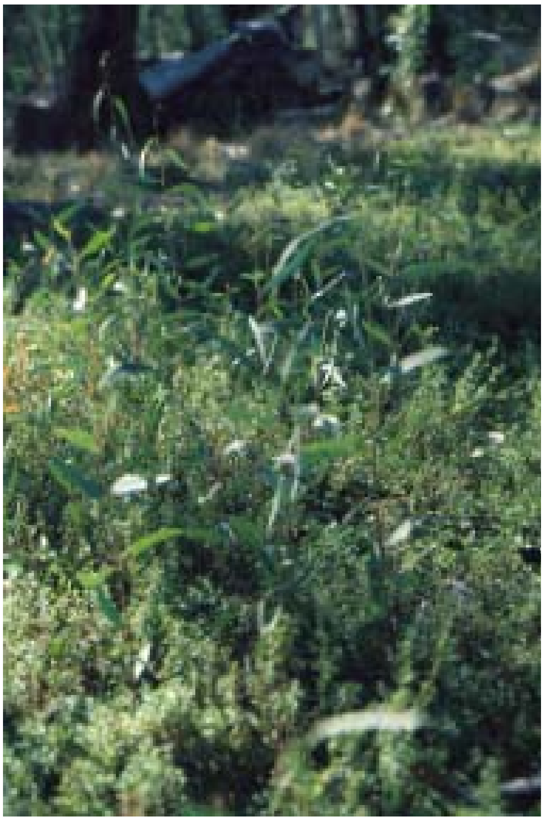
Tradeable recharge credits in Coleambally Irrigation Area: Report 6

Biophysical modelling for linking farms with regional net recharge targets

August 2005

Shahbaz Khan and Tariq Rana



For more information on the issues discussed in this document please contact the following people:

For information on biophysical modelling of recharge and recharge management in the Coleambally region (including the SWAGMAN® series of models):

Dr Shahbaz Khan
CSIRO Land and Water
Griffith, NSW 2680
(02) 6960 1500 (ph)
(02) 6960 1600 (fax)
shahbaz.khan@csiro.au
www.clw.csiro.au/division/griffith/

Khan, Shahbaz and Tariq Rana (2005) Tradeable recharge credits in Coleambally Irrigation Area: Report 6 Biophysical modelling for linking farms with regional net recharge targets. CSIRO

ISBN: 0975178369

This paper is an overview of a two-year research program. It synthesises the results presented in a series of reports investigating a market-based approach to manage the threat of salinity and waterlogging in the Coleambally Irrigation Area. Papers in this series are:

- *What are the issues?*
- *Economic impact of tradeable recharge credits and other net recharge abatement policies for the Coleambally Irrigation Area*
- *Designing experiments to test tradeable recharge credits in the Coleambally Irrigation Area*
- *Laboratory tests of alternative institutional frameworks*
- *Field trial and farm case studies*
- *Biophysical modelling for linking farms with regional net recharge targets*
- *Experiences, lessons and findings*

Acknowledgements:
Coleambally Irrigation Cooperative provided important assistance and support in undertaking the project. The research presented in this project has been funded by the National market Based Instruments Pilots Program under the National Action plan for Salinity and Water Quality and by CSIRO. All errors and omissions are entirely the responsibility of the authors.

Executive Summary

Across Australia, a range of complex natural resource management problems are confounding traditional management approaches. In many instances, the loss in resource yield or quality is impacting resource using industries while the costs of changing management practices and ensuring the future sustainability of our land, water and biodiversity resources appears substantial.

This has prompted Governments, industries and communities to investigate alternative strategies and policy instruments that could promote sustainable resource use at lowest cost. One initiative under the National Action Plan for Salinity and Water Quality is the National Market Based Instruments Pilots Program. Market Based Instruments (MBIs) are policy tools that encourage changes in management practices through market signals, rather than through explicit directives such as regulation. Instruments generally work through the modification of prices faced by resource users (such as through taxes or subsidies) or through the creation of tradeable rights (sometimes referred to as environmental markets).

The management of irrigation induced salinity in irrigation areas such as Coleambally in NSW represents one of the resource management challenges where MBIs are being investigated under the National Market Based Instruments Pilots Program.

Coleambally Irrigation Corporative Limited (CICL) is implementing Land and Water Management Options such as Net Recharge Management (NRM) to help improve water use efficiency and keep salinity affected areas (with root soil salinity levels > 2dS/m) less than 15 percent of the landscape. The net recharge management implementation process builds on strong research partnerships between CICL, CSIRO and the Rice CRC over the past seven years including a net recharge management model SWAGMAN Farm. SWAGMAN Farm is aimed at selecting a mix of crops which can maximise economic returns while maintaining watertables and soil salinity within desired limits considering appropriate irrigation levels which best suit the soils, climate and groundwater conditions in the area. One of the crucial parameters of SWAGMAN Farm is groundwater outflow under a farm. The groundwater outflow comprises both lateral and vertical components, which depend on the location of a farm with respect to variations in regional hydrogeology and groundwater pressure distribution in space and time.

Building on the previous hydrogeology studies in the CIA, further work was carried out to quantify vertical and lateral groundwater outflow capacity on a regional and sub-regional basis. This work can serve as a basis for forming net recharge target credits with individual farmers to help achieve CICL groundwater and salinity management targets and promote a rational environmental management dialogue between the farmers and CICL.

The analysis carried out during this study has shown changes in the area of recharge and discharge zones in the CIA. Currently the overall recharge area is around 30 percent of the region. This situation requires both on-farm and regional management options for the groundwater discharge zones and the need for rational sharing of costs between the net groundwater recharging and discharging farms.

On a regional basis the overall vertical leakage capacity between the shallow and deeper aquifers is around 30,000 ML/year. The total recharge needs to be less than the overall vertical leakage capacity of aquifers to maintain or lower current groundwater levels. Since groundwater levels in some regions e.g. central, southern and western parts are already within the root zone, there is a need to initially reduce groundwater recharge to less than the outflow capacity.

The specific LWMP options based on lumped area and zonal water balance are discussed on a zone by zone basis. There is a need to quantify wider environmental benefits e.g. reduced saline flows to natural streams, protection of ecosystem services in and around the CIA as a result of implementation of the Land and Water Management Plan.

Initially a brief background to net recharge methodology and analysis is provided as content. Discussion then focuses on target setting and refinement of paddock scale net recharge. An outline of the implications of extreme events on targets is provided before setting out the basis for estimating damage functions for the economic modelling.

Table of Contents

List of Figures

List of Tables

1. Net recharge analysis

To estimate the net yearly recharge to groundwater, a simple spatial method was used. In this model, for each of the monitoring times (i.e., March and September every year), a groundwater surface for the entire CIA (approx. 80,000ha) was developed using the contouring software ‘SURFER’. Net recharge was determined by establishing the volume change between the two surfaces. The groundwater table data monitored between 1994 and 2004 from piezometers located in CICL’s jurisdiction were used in this study. The spatial analysis of groundwater table, using Krigging with a linear variogram model, indicated the aquifer volume which was then multiplied by the effective porosity (5%) to calculate the change in the volume of groundwater for irrigation (September to February) and non-irrigation periods (March to August).

The groundwater table data was gridded to: X range (easting) from 378590m to 420875m, and Y range (northing) from 6120000m to 6162175m. Once gridding was performed, the resultant mesh was blanked out using a digitised boundary map of the CIA. The blanking operation warranted that data outside the boundary of the CIA was ignored in any calculations. Piezometric data gridded and blanked thus formed each piezometric surface and these surfaces were determined for March and September of each year. When a groundwater surface of a succeeding period was deducted from the surface of the previous period, this gave the net volume change between the two periods. If the volume change was positive then net recharge had occurred, and if the volume change was negative then net discharge had occurred. In this analysis, the following assumptions were also considered:

- The piezometers less than 15m deep accurately reflect watertable level. This is likely to be the case but some areas where aquifer confinement occurs to a greater or lesser degree may impact on the validity of this assumption;
- The effective porosity value used (5 percent) will affect the magnitude of the values estimated here but will not affect whether the result is net recharge or discharge and it will not affect the trend over time as this methodology is based upon differences. As this analysis uses a uniform effective porosity for the whole area, errors will be created as the piezometric rise/fall in a clayey soil and sandy soil will be assessed to be the result of the same volume of net recharge, which is not the case; and
- The results obtained from the area wide analysis are representative averages of the irrigation area, and can therefore be strongly influenced by distinct fluctuations in particular subregions of the CIA.

For net recharge analysis, the following four estimates were made:

1. Net annual recharge (September): the volumetric watertable difference between September of a given year and September of previous year;
2. Net annual recharge (March): same method as above, March values substituted for September values to calculate volumetric water table difference;
3. Net Seasonal Recharge (summer/Irrigation): the volumetric addition during irrigation season, calculated by the volumetric watertable difference between March of a given year and September of the preceding year; and
4. Net Seasonal Discharge (winter/non-irrigation): the dissipated volume of water during the winter months (the non-irrigation period) determined by the volumetric watertable difference between March and September of any given year.

2. Results of the net recharge analysis of CIA

Figure 1 shows seasonal net recharge, winter rainfall and irrigation allocation for different years (March 1994 and March 2004). In the CIA, recharge mainly appears to occur in summer and discharge in the following winter period.

