 319,584 | 10524 |
| 2.43 | 1997.15 | 1.49 | 2.48 | 0.05 | 171 | 46 | 17274 | 346,759 | 13450 |
| 2.87 | 1998.15 | 1.52 | 2.65 | -0.22 | 165 | 31 | 12096 | 240,972 | 13612 |
| 2.72 | 1999.15 | 1.91 | 2.76 | 0.04 | 202 | 63 | 14844 | 290,046 | 11206 |
| 2.93 | 2000.15 | 1.93 | 2.88 | -0.05 | 212 | 54 | 10526 | 155,708 | 12252 |
| 2.75 | 2001.15 | 2.31 | 3.12 | 0.37 | 307 | 92 | 19728 | 330,077 | 8160 |
| 2.90 | 2002.15 | 2.50 | 2.98 | 0.08 | 168 | 55 | 15402 | 291,803 | 9412 |
| 3.25 | 2003.15 | 2.82 | 3.01 | -0.24 | 84 | 26 | 374 | 70,792 | 6570 |
| 3.30 | 2004.15 | 1.55 | 3.21 | -0.09 | 197 | 66 | 200 | 50,000 | 3306 |
| | | 21.48 | 3.41 | | | | | | |
| 2.66 | 1990.15 | 3.24 | | 147.2 | 50.8 | | | | |

| | WKPsh_feb | Date | DeepGrad | WKPsh_aug | Rise | Rain S-F | HRM SF | Rice | WU | Pumps |
|---|---|---|---|---|---|---|---|---|---|---|
| WKPsh_feb | 1.000 | | | | | | | | | |
| Date | 0.842 | 1.000 | | | | | | | | |
| DeepGrad | 0.729 | 0.876 | 1.000 | | | | | | | |
| WKPsh_aug | 0.794 | 0.921 | 0.789 | 1.000 | | | | | | |
| Rise | -0.576 | -0.145 | -0.137 | 0.041 | 1.000 | | | | | |
| Rain S-F | -0.442 | -0.074 | -0.163 | 0.100 | 0.860 | 1.000 | | | | |
| HRM SF | -0.298 | 0.086 | -0.032 | 0.264 | 0.844 | 0.928 | 1.000 | | | |
| Rice | -0.725 | -0.646 | -0.411 | -0.572 | 0.422 | 0.165 | 0.055 | 1.000 | | |
| WU | -0.760 | -0.709 | -0.487 | -0.671 | 0.345 | 0.058 | -0.042 | 0.972 | 1.000 | |
| Pumps | -0.752 | -0.787 | -0.590 | -0.857 | 0.083 | 0.084 | -0.089 | 0.659 | 0.671 | 1.000 |

# WAKOOL "OTHER" THAN WTSSDS AREA

**AUGUST LEVEL PREDICTION**

| WKOsh_aug | Year | WKOsh_feb | Rise | DeepGrad | Rain_M-A | HRM_AW | Winter | MayAug | 90<br>WinRech |
|---|---|---|---|---|---|---|---|---|---|
| 4.83 | 1990.65 | 4.66 | -0.17 | -1.47 | 257 | 87 | 134 | 222 | 44 |
| 4.75 | 1991.65 | 4.52 | -0.23 | -1.38 | 146 | 62 | 119 | 125 | 29 |
| 4.76 | 1992.65 | 4.57 | -0.19 | -1.42 | 184 | 60 | 96 | 156 | 6 |
| 4.51 | 1993.65 | 4.32 | -0.19 | -1.08 | 172 | 62 | 85 | 109 | 0 |
| 4.38 | 1994.65 | 4.26 | -0.12 | -1.21 | 140 | 66 | 59 | 68 | 0 |
| 4.45 | 1995.65 | 4.53 | 0.08 | -0.78 | 227 | 78 | 116 | 194 | 26 |
| 4.27 | 1996.65 | 4.35 | 0.08 | -0.44 | 206 | 55 | 151 | 170 | 61 |
| 4.27 | 1997.65 | 4.00 | -0.27 | 0.10 | 158 | 49 | 71 | 107 | 0 |
| 4.64 | 1998.65 | 4.50 | -0.14 | -0.03 | 183 | 66 | 108 | 115 | 18 |
| 4.63 | 1999.65 | 4.47 | -0.16 | 0.13 | 265 | 107 | 98 | 144 | 8 |
| 4.71 | 2000.65 | 4.58 | -0.13 | -0.07 | 158 | 39 | 80 | 119 | 0 |
| 4.61 | 2001.65 | 4.48 | -0.13 | 0.22 | 137 | 37 | 94 | 101 | 4 |
| 4.76 | 2002.65 | 4.64 | -0.12 | 0.14 | 72 | 25 | 23 | 39 | 0 |
| 5.01 | 2003.65 | 4.97 | -0.04 | -0.45 | 211 | 70 | 156 | 181 | 66 |
| 5.13 | 2004.65 | 5.05 | -0.08 | -0.96 | 138 | 45 | 105 | 134 | 15 |

| | *WKOsh* | *Year* | *WKOsh* | *Rise* | *WKOdp* | *Rain_M-A* | *HRM_AW* | *Winter* | *MayAug* | *WinRech* |
|---|---|---|---|---|---|---|---|---|---|---|
| WKOsh | 1.000 | | | | | | | | | |
| Year | 0.374 | 1.000 | | | | | | | | |
| WKOsh | 0.924 | 0.458 | 1.000 | | | | | | | |
| Rise | -0.082 | 0.263 | 0.304 | 1.000 | | | | | | |
| WKOdp | 0.182 | 0.860 | 0.216 | 0.109 | 1.000 | | | | | |
| Rain_M-A | -0.061 | -0.327 | 0.029 | 0.226 | -0.177 | 1.000 | | | | |
| HRM_AW | -0.047 | -0.413 | -0.027 | 0.046 | -0.301 | 0.881 | 1.000 | | | |
| Winter | 0.187 | -0.152 | 0.339 | 0.420 | -0.178 | 0.685 | 0.477 | 1.000 | | |
| MayAug | 0.180 | -0.302 | 0.313 | 0.368 | -0.277 | 0.844 | 0.608 | 0.852 | 1.000 | |
| WinRech | 0.185 | -0.053 | 0.384 | 0.542 | -0.098 | 0.503 | 0.323 | 0.873 | 0.710 | 1.000 |

