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Quantifying Climate and Management Impacts on Watertables and Soil Salinity (Summary)

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Executive Summary

This report describes the development of a surface-groundwater interaction model for the Murrumbidgee Irrigation Area (MIA), situated in New South Wales, about 600 km west of Sydney and 900 km east of Adelaide. The MIA includes the town of Griffith and Leeton, and the study area covers the boundaries of 375250, 6150500 and 460000, 6230000 in UTM coordinate system shown in Figure E-1. On July 13, 1912 the irrigation scheme was opened bringing water to the area from storages (Burrinjuck dam – 1026 GL and Blowering dam – 1628 GL) through rivers and supply channels, using gravity as the means to manage water flow. Rice growing started in 1924 with its rapid development during 1970-80s. The total area for the MIA is 230,222 ha having dominant land use of rice with more than 32,000 ha in year 2000. Water use by crops is presented in Table E-1. The rising watertable and salinisation have threatened the viability of the MIA and this work is part of management strategies to ensure the sustainability of the area.

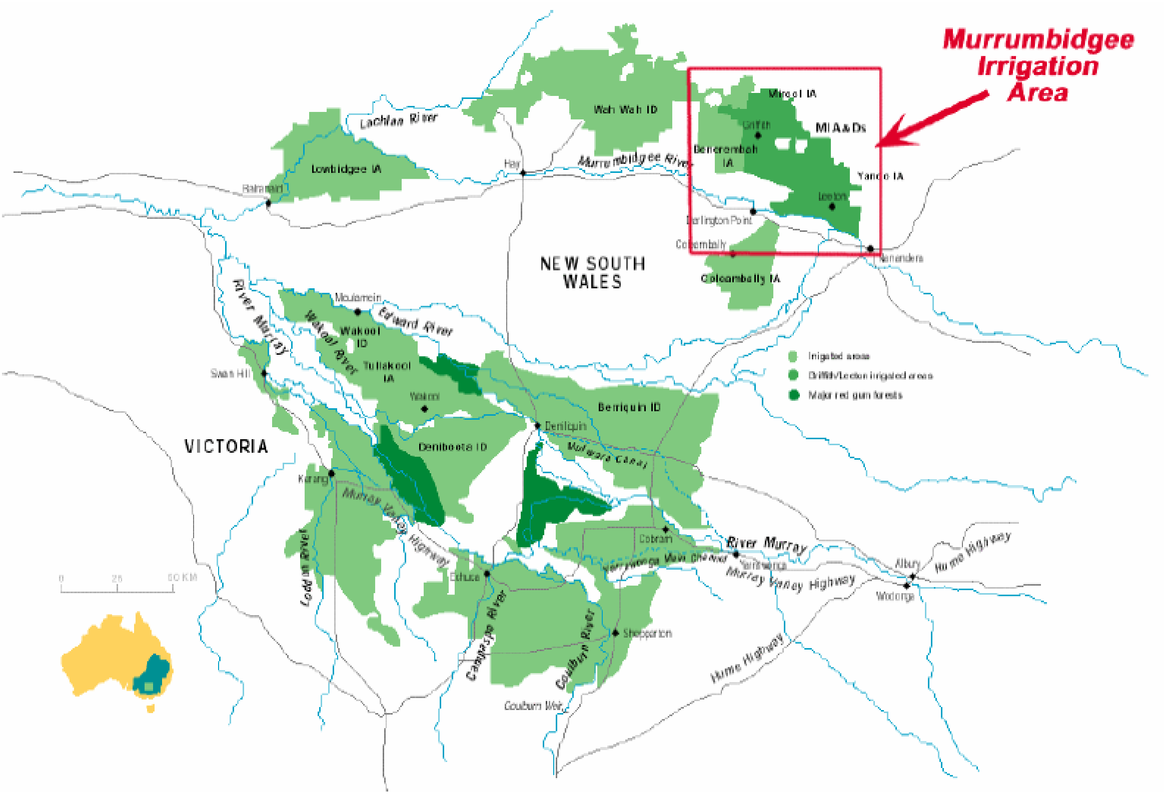


Figure E-1 Location of the MIA in New South Wales Irrigated Area

Table E1-1 Water use (ML) by crops for 1998-99 season;
Courtesy: MIA Report, 1999