Figure 1: Temporal variations in net recharge in the CIA

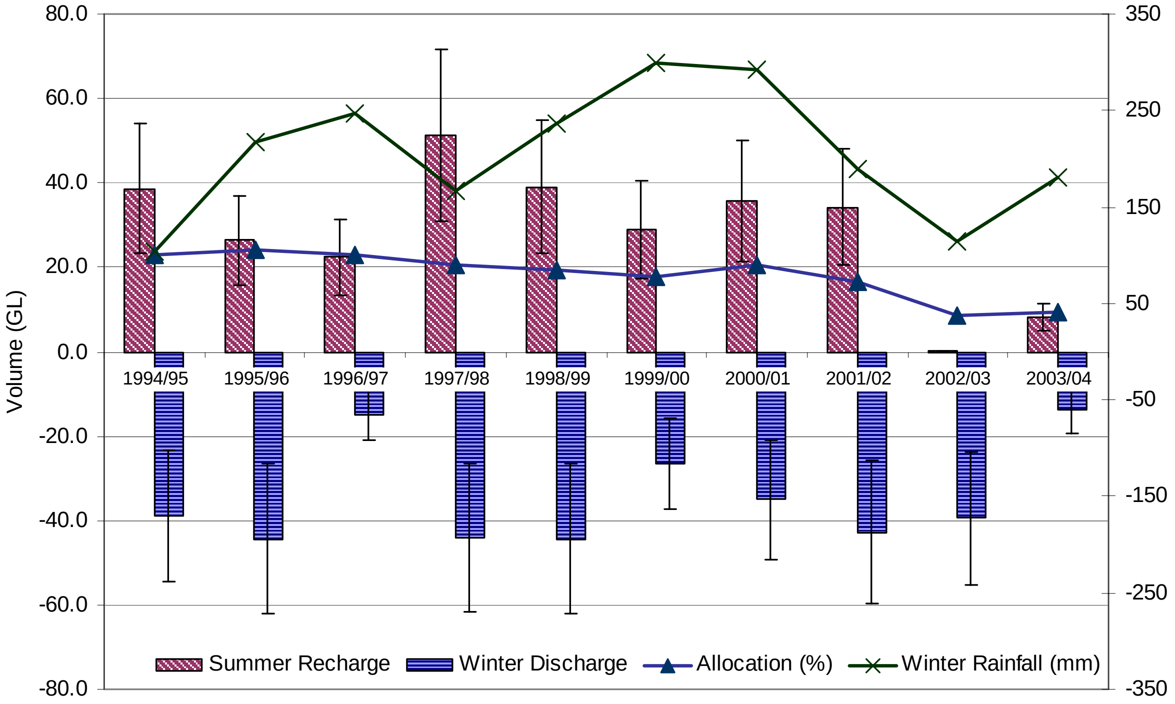
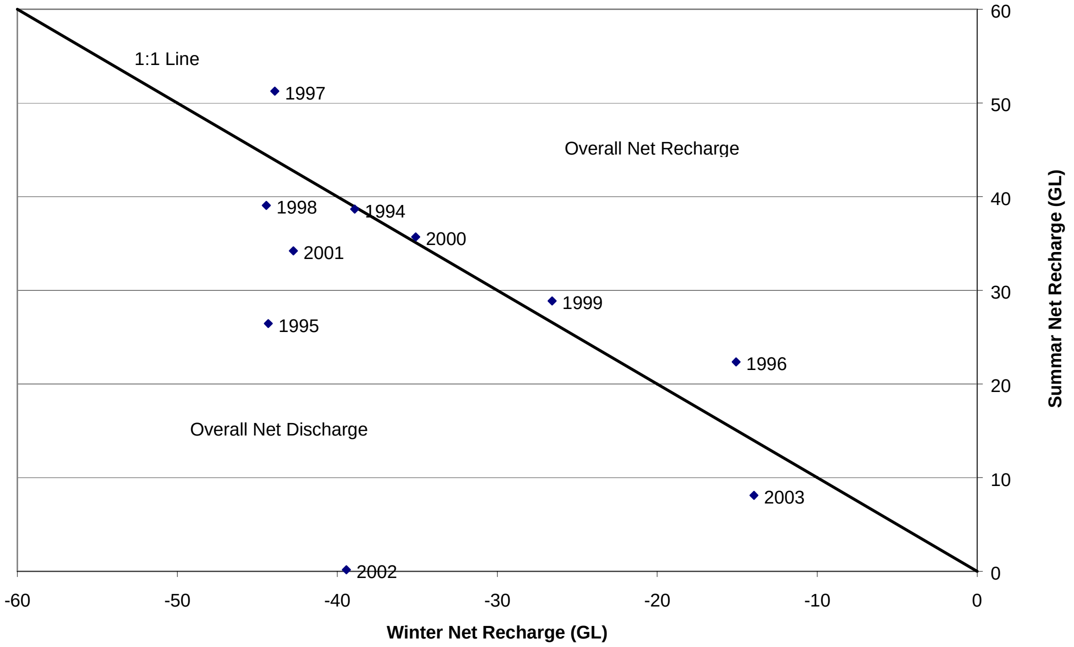


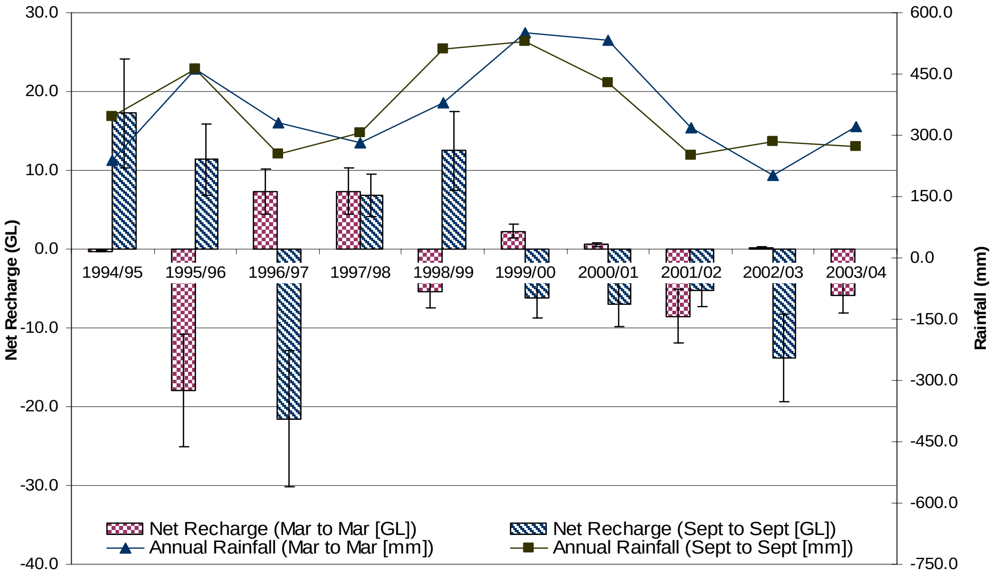
Figure 2 shows overall recharge and discharge periods. The net recharge values lying below the 45 degree line show an overall net discharge, whereas the values lying above this line show net accessions to the groundwater aquifer. During the 1996, 1997 and 1999 periods there was net recharge to the groundwater aquifer, whereas during the 1995, 1998, 2001, 2002 and 2003 there was a net discharge from the groundwater aquifer, mainly in shallow groundwater areas. Seasonal recharge and discharge for winter and summer are in balance for the year 1994 and 2000. The large winter discharge in 2002 was due to dry conditions in that year with a record deficit of evapotranspiration minus rainfall. This relationship could be useful in determining what levels not to exceed for net recharge management and what subsequent summer recharge values can be absorbed by the groundwater aquifer system.

Figure 2: Summary of overall net recharge and discharge periods in the CIA from 1994 to 2004



The annual net recharge estimated over longer time frame (including summer and winter seasons) provides alternative analysis on recharge trends (Figure 3). The March to March period analysis shows lesser fluctuation than the September to September period analysis. This might be because the March to March analysis is dominated by the recent irrigation activities and not complicated by the following winter conditions.