**FEBRUARY LEVEL PREDICTION**

| WKOsh_feb | Date | Previous<br>WKOsh_au | DeepGrad | Rise | Rain S-F | HRM SF | Rice | WU |
|---|---|---|---|---|---|---|---|---|
| 4.52 | 1991.15 | 4.83 | -1.43 | 0.31 | 88 | 25 | 18779 | 360000 |
| 4.57 | 1992.15 | 4.75 | -1.39 | 0.18 | 111 | 24 | 20605 | 395000 |
| 4.32 | 1993.15 | 4.76 | -1.29 | 0.44 | 396 | 107 | 13302 | 255000 |
| 4.26 | 1994.15 | 4.51 | -1.14 | 0.25 | 358 | 81 | 16953 | 325000 |
| 4.53 | 1995.15 | 4.38 | -0.97 | -0.15 | 148 | 58 | 12371 | 279,450 |
| 4.35 | 1996.15 | 4.45 | -0.63 | 0.10 | 135 | 30 | 15389 | 319,584 |
| 4.00 | 1997.15 | 4.27 | -0.02 | 0.27 | 171 | 46 | 17274 | 346,759 |
| 4.50 | 1998.15 | 4.27 | 0.02 | -0.23 | 165 | 31 | 12096 | 240,972 |
| 4.47 | 1999.15 | 4.64 | 0.03 | 0.17 | 202 | 63 | 14844 | 290,046 |
| 4.58 | 2000.15 | 4.63 | -0.13 | 0.05 | 212 | 54 | 10526 | 155,708 |
| 4.48 | 2001.15 | 4.71 | 0.10 | 0.23 | 307 | 92 | 19728 | 330,077 |
| 4.64 | 2002.15 | 4.61 | 0.12 | -0.03 | 168 | 55 | 15402 | 291,803 |
| 4.97 | 2003.15 | 4.76 | 0.12 | -0.21 | 84 | 26 | 374 | 70,792 |
| 5.05 | 2004.15 | 5.01 | -1.08 | -0.04 | 197 | 66 | 200 | 50,000 |

| | *WKOsh* | *Date* | *WKOsh* | *WKOdp* | *Rise* | *Rain S-F* | *HRM SF* | *Rice* | *WU* |
|---|---|---|---|---|---|---|---|---|---|
| WKOsh | 1.000 | | | | | | | | |
| Date | 0.583 | 1.000 | | | | | | | |
| WKOsh | 0.655 | 0.184 | 1.000 | | | | | | |
| WKOdp | 0.343 | 0.854 | -0.055 | 1.000 | | | | | |
| Rise | -0.606 | -0.561 | 0.204 | -0.503 | 1.000 | | | | |
| Rain S-F | -0.363 | -0.074 | 0.049 | -0.186 | 0.522 | 1.000 | | | |
| HRM SF | -0.203 | 0.086 | 0.173 | -0.083 | 0.445 | 0.928 | 1.000 | | |
| Rice | -0.738 | -0.646 | -0.326 | -0.359 | 0.612 | 0.165 | 0.055 | 1.000 | |
| WU | -0.741 | -0.709 | -0.377 | -0.436 | 0.564 | 0.058 | -0.042 | 0.972 | 1.000 |

# DENIBOOTA

**AUGUST LEVEL PREDICTION**

| DBsh_aug | Year | DBsh_feb | Rise | GraddpFA | Rain_M-A | HRM_AW | Winter | MayAug | WinRech |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 50 |
| 5.03 | 1990.65 | 5.14 | 0.11 | 0.75 | 257 | 87 | 134 | 222 | 84 |
| 5 | 1991.65 | 4.99 | -0.01 | 0.99 | 146 | 62 | 119 | 125 | 69 |
| 4.93 | 1992.65 | 4.99 | 0.06 | 1.07 | 184 | 60 | 96 | 156 | 46 |
| 4.66 | 1993.65 | 4.56 | -0.10 | 1.30 | 172 | 62 | 85 | 109 | 35 |
| 4.49 | 1994.65 | 4.43 | -0.06 | 1.42 | 140 | 66 | 59 | 68 | 9 |
| 4.46 | 1995.65 | 4.56 | 0.10 | 2.50 | 227 | 78 | 116 | 194 | 66 |
| 4.46 | 1996.65 | 4.26 | -0.20 | 3.47 | 206 | 55 | 151 | 170 | 101 |
| 4.31 | 1997.65 | 4.23 | -0.08 | 4.21 | 158 | 49 | 71 | 107 | 21 |
| 4.39 | 1998.65 | 4.53 | 0.14 | 5.26 | 183 | 66 | 108 | 115 | 58 |
| 4.39 | 1999.65 | 4.34 | -0.05 | 6.10 | 265 | 107 | 98 | 144 | 48 |
| 4.61 | 2000.65 | 4.3 | -0.31 | 5.70 | 158 | 39 | 80 | 119 | 30 |
| 4.36 | 2001.65 | 4.31 | -0.05 | 6.66 | 137 | 37 | 94 | 101 | 44 |
| 4.47 | 2002.65 | 4.36 | -0.11 | 6.09 | 72 | 25 | 23 | 39 | 0 |
| 4.61 | 2003.65 | 4.6 | -0.01 | 6.52 | 211 | 70 | 156 | 181 | 106 |
| 4.74 | 2004.65 | 4.65 | -0.09 | 6.09 | 138 | 45 | 105 | 134 | 55 |
| | | Stdev | 0.156 | | | | | | |