Month	Rice	Pasture	Cereal	Vegetables	Horticulture	Misc	Total	% of Total
August	-	2,184	6,307	14	8	1,204	9,717	1.2
September	801	1,755	3,140	19	365	1,205	7,285	0.9
October	77,758	2,030	8,925	1,629	5,370	2,937	98,649	12.0
November	73,339	4,251	8,882	3,108	13,187	4,223	106,990	13.0
December	109,170	6,259	9,605	5,457	24,829	6,623	161,943	19.6
January	126,336	6,270	11,769	6,539	23,089	5,835	179,838	21.8
February	75,530	11,148	8,160	4,790	20,360	4,866	124,854	15.1
March	14,517	37,279	3,836	2,039	10,215	13,011	80,897	9.8
April	23	9,209	1,203	237	3,300	6,059	20,031	2.4
May	89	15,209	2,678	1,005	3,891	3,003	25,875	3.1
June	-	6,197	726	130	908	1,350	9,311	1.1
Total	477,563	101,791	65,231	24,967	105,522	50,316	825,390	100
% of Total	57.9	12.3	7.9	3.0	12.8	6.1	100	

E-1 Hydrogeology and Soils of the MIA

The climate of MIA is semi-arid, with average annual rainfall ranging from 256 mm to 609 mm while at Griffith is 406 mm. The geology is described by three major aquifer systems i.e. Shepparton, Calivil and Renmark Formations. The Shepparton formation mainly consists of unconsolidated to poorly consolidated, mottled, variegated clays and silty clays with lenses of polymictic, coarse to fine sand and gravel, partly modified by pedogenesis. The Calivil formation consists of poorly consolidated, pale grey, poorly sorted, coarse to granular quartz and conglomerate, with white kaolinitic matrix. The Renmark formation is distinguished from the Calivil formation by the presence of grey, carbonaceous sand.

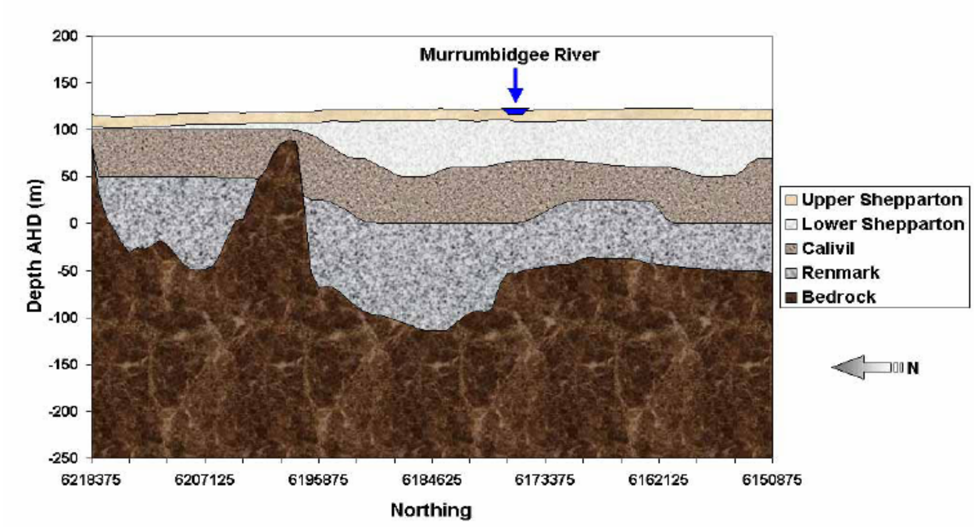


Figure E-2 Lithology of Murrumbidgee Irrigation Area at Easting 402625

The soils (0-5 m depth) in the study area consist of more than 90 different soil types. These soils are generally grouped into five distinct groups.

1. *Clays* - self mulching and hard setting (non self mulching clays)- The hydraulic conductivity of self mulching clays (up to 0.5 m depth) is around 30 mm/day) whereas for deeper horizons (1.5 to 3 m) is relatively low (0.5 to 1 mm/day). The hydraulic conductivity for shallow non-self mulching clays is around 4 mm/day.