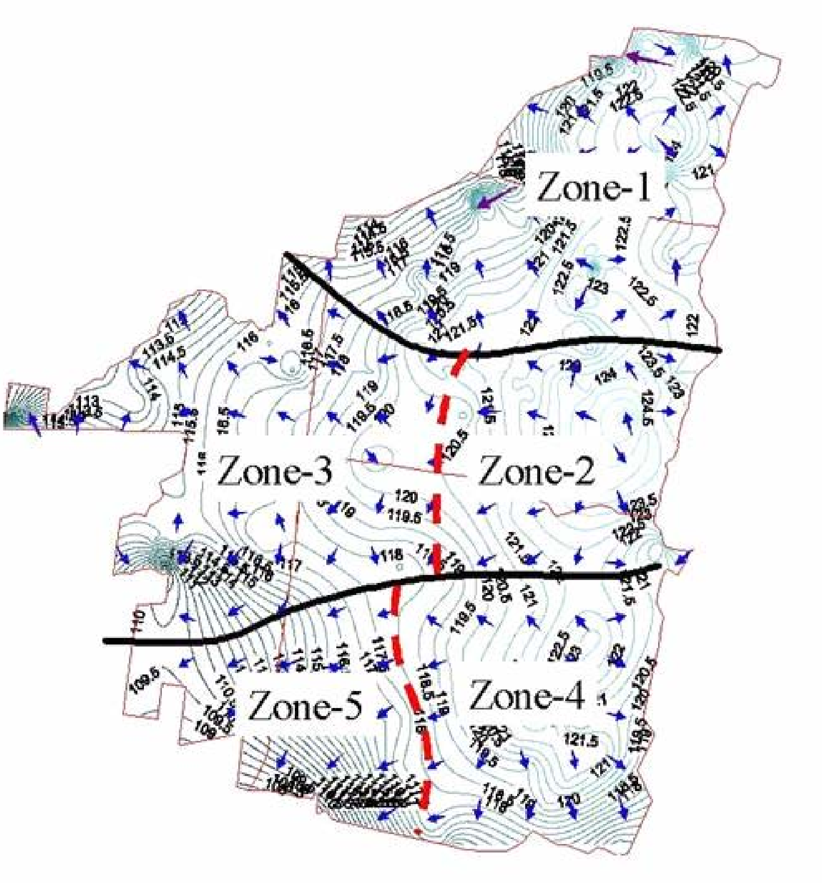
Figure 3: Net annual recharge for the CIA from 1994 to 2004



3. Net recharge targets for different zones in the CIA

Based on studies by Khan et al (2004a), the net recharge targets for 5 zones (Figure 4), derived using MODFLOW for the period 1999-2000, are presented in Table 1. For each of the zones, the water balance was computed for the upper Shepparton formation using the water budget analysis. The water budget provides estimates of net inflow, net outflow, total recharge, and vertical leakage from the upper Shepparton to Lower Shepparton formations.

Figure 4: Different zones for water balance in the CIA



On the basis of these calculations the total vertical leakage from shallow to deeper aquifers was estimated to be 31 GL. This estimate was twice the previously estimated vertical outflow capacity of the aquifers in the CIA. This is mainly due to decline in deeper aquifer pressures due to continued groundwater pumping. The net lateral flow from the upper Shepparton formation was small due to the smaller transmissivity of this aquifer. If the total transmissivity of the Shepparton formation was considered the total lateral outflow would be around 15 GL, as estimated by the previous studies. The total estimated recharge for 1999/2000 was 55.70 GL. Considering the lateral and the vertical outflow capacities (15+31 GL), the total recharge reduction requirement was 9.7 GL (0.12 ML/ha on the average). If the total recharge to the Shepparton formation could be managed according to the vertical leakage between aquifers, the watertable would remain static or decline over a period of time.

The upper limits of net recharge for the different zones were computed by adding the vertical leakage with the net local outflow and are given in the last row of Table 1.

Table 1: Net recharge targets for 5 zones in the CIA

Period	Water Balance Component	Zone1	Zone2	Zone3	Zone4	Zone5
Mar99-Aug99 (non irrigation period)	Horizontal Inflow (ML)	133	39	155	46	72
	Horizontal outflow (ML)	296	147	202	151	99
	Net Recharge(+)/Discharge (-) (ML/ha)	0.11	-0.16	-0.1	-0.02	0.12
	Leakage(ML/ha)	0.19	0.17	0.15	0.12	0.13
	Total Recharge(ML)	2613	-2075	-2656	-375	1556
	Leakage (ML)	4513	2205	3984	2250	1686
	Net recharge (ML)	-1900	-4280	-6640	-2625	-130
Sep99-Feb00 (irrigation period)	Horizontal Inflow (ML)	147	27	160	49	81
	Horizontal outflow (ML)	304	179	246	167	119
	Net Recharge(+)/Discharge (-) (ML/ha)	0.27	0.69	0.85	0.47	0.69
	Leakage(ML/ha)	0.17	0.27	0.16	0.14	0.14
	Total Recharge(ML)	6413	8948	22578	8813	8948
	Leakage (ML)	4038	3502	4250	2625	1816
	Net recharge(ML)	2375	5446	18328	6188	7132
Yearly Total	Horizontal Inflow (ML)	280	66	315	95	153
	Horizontal outflow (ML)	600	326	448	318	218
	Total Recharge(ML)	9026	6873	19922	8438	10504
	Leakage (ML)	8551	5707	8234	4875	3502
	Net Recharge (ML)	475	1166	11688	3563	7002
	Upper Limit of Total Recharge(ML)	8871	5967	8367	5098	3567

Water budget results for these five zones show a consistent pattern of groundwater recharge during the irrigation period and groundwater discharge during the non-irrigation period (Figure 5 & 6). The highest vertical groundwater leakage was around 0.2 ML/ha/six months for Zone 1, which was also associated with the lowest net recharge due to relatively deeper groundwater depth and groundwater pumping in and around the zone. Zones 3 & 4 had the lowest vertical groundwater leakage associated with high recharge rates. Zones 2, 3 & 4 had the highest risk of soil salinisation due to net vertical capillary upflows. The estimates provided in this report show that total CIA shallow to deep groundwater outflow capacity was around 15,000 ML/season or 30,000 ML/year. For the whole of the CIA, there was a need to reduce total recharge by around 20,000 to 25,000 ML/year through a combination of on-farm and regional management options.

Figure 5: Zonal water balance from March 1999 to August 1999 (i.e., non irrigation period) in the CIA.

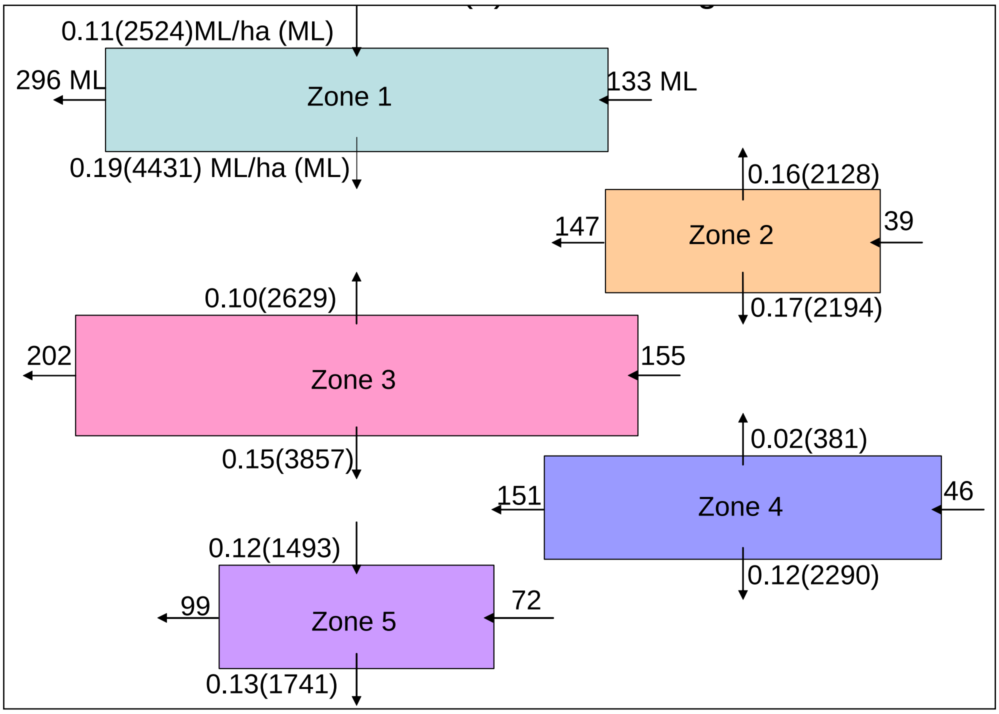


Figure 6: Zonal water balance from September 1999 to February 2000 (i.e., irrigation period) in the CIA