| | *DBsh_aug* | *Year* | *DBsh_feb* | *Rise* | *GraddpFA* | *Rain_M-A* | *HRM_AW* | *Winter* | *MayAug* | *WinRech* |
|---|---|---|---|---|---|---|---|---|---|---|
| DBsh_aug | 1.000 | | | | | | | | | |
| Year | -0.524 | 1.000 | | | | | | | | |
| DBsh_feb | 0.915 | -0.584 | 1.000 | | | | | | | |
| Rise | 0.226 | -0.371 | 0.600 | 1.000 | | | | | | |
| GraddpFA | -0.590 | 0.955 | -0.619 | -0.325 | 1.000 | | | | | |
| Rain_M-A | 0.124 | -0.327 | 0.259 | 0.378 | -0.202 | 1.000 | | | | |
| HRM_AW | 0.146 | -0.413 | 0.334 | 0.516 | -0.314 | 0.881 | 1.000 | | | |
| Winter | 0.308 | -0.152 | 0.366 | 0.274 | -0.109 | 0.685 | 0.477 | 1.000 | | |
| MayAug | 0.405 | -0.302 | 0.492 | 0.384 | -0.258 | 0.844 | 0.608 | 0.852 | 1.000 | |
| WinRech | 0.313 | -0.100 | 0.370 | 0.273 | -0.062 | 0.639 | 0.427 | 0.983 | 0.834 | 1.000 |

**FEBRUARY LEVEL PREDICTION**

| DBsh_feb | Date | Previous DBsh_aug | DeepGrad | Rise | Rain S-F | HRM SF | Rice | WU |
|---|---|---|---|---|---|---|---|---|
| 4.99 | 1991.15 | 5.03 | 0.79 | 0.04 | 88 | 25 | 11102 | 195000 |
| 4.99 | 1992.15 | 5 | 1.05 | 0.01 | 111 | 24 | 12389 | 217600 |
| 4.56 | 1993.15 | 4.93 | 1.19 | 0.37 | 396 | 107 | 7686 | 135000 |
| 4.43 | 1994.15 | 4.66 | 1.36 | 0.23 | 358 | 81 | 9110 | 160000 |
| 4.56 | 1995.15 | 4.49 | 2.05 | -0.07 | 148 | 58 | 10050 | 176520 |
| 4.26 | 1996.15 | 4.46 | 3.05 | 0.20 | 135 | 30 | 9942 | 167999 |
| 4.23 | 1997.15 | 4.46 | 3.96 | 0.23 | 171 | 46 | 10860 | 207083 |
| 4.53 | 1998.15 | 4.31 | 4.55 | -0.22 | 165 | 31 | 7702 | 136546 |
| 4.34 | 1999.15 | 4.39 | 5.79 | 0.05 | 202 | 63 | 8518 | 155857 |
| 4.30 | 2000.15 | 4.39 | 5.17 | 0.09 | 212 | 54 | 4849 | 72754 |
| 4.31 | 2001.15 | 4.61 | 6.79 | 0.30 | 307 | 92 | 10471 | 174946 |
| 4.36 | 2002.15 | 4.36 | 6.20 | 0.00 | 168 | 55 | 8394 | 161513 |
| 4.60 | 2003.15 | 4.47 | 6.59 | -0.13 | 84 | 26 | 484 | 44400 |
| 4.65 | 2004.15 | 4.61 | 5.97 | -0.04 | 197 | 66 | 400 | 40000 |

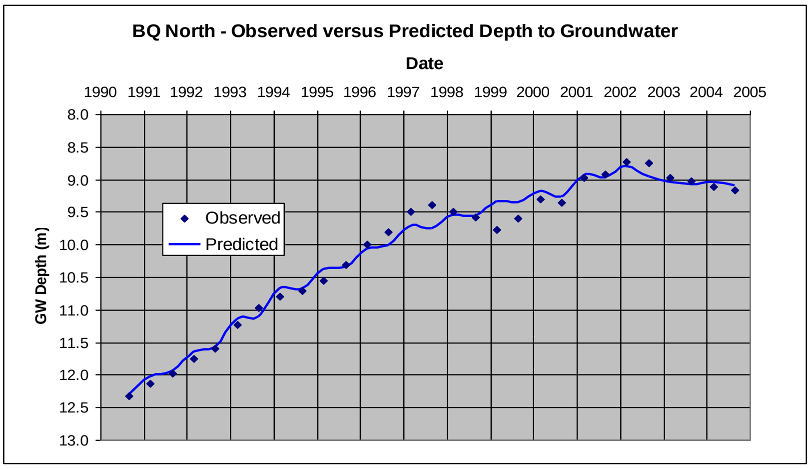
| | *DBsh_feb* | *Date* | *DBsh_aug* | *DeepGrad* | *Rise* | *Rain S-F* | *HRM SF* | *Rice* | *WU* |
|---|---|---|---|---|---|---|---|---|---|
| DBsh_feb | 1.000 | | | | | | | | |
| Date | -0.456 | 1.000 | | | | | | | |
| DBsh_aug | 0.754 | -0.674 | 1.000 | | | | | | |
| DeepGrad | -0.508 | 0.958 | -0.695 | 1.000 | | | | | |
| Rise | -0.371 | -0.298 | 0.331 | -0.252 | 1.000 | | | | |
| Rain S-F | -0.358 | -0.074 | 0.131 | -0.095 | 0.700 | 1.000 | | | |
| HRM SF | -0.366 | 0.086 | 0.084 | 0.056 | 0.644 | 0.928 | 1.000 | | |
| Rice | 0.050 | -0.716 | 0.314 | -0.557 | 0.373 | 0.039 | -0.039 | 1.000 | |
| WU | 0.093 | -0.687 | 0.322 | -0.536 | 0.323 | -0.034 | -0.091 | 0.981 | 1.000 |