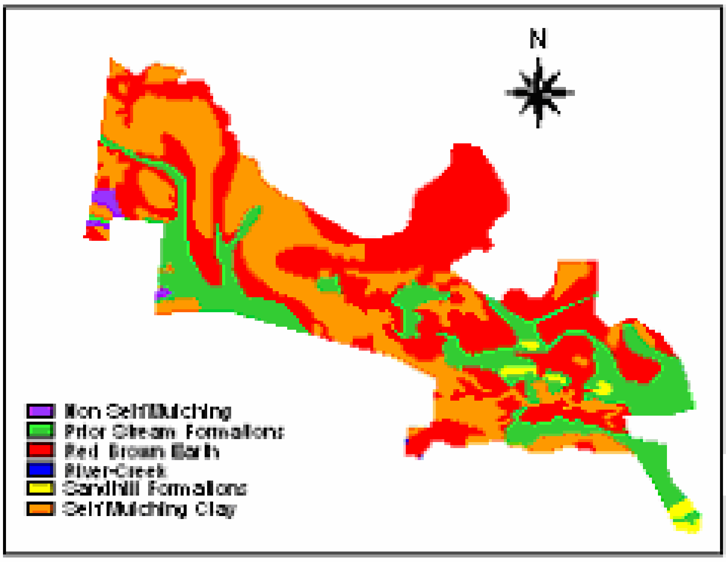


Figure E-3 Soils of Murrumbidgee Irrigation Area

2. *Red Brown Earths* - this group consists of loamy or sandy surface horizons of more than 0.1 m depth which abruptly change to clay subsoils. The reported hydraulic conductivity values for this soil group vary greatly between 58 mm/day to 1039 mm/day.

3. *Transitional Red Brown Earths* – these soils have hydraulic characteristics of clays and red brown earths, ranging from 0.026 to 10 mm/day in 0.2-0.6 m depth. The top clay layer is very shallow (0.08-0.1m). The deeper profiles contain lime and gypsum.

4. *Sands Over Clay* – these soils mainly consist of sandy top soils (0.1 to 0.6 m) with a dense sub clay soils. The hydraulic conductivity is greater than 100 mm/day.

5. *Deep Sandy Soils* – these soils are of aeolian origin and contain coarse sands to a depth of 4 meters with hydraulic conductivity maybe greater than 1000 mm/day.

E-2 Conceptual Model

The US geological survey model MODFLOW coupled with the MT3D solute transport simulator under a PMWIN environment was used as the modelling framework. The model covers an area of 674 ha. The spatial domain represented in the model consists of four layers each of 106 rows and 113 columns (750m x 750m cell size). A stress period length of 30-days was used to enable simulation of irrigation and on-irrigation seasons with a computational time step of one day.

Initially the model parameters have been specified for the 1995 to 2000 period for calibration purposes. Extensive datasets on the aquifer lithology (structural contours, borelogs, and aquifer properties), piezometric levels, groundwater salinity, aquifer abstractions, channel network, Murrumbidgee River and rice area locations have been collected and collated in ArcView GIS format. There are 4 layers in the MIA model and 9905 active cells per model layer.

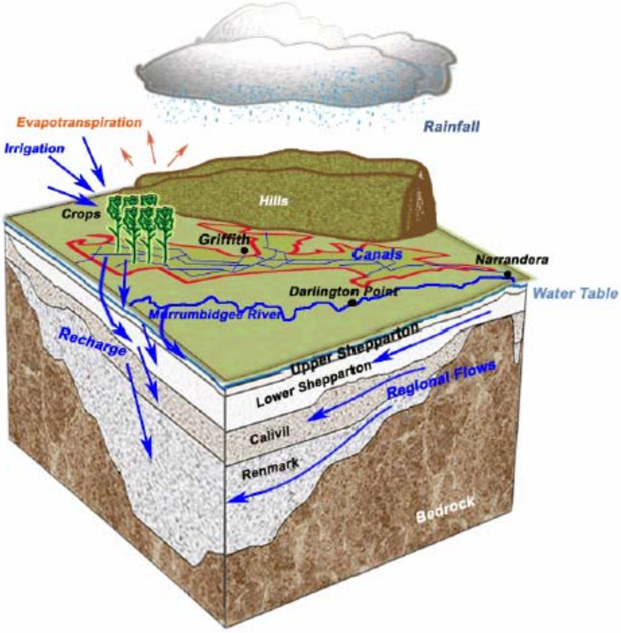
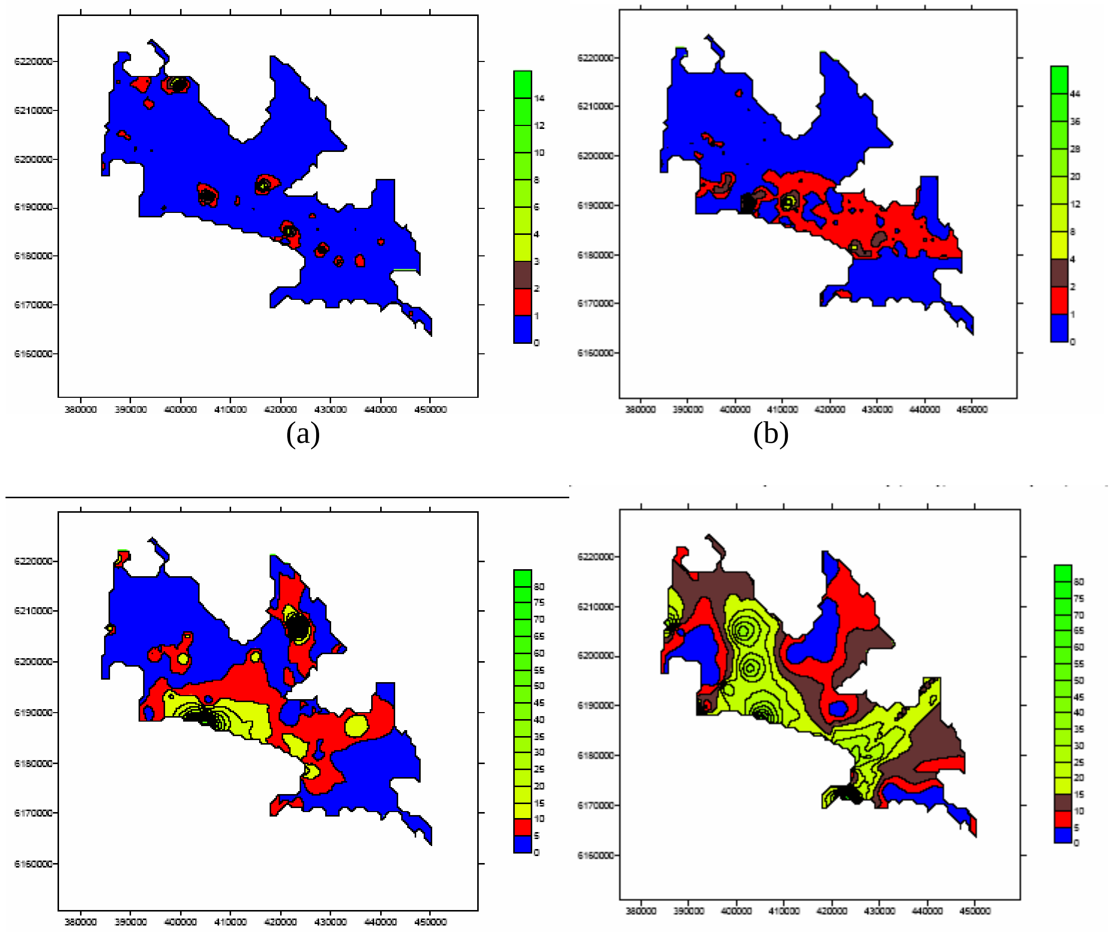