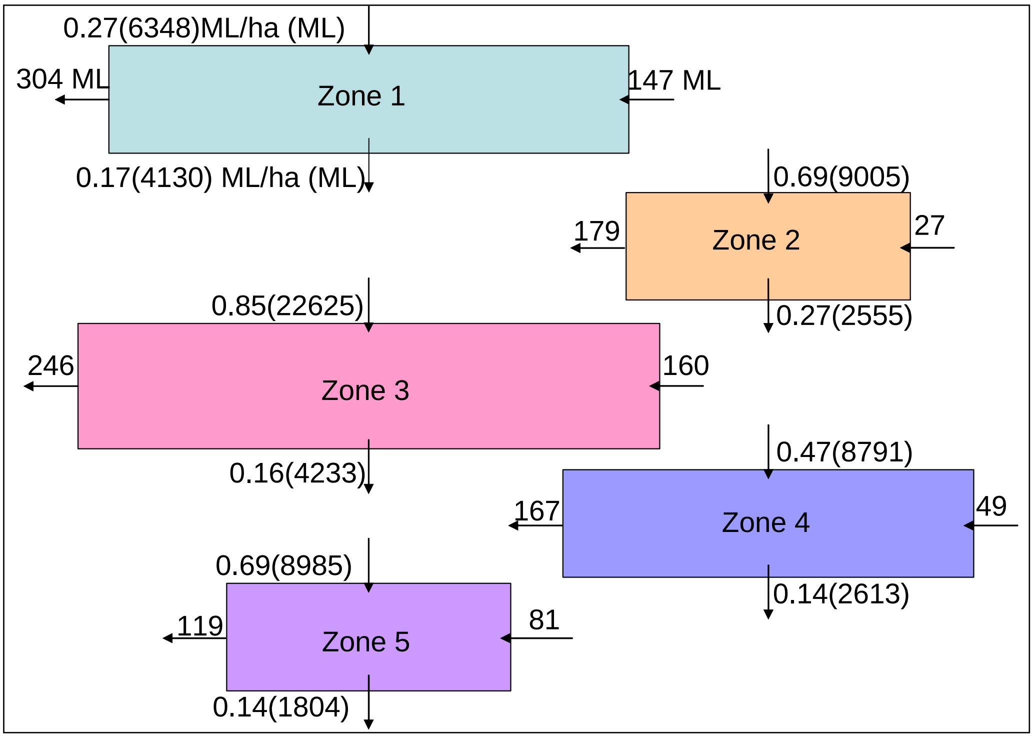


Figure 7 shows that recent dry conditions combined with higher groundwater pumping and low water allocations caused a net decline of 0.5 to 2 m in shallow groundwater levels in the region over a one year period. Figure 8 shows relative locations of pumping wells and groundwater outflow rates in shallow aquifers. It is noted that areas of greatest groundwater decline are located in close proximity of the deep groundwater pumping wells. This could also be explained by relatively higher vertical leakance between the Shepparton and Renmark formations, as shown by the recent analysis of Coleambally pumping test data by Khan et al (2004b).

Figure 7: Total groundwater declines from March 2002 to March 2003 in the CIA

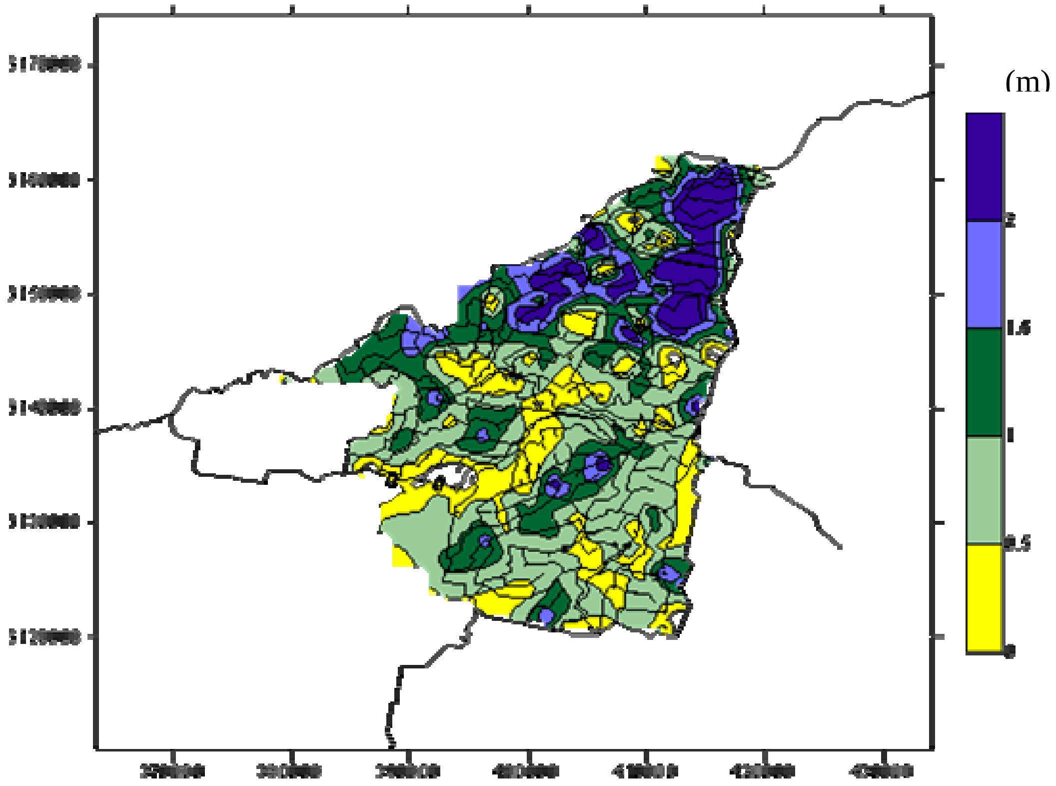
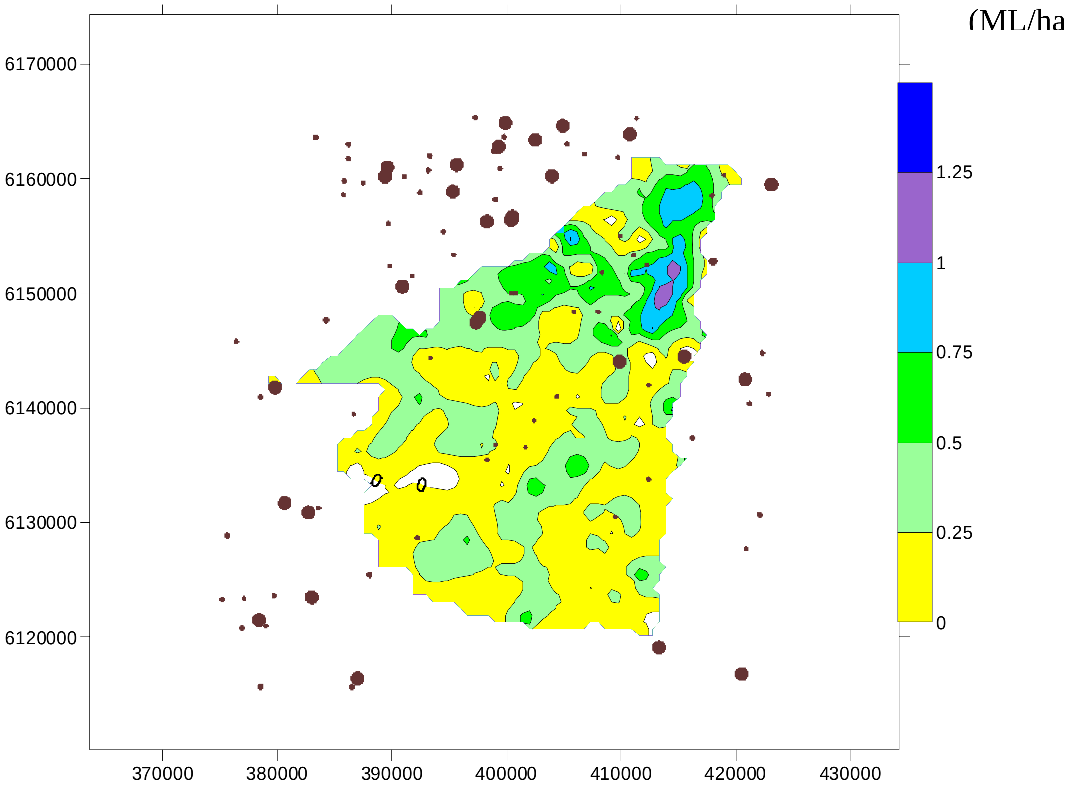


Figure 8: Estimated groundwater outflow from March 2002 to March 2003 in the CIA



4. Implications of extreme events on the net recharge targets

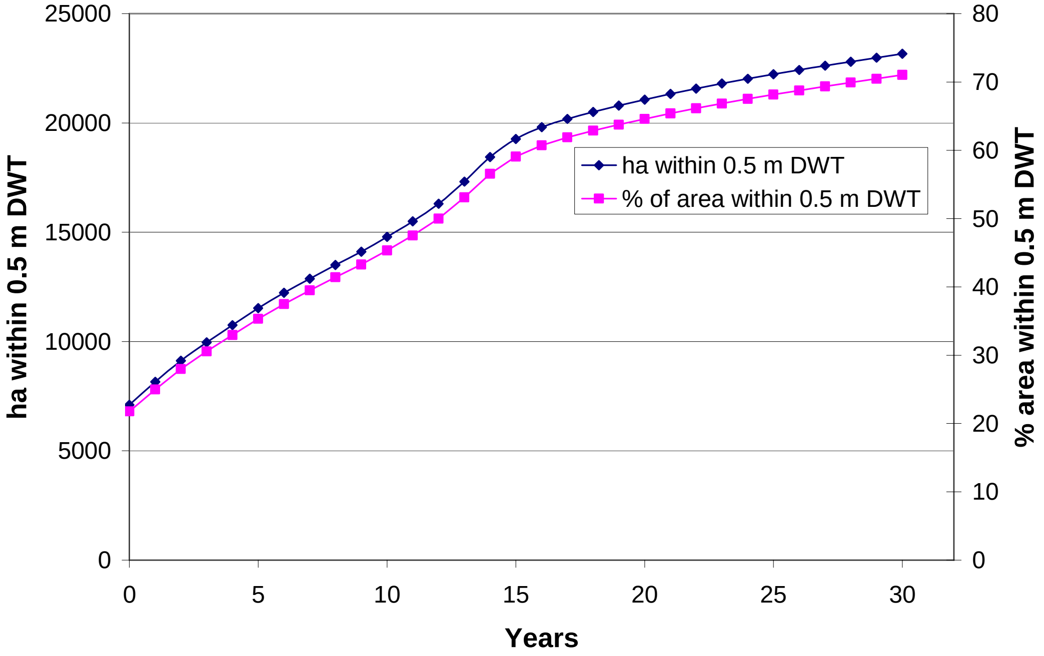
The results of the net recharge analysis for the last 10 years for non irrigation and irrigation periods show that the net recharge for the year/season 1997/98 was the highest, and therefore it could be considered as the extreme event for the study area. By using this net recharge estimates in the calibrated MODFLOW model of the CIA (Khan et al, 2004a), the simulation was run for the next 30 years to analyse the impact of this extreme event on the depth to watertable in the western Coleambally Irrigation Area. Table 2 and Figure 9 show the time dependent increase in the western CIA under 0-0.5 m depth to watertable for the next 30 year scenario.