# APPENDIX 3.

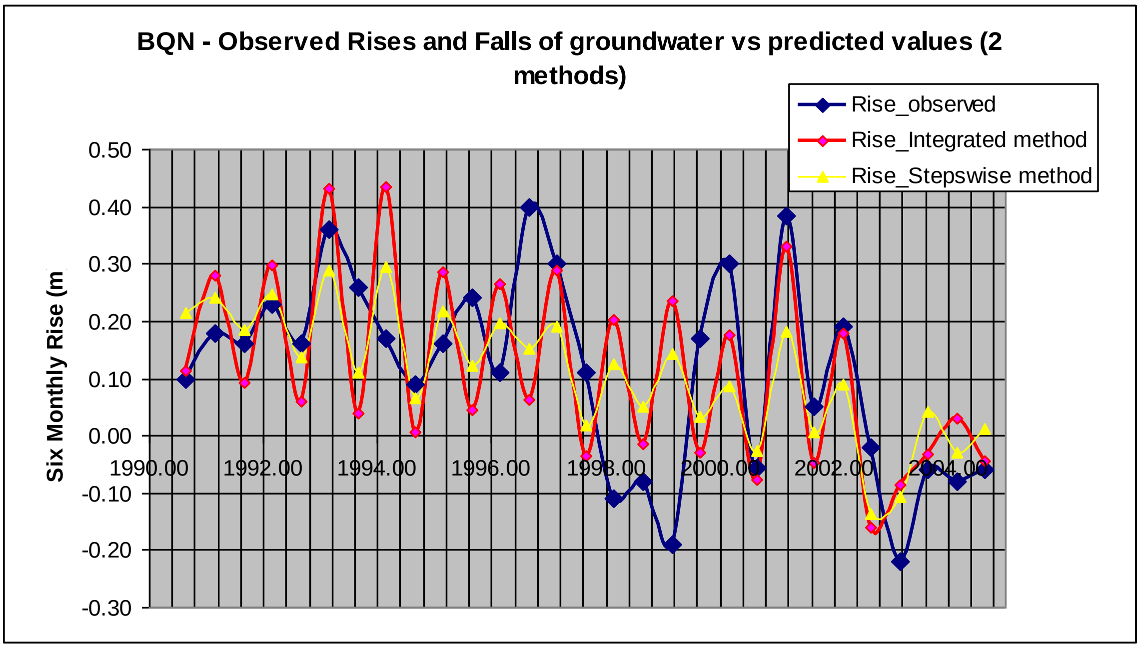
## RESULTS OF OPTIMISATION USING THE INTEGRATED METHOD

(showing GW hydrograph of observed/predicted, GW balance as optimised, and GW Rise/ Fall observed/predicted)

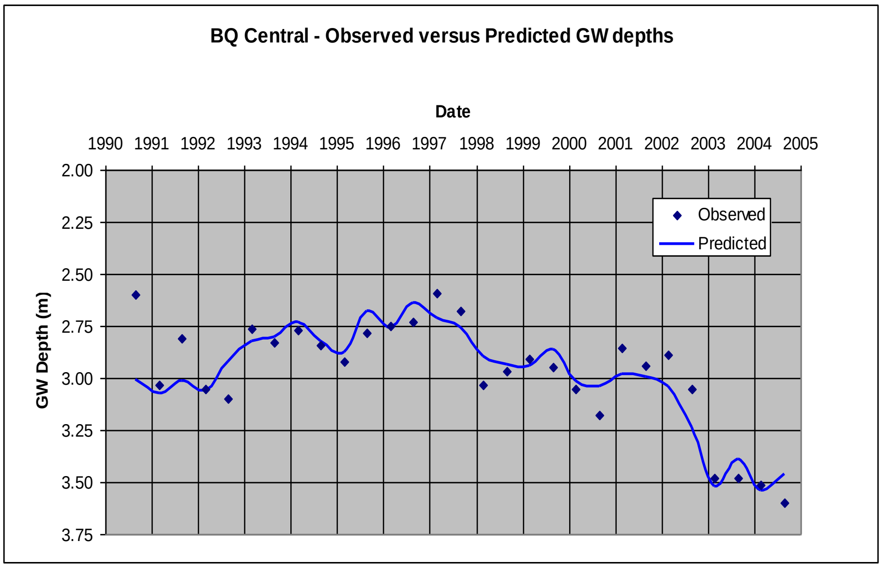
### Berriquin North



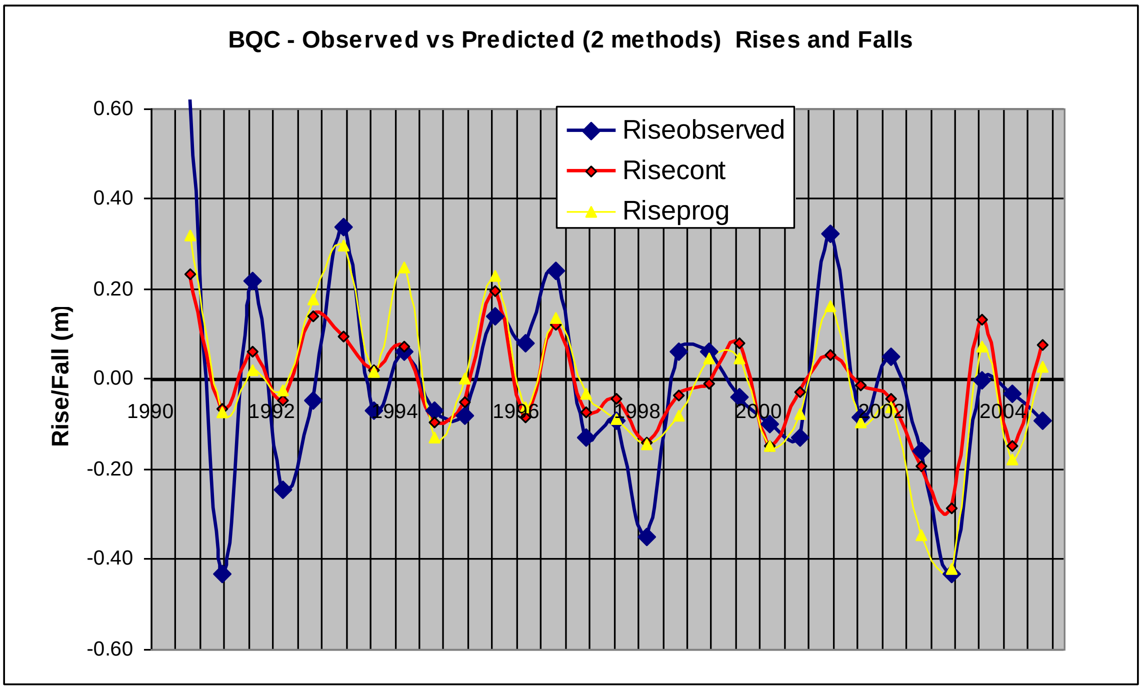

| BQ North | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 16.3 | 17467 | |
| Lateral GW Flow | | -7125 | From BQ Central |
| W Rainfall % | -0.054 | -7020 | |
| S Rainfall % | -0.033 | -8458 | |
| Rice Recharge ML/ha | -0.82 | -10257 | |
| Water Use Excess (%) | | 0 | not assessed |
| Channel Seepage | | -10000 | Assumed |
| Tree Uptake | | 10000 | Assumed |
| Change Storage/yr | | 15385 | Average 14 yrs |
| **Balance** | | **-8** | Unaccounted for |



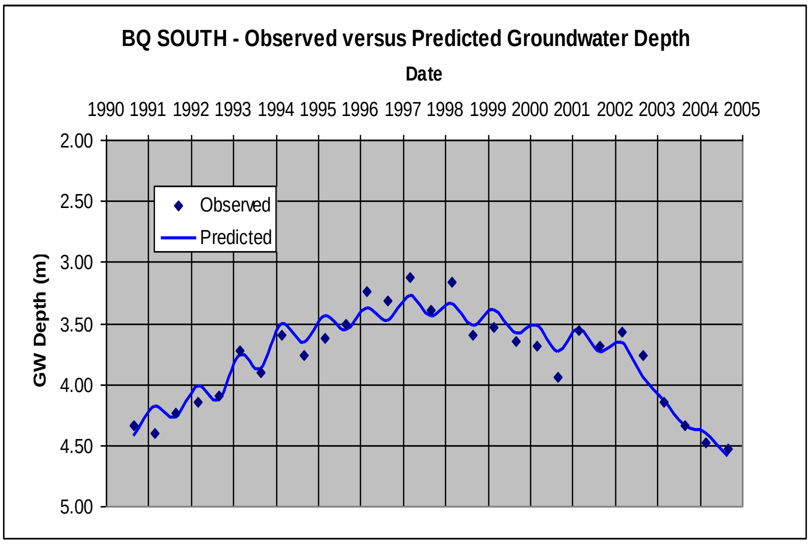
## Berriquin Central



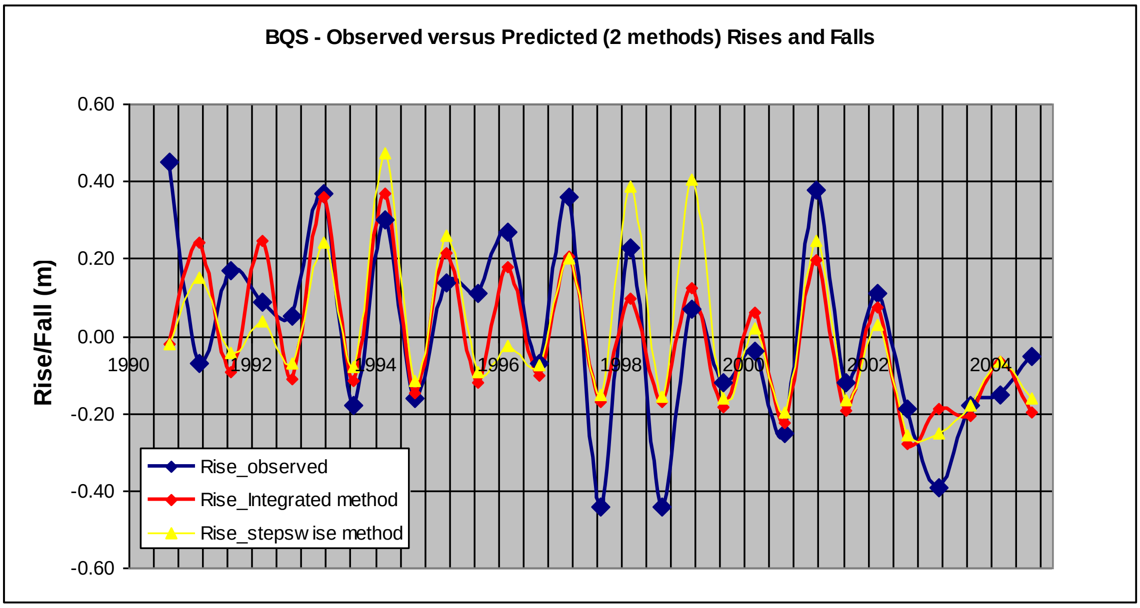

| BQ Central | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 8.8 | 15469 | |
| Lateral GW Flow | | 5404 | To North |
| W Rainfall % | -0.121 | -18422 | |
| S Rainfall % | -0.018 | -4135 | |
| Rice Recharge ML/ha | | | Not assessed |
| Water Use Excess (%) | -0.01 | -3641 | |
| Channel Seepage ML | | -30000 | Assumed |
| GW Pumping ML | | 17689 | |
| Tree Uptake ML | | | Not assessed |
| GW Evaporation mm/day | 0.09 | 19203 | |
| Change Storage/yr | | -1231 | Average 14 yrs |
| **Balance** | | **337** | Not explained |