Table 2: Impact of extreme events on the depth to watertable in western CIA

Year	**Ha**	**%(32612 ha)**
Start	7099	22
1	8148	25
2	9119	28
3	9962	31
4	10744	33
5	11522	35
6	12225	37
7	12878	39
8	13505	41
9	14112	43
10	14783	45
11	15498	48
12	16302	50
13	17315	53
14	18445	57
15	19268	59
16	19805	61
17	20182	62
18	20502	63
19	20791	64
20	21063	65
21	21323	65
22	21569	66
23	21801	67
24	22020	68
25	22229	68
26	22427	69
27	22618	69
28	22802	70
29	22983	70
30	23163	71

Note: Assumed net recharge for irrigated CIA during the irrigation period was 0.356 mmd^{-1}*, whereas during the non-irrigation period, it was -0.305 mmd*$^{-1}$*.*

Figure 9: Simulated watertable depth rise in western CIA



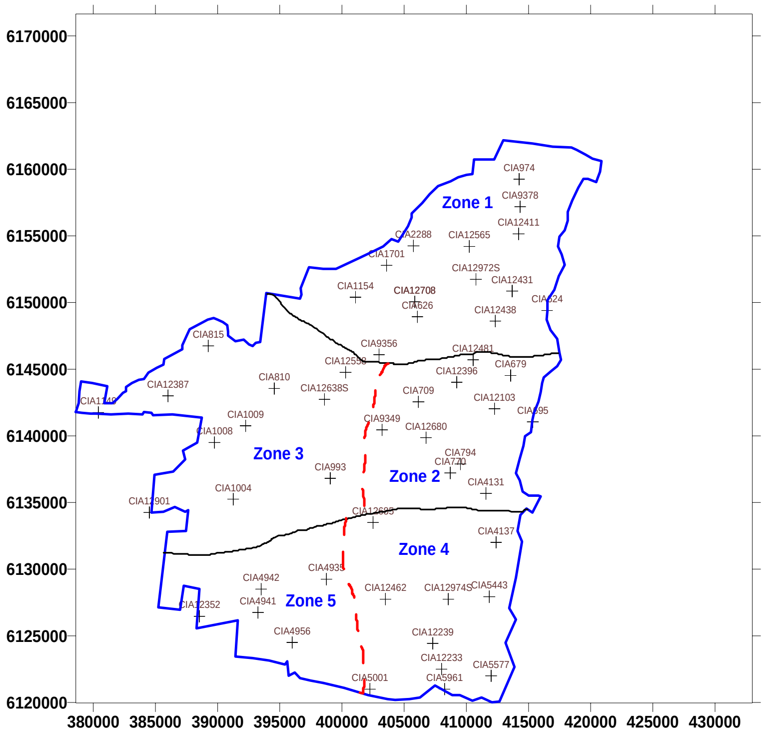
5. Possible LWMP options for different zones in the CIA

The analysis carried out under this study has shown changes in the area of recharge and discharge zones in the CIA, where at present the overall recharge areas are around 30 percent of the region. This situation requires to: (i) implement both on-farm and regional management options for the groundwater discharge zones and (ii) investigate the need for rational sharing of costs between the net groundwater recharging farms, discharging farms and the wider environment. The present work could serve as a basis for forming net recharge target credits with individual farmers to: (i) help achieve CICL groundwater and salinity management targets and (ii) promote a rational environmental management dialogue between the farmers and CICL.

On a regional basis, the overall vertical leakage capacity between the shallow and deeper aquifers is around 30,000 ML/year. To maintain or lower current groundwater levels, the total recharge needs to be less than the overall vertical leakage capacity of aquifers. Since groundwater levels in some regions, e.g., central, southern and western parts are already within the root zone so there is a need to initially reduced groundwater recharge to less than the outflow capacity. On sub-regional (hereby called zonal) basis, water balances indicated that there is a need to quantify wider environmental benefits e.g. reduced saline flows to natural streams, protection of ecosystem services in and around the CIA as a result of implementation of the Land and Water Management Plan.

Groundwater discharge zones, which are usually located in low lying areas, such as around Bull Road, are impacted by both regional and local groundwater inflows. An immediate remedial action would be to stop growing rice within 100m of these depressions because groundwater levels are already too close to the surface and any hydraulic loading in the near vicinity could cause lateral flows to these depressions. In addition to this local action, there is also a need to intercept regional saline groundwater flows towards these depressions. Figure 10 presents the location map of the selected piezometers to help visualizing the trends in groundwater dynamics in different zones of the CIA.

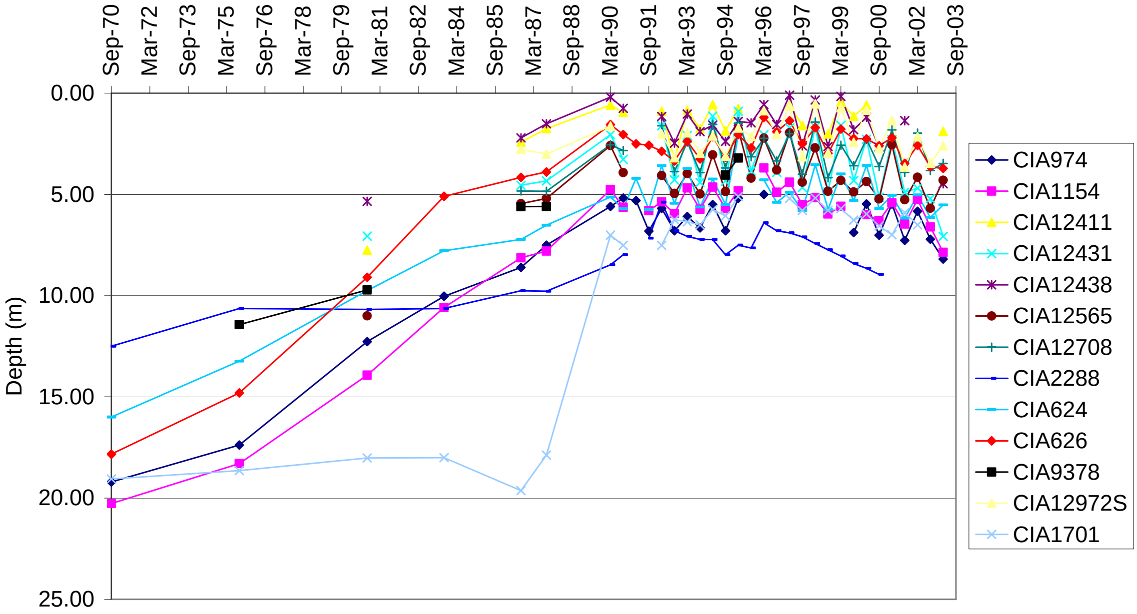
Figure 10: Location map of the selected piezometers in different zones of the CIA



5.1 Possible LWMP options for Zone 1

The total groundwater outflow capacity of this zone is around 7000 ML/year. The piezometric levels close to the eastern edge of this zone are very close to the ground surface whereas groundwater levels close to western edge are deeper than 5 m. There is an overall groundwater level declining trend in this region (Figure 11) and it is anticipated that the downward leakage rates in this region will increase in future. It is recommended that rice growing with high water use in this region should be converted to non-ponded crops such as maize to improve the overall water use efficiency of this region.