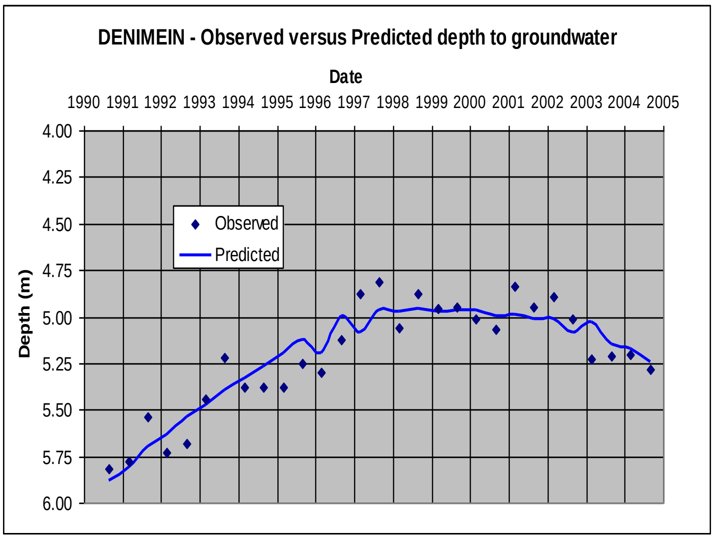

Berriquin South



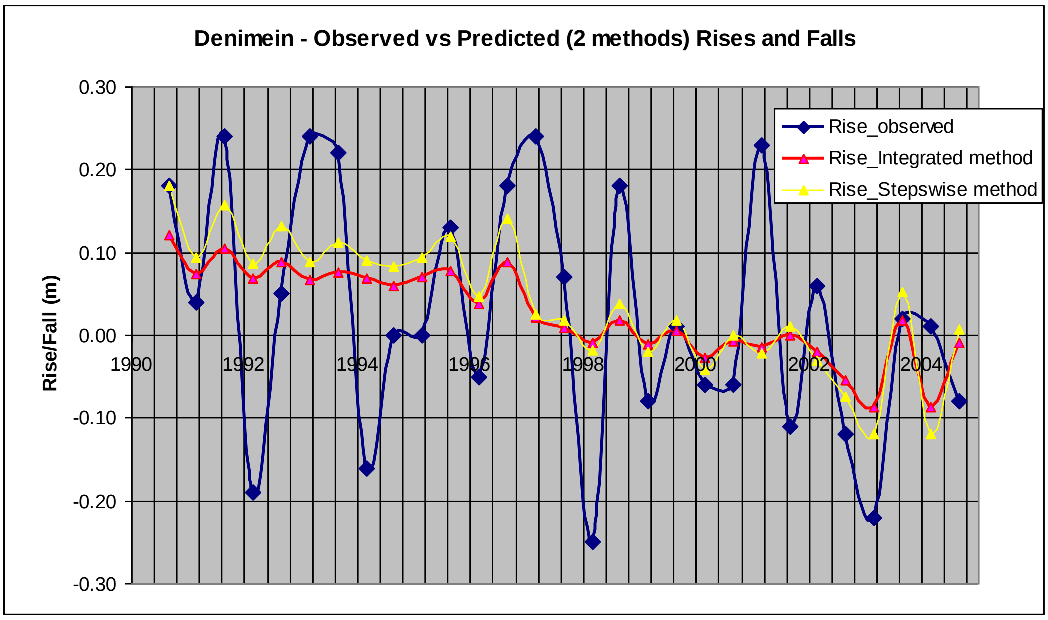

| BQ South | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 12.5 | 7546 | |
| Lateral GW Flow | | -176 | From BQ Central |
| W Rainfall % | -0.039 | -1567 | |
| S Rainfall % | -0.029 | -2343 | |
| Rice Recharge ML/ha | -0.72 | -2720 | |
| Water Use Excess (%) | | | not assessed |
| Channel Seepage | | -5000 | assumed |
| Tree Uptake | | 5000 | not assessed |
| Change Storage/yr | | -279 | Average 14 yrs |
| **Balance** | | **461** | Not explained |