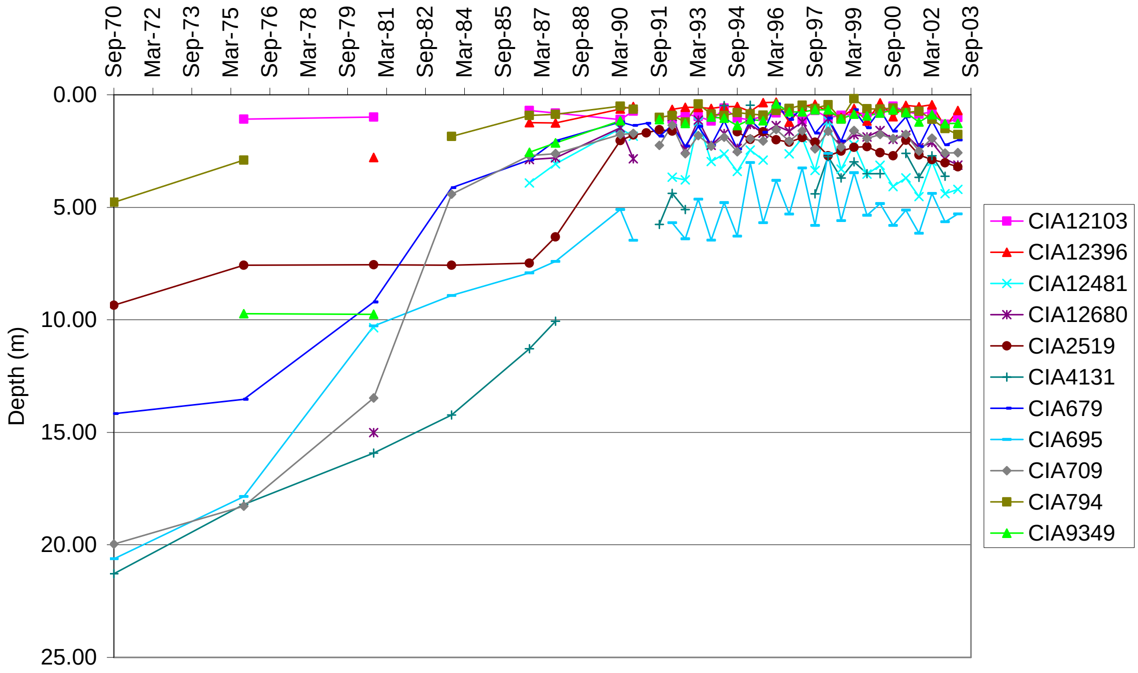
Figure 11: Historic groundwater trends in Zone 1 of the CIA



5.2 Possible LWMP options for Zone 2

The total groundwater outflow capacity in this zone is around 4000 ML/yr. Some of the groundwater levels away from the Coleambally deep groundwater bore are very close to the ground surface (Figure 12). There is a need to implement net recharge management on a priority basis to all farms within this region with total on farm recharge reduced to less than 0.5 ML/ha using winter cropping options as well as limited rice water use to less than ETrice+1 ML/ha. Spear point pumping and conjunctive use of surface and groundwater is recommended as a management option on the eastern edges of this zone in areas where shallow groundwater salinity is less than 2500 EC.

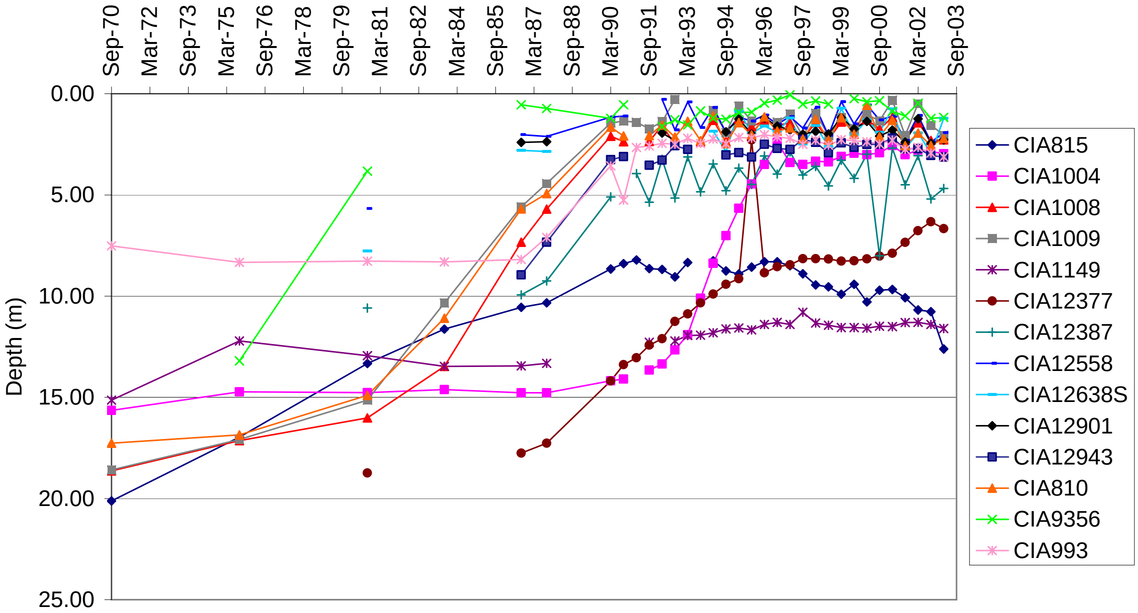
Figure 12: Historic groundwater trends in Zone 2 of the CIA



5.3 Possible LWMP options for Zone 3

The total groundwater outflow capacity of this zone is around 7000 ML/yr. The groundwater levels close to the intersections between zones 2 and 3 are near the ground surface and the groundwater levels at the western edge are well below the root zone. Although groundwater levels have shown a declining trend (Figure 13) in the last couple of years, this is a net groundwater importing/discharge zone and therefore remains the highest salinity risk area due to higher capillary outflows from the saline watertable surface. There is a need to implement net recharge management on a priority basis with an objective to reduce total recharge by 0.6 ML/ha/year through winter cropping, on farm water use efficiency improvement and shallow groundwater pumping. However due to higher salinity of shallow groundwater drainage reuse options may be limited. Drainage options combined with the serial biological concentration of salts should be considered in the eastern and middle parts of this region.

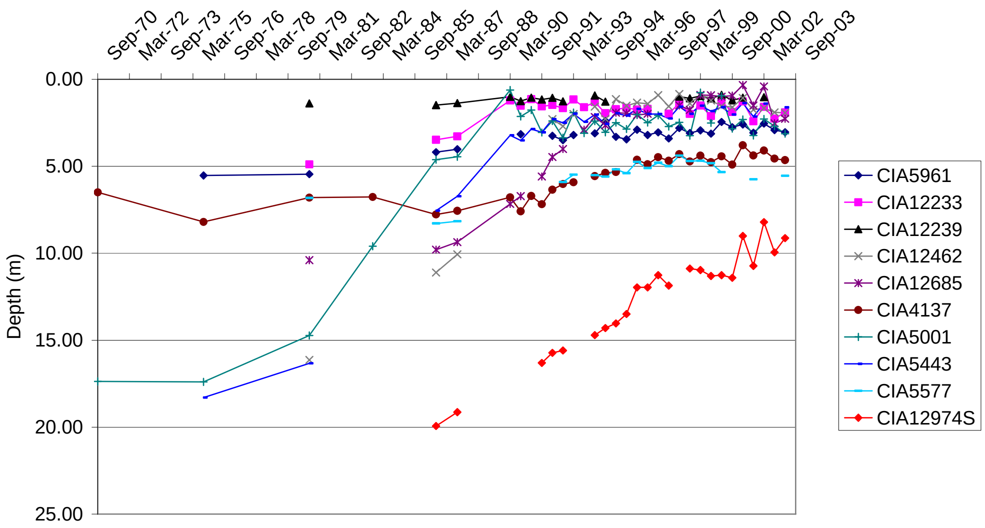
Figure 13: Historic groundwater trends in Zone 3 of the CIA



5.4 Possible LWMP options for Zone 4

The total groundwater outflow capacity in this zone is around 5000 ML/yr. Despite very dry climate and low water allocations over the past couple of years this area has not shown any dramatic decline in the piezometric levels (Figure 14) therefore confirming a very low rate of vertical leakage between the shallow and deeper aquifer. Similar to zone-3 this zone is at the highest salinity risk due to shallow watertables and higher capillary outflows through the soil. There is a need to implement net recharge management on a priority basis with an objective to reduce total recharge by 0.5 ML/ha/year through winter cropping, conversion from annual pastures to lucerne, on-farm water use efficiency improvement and shallow groundwater pumping. Rotation of rice paddocks to leach out salts from the root zone should also be considered as an option. There is some potential for good quality shallow groundwater pumping at the eastern edges of this area. However due to higher salinity of shallow groundwater drainage from most of this zone reuse options may be limited. Drainage options combined with the evaporation basins and serial biological concentration of salts should be considered in the middle parts of this region.

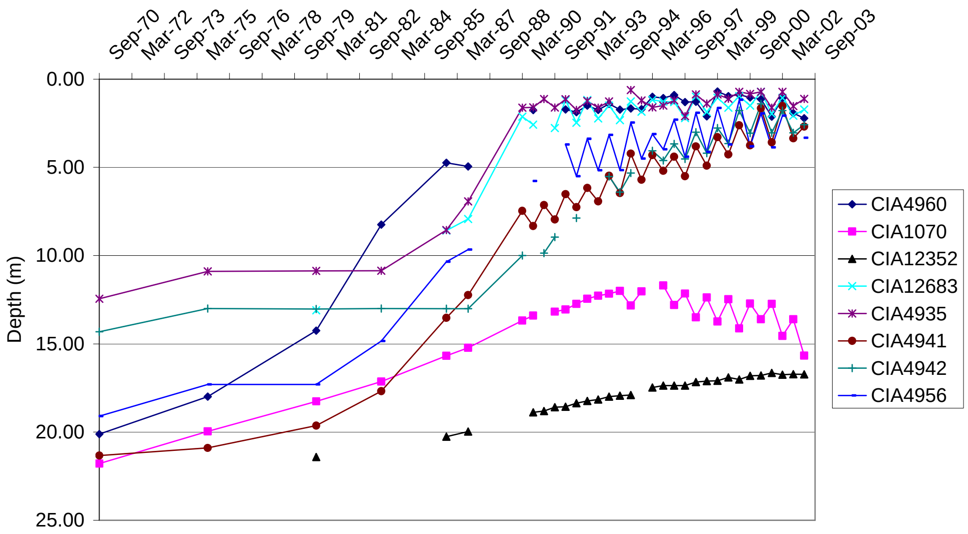
Figure 14: Historic groundwater trends in Zone 4 of the CIA



5.5 Possible LWMP options for Zone 5

The total groundwater outflow capacity in this zone is around 3000 ML/yr. The piezometric levels at the extreme western edges of this region have shown a declining trend over the last few years indicating a good impact of deep groundwater pumping and reduced lateral inflows (Figure 15). It is recommended that net recharge management should be implemented with a target to reduce overall recharge by 0.4 ML/ha and to enhance vertical leakage by encouraging deeper groundwater pumping. Local improvements in this zone combined with improvements in zone-4 will achieve the long term sustainability of this zone.