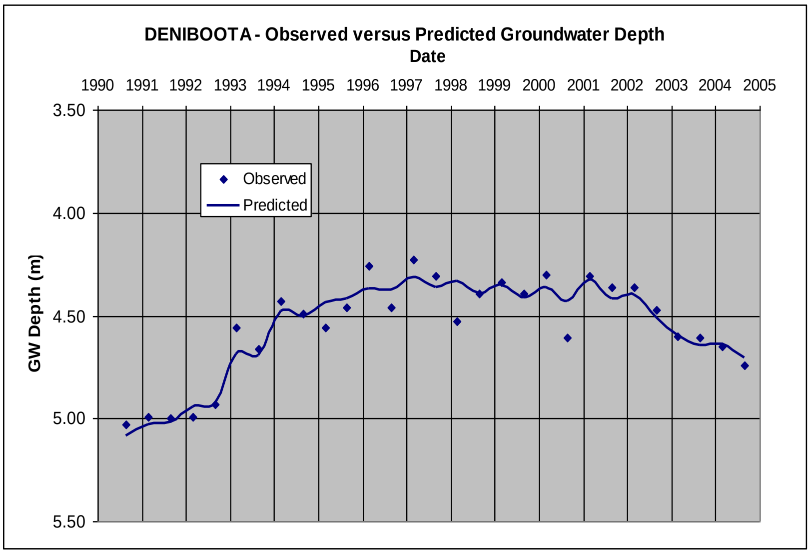

## Denimein



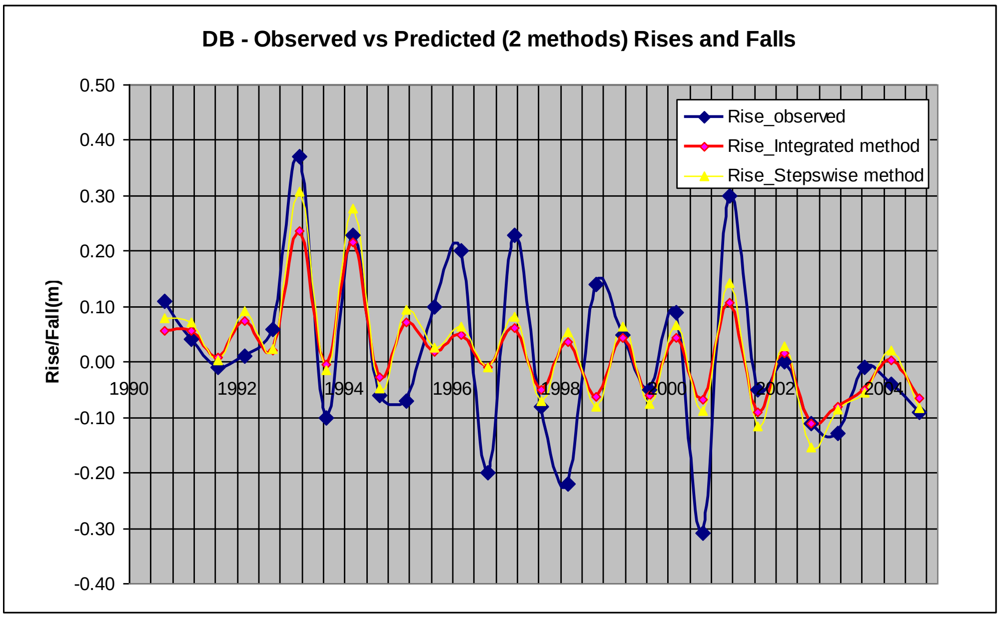

| **Denimein** | **Rate** | **Annual ML** | **Comment** |
|---|---|---|---|
| Deep Leakage (mm/10m) | 13.5 | 3316 | |
| Lateral GW Flow | | | not assessed |
| W Rainfall % | -0.039 | -2321 | |
| S Rainfall % | 0.000 | 0 | |
| Rice Recharge ML/ha | -0.18 | -770 | |
| Water Use Excess (%) | | | not assessed |
| Channel Seepage | | -3000 | Assumed |
| Groundwater Pumping | | 1239 | |
| Tree Uptake | | | not assessed |
| Change Storage/yr | | 1626 | average 14 yrs |
| **Balance** | | **91** | Unaccounted for |



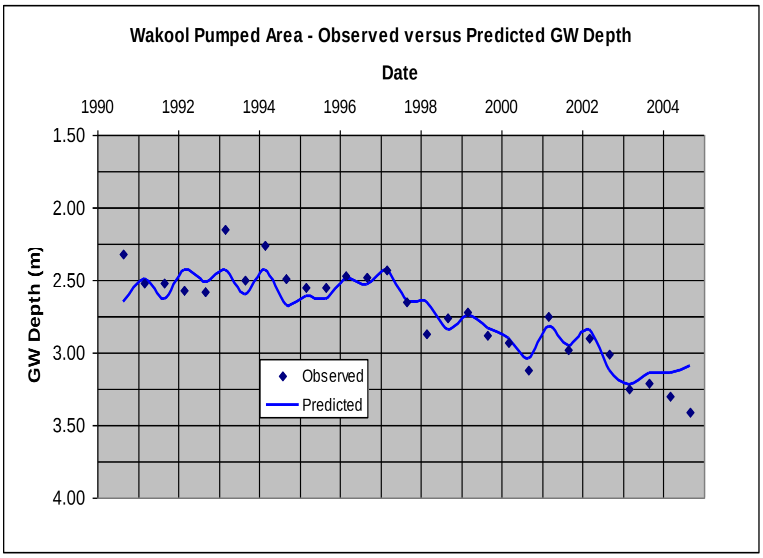

## Deniboota



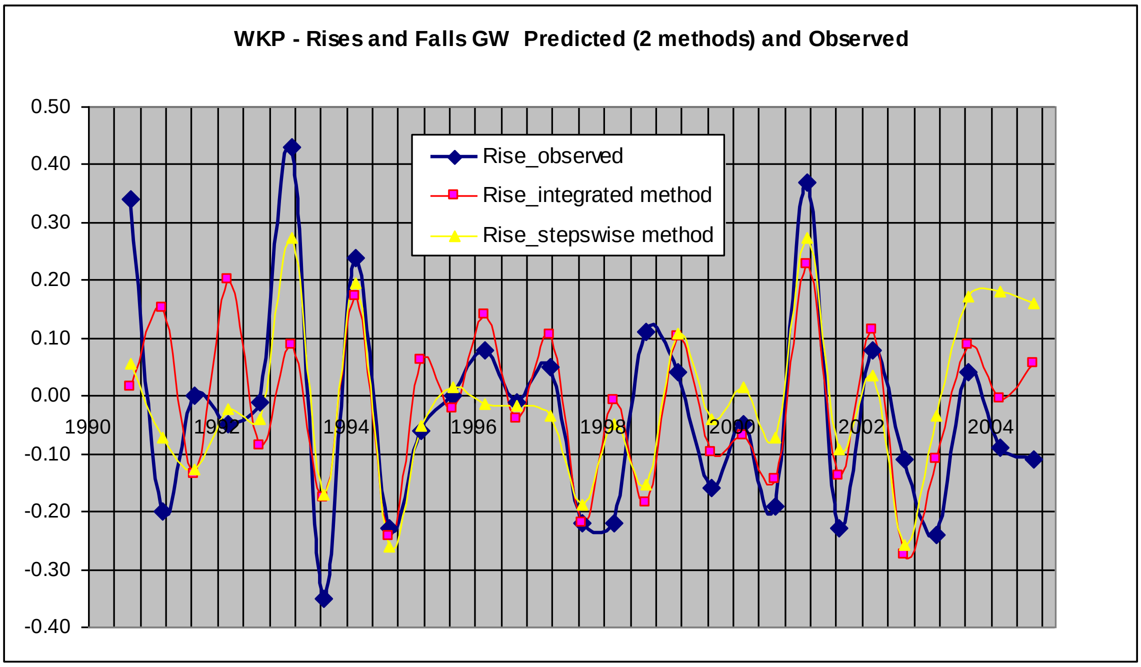

| Deniboota | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 15.1 | 7695 | |
| Lateral GW Flow | | 0 | Green Gulley, trees |
| W Rainfall % | -0.024 | -4180 | |
| S Rainfall % | -0.033 | -8380 | |
| Rice Recharge ML/ha | -0.29 | -2328 | |
| Water Use Excess (%) | | 0 | not assessed |
| Channel Seepage | | -10000 | not assessed |
| Tree Uptake | | 15000 | not assessed |
| Change Storage/yr | | 2038 | Average 14 yrs |
| **Balance** | | **-154** | Unaccounted for |



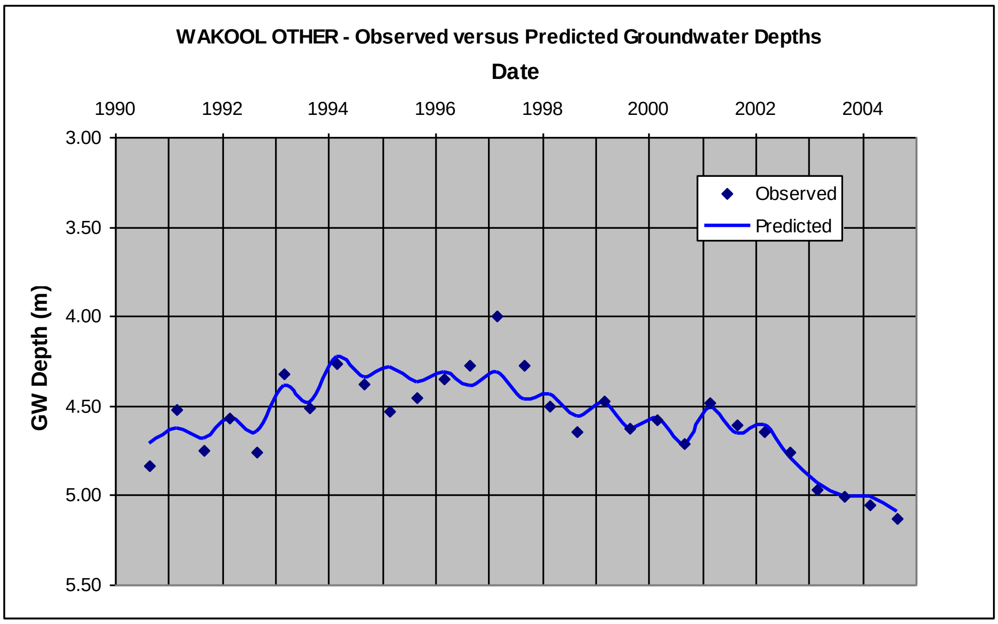

## Wakool Pumped Area



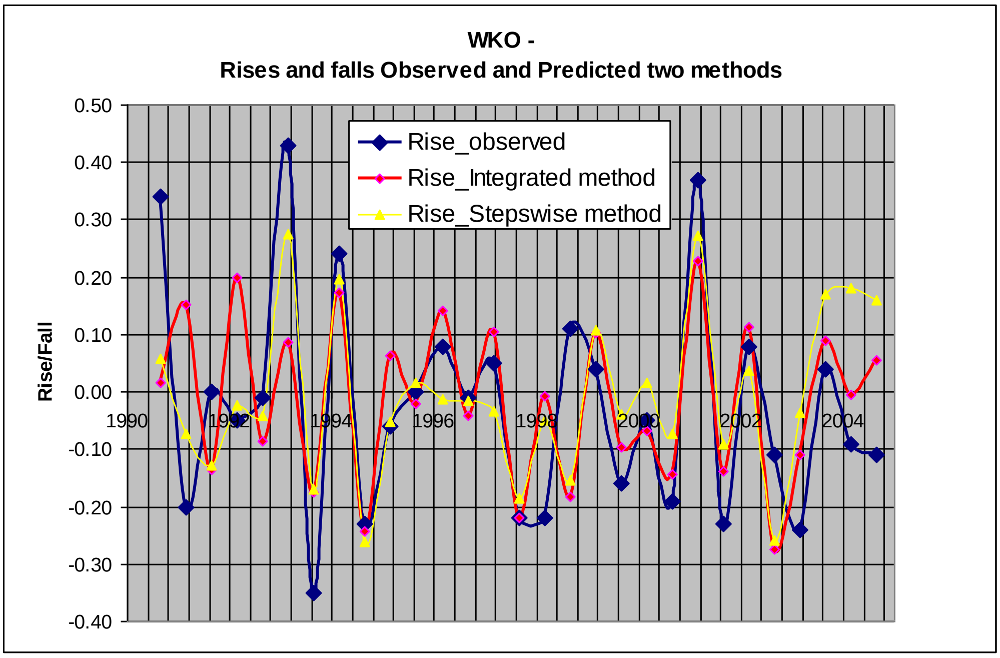

| Wakool WTSSDS area | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 40.0 | 3810 | |
| Lateral GW Flow ML | | | not assessed |
| W Rainfall (%/100) | -0.089 | -7632 | |
| S Rainfall (%/100) | -0.011 | -1452 | |
| Water Use Excess (%/100) | -0.09 | -9852 | |
| Rice Percolation (ML/ha) | | | not assessed |
| Channel Seepage (ML) | | -5000 | assumed |
| Groundwater Pumping | | 11024 | |
| Groundwater evaporation M | | 9999 | |
| Tree Uptake (ML) | | | not assessed |
| Change Storage/yr | | -983 | average 14 yrs |
| **Balance** | | **-86** | Unaccounted for |




## Wakool – "OTHER"




| Wakool "Other" | Rate | Annual ML | Comment |
|---|---|---|---|
| Deep Leakage (mm/10m) | 39.7 | -2830 | |
| Lateral GW Flow | | 25000 | To treed areas |
| W Rainfall % | -0.034 | -4329 | |
| S Rainfall % | -0.037 | -9209 | |
| Rice Recharge ML/ha | -0.89 | -7145 | |
| Water Use Excess (%) | | 0 | not assessed |
| Channel Seepage | | | not assessed |
| Tree Uptake | | | not assessed |
| Change Storage/yr | | -1966 | Average 14 yrs |
| **Balance** | | **-480** | Unaccounted for |


WKO -
Rises and falls Observed and Predicted two methods
Rise/Fall
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1990
1992
1994
1996
1998
2000
2002
2004
Rise_observed
Rise_Integrated method
Rise_Stepswise method