Figure 15: Historic groundwater trends in Zone 5 of the CIA



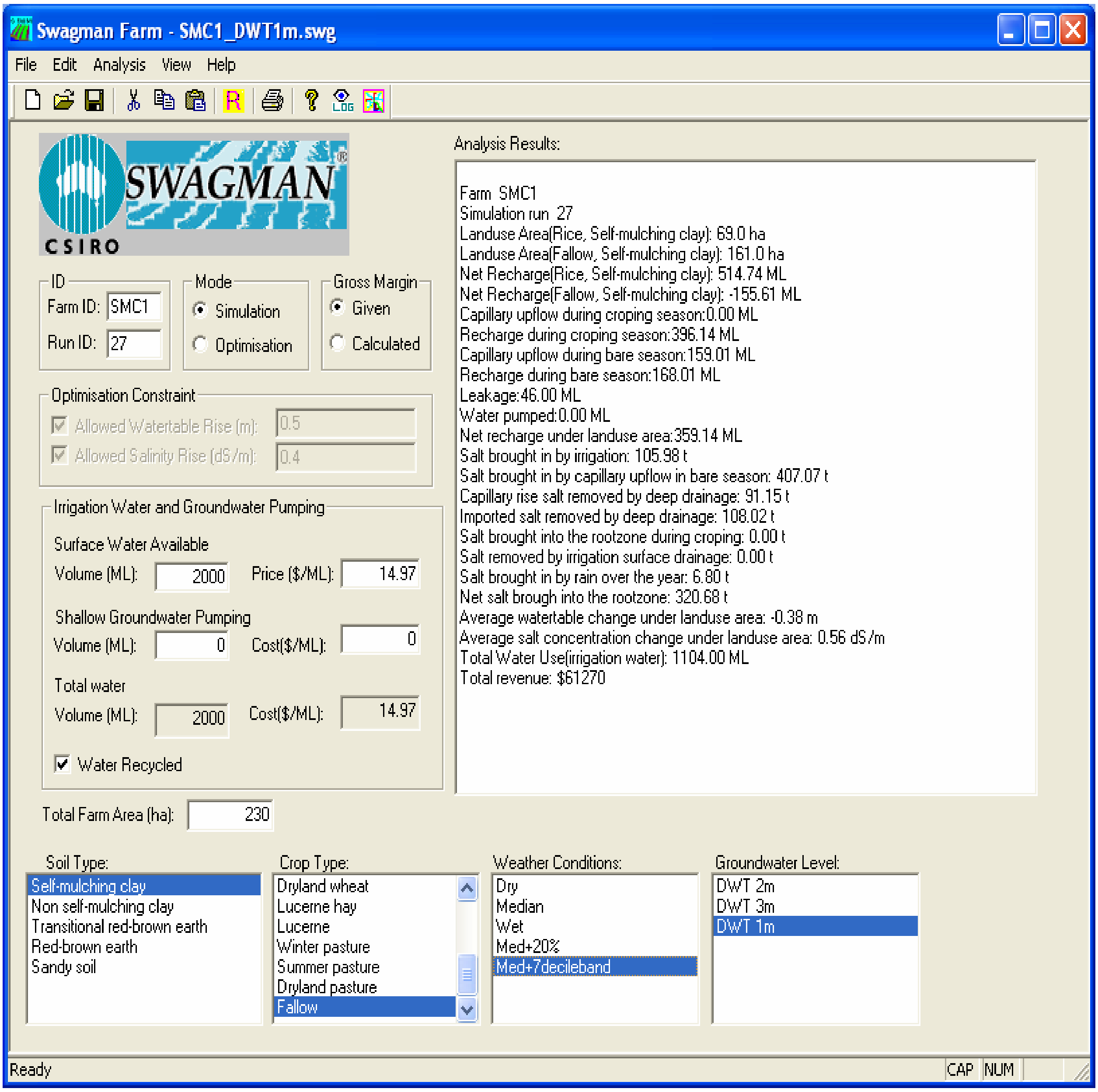
6. Implementing net recharge at the farm level

The net recharge management implementation process builds on strong research partnerships between CICL, CSIRO and the CRC for Sustainable Rice Production over the past seven years.

New software tools have helped promote rational land and water management options and provide a means to monitor change in water use efficiency and environmental conditions. One of the innovative tools is a state of the art farm level hydrological economic model, SWAGMAN Farm (Salt Water And Groundwater MANagement). SWAGMAN Farm can clearly show economic and environmental tradeoffs in adopting different land and water management options and help to decide sustainable irrigation intensities. Regional groundwater investigations, surface-groundwater interaction models of the irrigation regions and the SWAGMAN Farm model are strategic developments in natural resource management which are serving as the backbone for strategies such as improving water use efficiency, reducing net recharge to groundwater and monitoring changes in environmental conditions on a spatial basis. Coleambally Irrigation has structured its environmental management business around on-farm net recharge management using SWAGMAN Farm and groundwater management zones.

SWAGMAN Farm is lumped water and salt balance model which integrates agronomic, climatic, irrigation, hydrogeological and economic aspects of irrigated agriculture under shallow watertable conditions at a farm scale (Khan et al., 2000). The model has a dedicated standalone (Figure-16) and web based user-interface to help input data and visualise results. This model has been used to develop management options such as net recharge management for control of shallow watertables which focuses on managing the net recharge beneath the root zone in relation to the vertical and lateral regional groundwater flow. In SWAGMAN Farm, the lumped estimates of the water and salt balance components for the cropping and fallow periods are computed for a range of irrigated crops such as rice, soybean, maize, sunflower, fababean, canola, wheat, barley, hay lucerne, grazed lucerne, annual pasture, perennial pasture as well as dryland wheat and uncropped areas, for different irrigation, soil, climatic and hydrogeological conditions. The water and salt balance computations for each of the crops are derived using the results of detailed monitoring (Edraki et al 2003).

Figure 16: Interface of SWAGMAN Farm as tool in aiding in net recharge management



ID

Farm ID: SMC1

Run ID: 27

Mode

● Simulation

○ Optimisation

Gross Margin

● Given

○ Calculated

Optimisation Constraint

☑ Allowed Watertable Rise (m): 0.5

☑ Allowed Salinity Rise (dS/m): 0.4

Irrigation Water and Groundwater Pumping

Surface Water Available

Volume (ML): 2000 Price ($/ML): 14.97

Shallow Groundwater Pumping

Volume (ML): 0 Cost($/ML): 0

Total water

Volume (ML): 2000 Cost($/ML): 14.97

☑ Water Recycled

Total Farm Area (ha): 230

Soil Type:
- Self-mulching clay
- Non self-mulching clay
- Transitional red-brown earth
- Red-brown earth
- Sandy soil

Crop Type:
- Dryland wheat
- Lucerne hay
- Lucerne
- Winter pasture
- Summer pasture
- Dryland pasture
- Fallow

Weather Conditions:
- Dry
- Median
- Wet
- Med+20%
- Med+7decileband

Groundwater Level:
- DWT 2m
- DWT 3m
- DWT 1m

Analysis Results:

```
Farm SMC1
Simulation run 27
Landuse Area(Rice, Self-mulching clay): 69.0 ha
Landuse Area(Fallow, Self-mulching clay): 161.0 ha
Net Recharge(Rice, Self-mulching clay): 514.74 ML
Net Recharge(Fallow, Self-mulching clay): -155.61 ML
Capillary upflow during croping season:0.00 ML
Recharge during croping season:396.14 ML
Capillary upflow during bare season:159.01 ML
Recharge during bare season:168.01 ML
Leakage:46.00 ML
Water pumped:0.00 ML
Net recharge under landuse area:359.14 ML
Salt brought in by irrigation: 105.98 t
Salt brought in by capillary upflow in bare season: 407.07 t
Capillary rise salt removed by deep drainage: 91.15 t
Imported salt removed by deep drainage: 108.02 t
Salt brought into the rootzone during croping: 0.00 t
Salt removed by irrigation surface drainage: 0.00 t
Salt brought in by rain over the year: 6.80 t
Net salt brough into the rootzone: 320.68 t
Average watertable change under landuse area: -0.38 m
Average salt concentration change under landuse area: 0.56 dS/m
Total Water Use(irrigation water): 1104.00 ML
Total revenue: $61270
```

6.1 Application of SWAGMAN farm to manage net recharge targets

In order to analyse watertable and salinity impacts of different rice based irrigation systems, 10 scenarios were undertaken for a single farm with an area of 230 ha. These scenarios included single crops grown in individual paddocks as well as rotations such as rice/wheat and corn/wheat in the same paddock over a given year. For these scenarios 5th deciles of rainfall were considered (Table 3). These scenarios included crop mixes given in Table 4. The irrigation levels used for these crops are given in Table 5.

The effect of initial watertable depth on net recharge was explored for each of the scenarios, with starting water levels of 1m and 3m employed. These levels were assumed to be consistent over the whole areas of the farm with no local fluctuations anticipated for this application. No groundwater pumping was included and the runoff from the farm/paddocks was considered minimal due to the water being recycled back onto the farm. Three regional groundwater outflow rates (0.2, 0.5 and 1 ML/ha) were used to explore options for the southern, central and northern parts of the study area. The initial water content for both soils was considered to be 0.3.

Table 3: Rainfall Analysis Using Decile Method on the Coleambally Rainfall Data (1920-2003)

Decile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1st	23	22	20	34	11	4	11	101	0	0	14	3	244
2nd	0	6	54	10	30	11	20	6	32	73	34	3	277
3rd	17	12	25	59	14	24	37	45	13	27	5	46	323
4th	0	45	0	14	18	21	63	53	12	59	30	35	350
5th	0	1	10	28	26	23	45	33	9	69	11	114	368
6th	14	0	1	2	32	149	89	19	10	20	7	77	419
7th	54	59	6	75	66	21	61	45	38	25	4	7	462
8th	153	14	20	12	85	3	38	27	81	5	32	27	498
9th	4	5	33	44	34	19	13	61	43	121	66	124	566
10th	75	1	124	46	115	64	81	20	48	155	15	9	752

Table 4: Landuse Areas (ha) and cropping patterns for Selected Scenarios

Scenario	Landuse Areas (ha)
1	69 rice, 161 fallow
2	69 rice, 75 wheat, 25 winter pasture, 61 fallow
3	69 rice, 25 wheat, 25 lucerne, 111 fallow
4	69 rice, 50 wheat, 25 lucerne, 25 winter pasture, 61 fallow
5	69 rice, 25 soybeans, 25 corn, 111 fallow
6	19 rice, 50 rice/wheat, 50 corn, 111 fallow
7	19 rice, 50 rice/wheat, 25 lucerne, 136 fallow
8	200 corn, 30 fallow
9	100 corn, 100 wheat, 30 fallow
10	100 corn/wheat, 130 fallow

Table 5: Irrigation Levels (ML/ha) for Selected Scenarios

Crop	Irrigation requirement (ML/ha)
Rice	16
Rice/Wheat (R-W)	19
Wheat	3
Winter Pasture	6
Lucerne	5
Soybeans	8
Corn	10
Corn/Wheat (C-W)	13

6.2 Model results and outputs

The proposed cropping scenarios were modelled for transitional red brown earths soil type, 5th decile band of rainfall pattern, two groundwater depths (1 and 3 m) and three groundwater flow rates i.e. 0.2, 0.5 and 1 ML/ha (10x1x1x2x3=60 model runs) to explore effect of different factors on net recharge and salinity changes. This analysis is based on irrigation water use provided in Table 5. The model results are given in Tables 6 and summarized below.

Implications for Southern CIA

For 0.2 ML/ha groundwater outflow (typical for the Southern CIA) all scenarios result in a net positive recharge except scenario 7 with 50 ha rice-wheat rotation, 15 ha rice, 25 ha of lucerne and 136 ha of fallow. The first 5 scenarios with 69 ha of rice crops without a crop after rice result in the higher rates of groundwater recharge. For 1 m depth to watertable there is a net accumulation of salt resulting in 0.4 to 0.7 dS/m increase in groundwater salinity. For the deeper groundwater depths the net recharge is able to keep the root zone free of salts. Scenarios 8, 9 and 10 show Corn-Wheat rotation is a better option in terms of relatively less recharge (still the recharge is around 1 Ml/ha) however there is greater risk of salinisation if the watertable is at 1 m depth from the ground surface.

Implications for Central and Western CIA

The 0.5 ML/ha regional groundwater outflow rate is quite typical for the central and Western parts of the CIA. The best cropping option to control groundwater recharge appears to be scenario 7 with 3 m depth to watertable with the lowest net recharge and net increase in salinity. Other options such as scenario 10 with a corn-wheat rotation again give lower net recharge (0.4 to 0.6 ML/ha). All other options result in net recharge greater than 0.7 ML/ha.

Implications for Northern CIA

The regional groundwater outflow rates of 1 ML/ha and watertable depth of 3 m roughly represent the groundwater conditions in the Northern CIA. For these conditions cropping scenarios 7 and 10 result in lowest net recharge (-0.3 and 0.1 ML/ha). In this region if rice-wheat rotation with some area under lucerne or a corn-wheat rotation is practiced the net recharge can be reduced to below or very close to the target levels.

Table 6: Watertable and Salinity Impacts of Different Rice Growing Scenarios for Transitional Red Brown Earth Soils using 5th decile band for rainfall data

Scenario (Total Farm: 230 ha)	**Depth of Water Table (m)**	**Net Recharge/Discharge under Land use (ML)**			**Net Recharge (ML/ha)**			**Salt from Irrigation (tons)**	**Net Salt into rootzone (tons)**	**Ave WT Change under Landuse (m)**	**Ave salt conc change under landuse (dS/m)**
		Leakage @ 0.2 (ML/ha)	Leakage @ 0.5 (ML/ha)	Leakage @ 1.0 (ML/ha)	Leakage @ 0.2 (ML/ha)	Leakage @ 0.5 (ML/ha)	Leakage @ 1.0 (ML/ha)				
1	1	177	108	-7	0.8	0.5	0.0	106	486.2	-1.0	0.8
	3	260	191	76	1.1	0.8	0.3	106	4.8	0.6	0.0
2	1	355	286	171	1.5	1.2	0.7	164	184.2	0.2	0.3
	3	262	193	78	1.1	0.8	0.3	164	44.8	0.9	0.0
3	1	121	52	-63	0.5	0.2	-0.3	132	661.9	-1.2	1.1
	3	270	201	86	1.2	0.9	0.4	132	30.4	0.6	0.0
4	1	224	155	40	1	0.7	0.2	161	510.4	-0.6	0.8
	3	262	193	78	1.1	0.8	0.3	161	43.2	0.9	0.0
5	1	322	253	138	1.4	1.1	0.6	149	335.2	-0.4	0.5
	3	324	255	140	1.4	1.1	0.6	149	8.5	1.1	0.0
6	1	94	25	-90	0.4	0.1	-0.4	168	335.2	-0.4	0.5
	3	170	101	-14	0.7	0.4	-0.1	168	3.3	1.4	0.0
7	1	-225	-294	-409	-1.0	-1.3	-1.8	132	737.4	-1.5	1.2
	3	42	-27	-142	0.2	-0.1	-0.6	132	16.8	0.6	0.0
8	1	587	518	403	2.6	2.3	1.8	192	90.6	0.6	0.1
	3	466	397	282	2.0	1.7	1.2	192	0.9	2.6	0.0
9	1	288	219	104	1.3	1.0	0.5	154	90.6	0.6	0.1
	3	210	141	26	0.9	0.6	0.1	154	58.2	1.1	0.0
10	1	-14	-83	-198	-0.1	-0.4	-0.9	125	391.7	-0.6	0.6
	3	-14	-83	-198	-0.1	-0.4	-0.9	125	3.84	0.7	0.0

**Negative watertable changes (drawdowns) reflect watertable changes due to capillary upflow responses. When the watertables are within 1 m from the surface they will fluctuate between 1 and 2 m.*

7. Future research directions

Further research efforts are required to revise existing LWMP options. This can be facilitated by:

- Hydrologic-economic ranking of on-farm and regional options for regional groundwater management.
- Hydrological assessment of downstream environmental benefits of net recharge management by implementing promising on-farm and regional groundwater management options.
- Investigation and promotion of market based instruments for sharing environmental costs and benefits among the stakeholders in catchments, for example, tiered water pricing to reward better performing farmers.

It is recommended to validate SWAGMAN Farm watertable change by installing two shallow test wells (to be cited according to the low and high electromagnetic response) on each farm. This will help confirm the watertable fluctuations under each of the farm at the start and the end of a given year. Development of guidelines for shallow groundwater pumping utilizing beneficially and effectively the aquifer recharging corridors along the channels.

References

Khan, S. Paydar, Z., and Rana, T. (2004a) Net Recharge Targets to meet Regional Environmental Goals, CSIRO Land and Water Technical Report, December 2004.

Khan, S., Blackwell, J., Rana, T. and Leitte, A. (2004b) Surface-ground water and intra-aquifer interactions: the sustainable development potential of aquifers, 9th Murray Darling Basin Conferenc,. Bendigo, February, 2004. CD of Conference Proceedings.

Edraki, M, Smith D, Humphreys E, Khan S, O'Connell N, and Xevi E. (2003) Validation of the SWAGMAN® Farm and SWAGMAN® Destiny models, CSIRO Land and Water Technical Report 44/03.