Figure E-4 Schematic view of the conceptual model for MIA

E-3 Model Calibration

Observed water levels in the Murrumbidgee Irrigation Area (MIA) were used for calibration purpose. The first step in model calibration is the identification of the calibration targets. The second step consists of determining the acceptable range of errors between simulated and measured calibration targets. These errors in heads are referred to as residuals. Residual heads are defined as the observed water levels minus the simulated water levels. As the third step, trial-and-error and inverse simulations are performed until simulated parameters are within the acceptable range of errors. A combination of PEST and UCODE methods were used. The model inputs include leakage between layers, storage, hydraulic conductivity and conductance of channels consisting of possible 118,860 input variables. A set of 202 piezometer hydrographs was selected from the piezometer database for dynamic history matching.

The results of calibrated model indicate that the horizontal hydraulic conductivity of layer-1 ranges between 0.0025 –14 m/day, of layer 2 ranges between 0.02–44 m/day, of layer 3 ranges between 0.075–77 m/day and of layer 4 range between 0.4-75 m/day (Figure E-5). The results show that the vertical hydraulic conductivity of layer-1 ranges between 2.5×10^{-6}-1.4×10^{-2} m/day, of layer 2 are between 6.5×10^{-6}–0.19 m/day, of layer 3 ranges between 7.8×10^{-4} -7.8×10^{-1} m/day, and of layer 4 ranges between 4.1×10^{-3}-7.5×10^{-1} m/day (Figure E-6).



(a) (b) (c) (d)

Figure E-5 Calibrated hydraulic conductivity (m/day) for model layers (a) Upper Shepparton (b) Lower Shepparton (c) Calivil and (d) Renmark Formations

Calibrated specific storage in the first layer of the model ranges between 3.4×10^{-4} to 6.3×10^{-3} m^{-1} and the average specific storage of the whole formation is 2.6×10^{-3} m^{-1}, of layer 2 ranges between 2.5×10^{-4} to 9.2×10^{-3} m^{-1} and the average specific storage of the whole formation is $2.0\times10^{-3}m^{-1}$, of layer 3 ranges between 1.4×10^{-4} to 9.5×10^{-3} m^{-1} and the average specific storage is 1.9×10^{-3} m^{-1}, of layer 4 ranges between 1.8×10^{-5} to 4.5×10^{-3} m^{-1} and the overall average specific storage of the formation is 4 is 8.6×10-4 m^{-1} (Figure E-7).

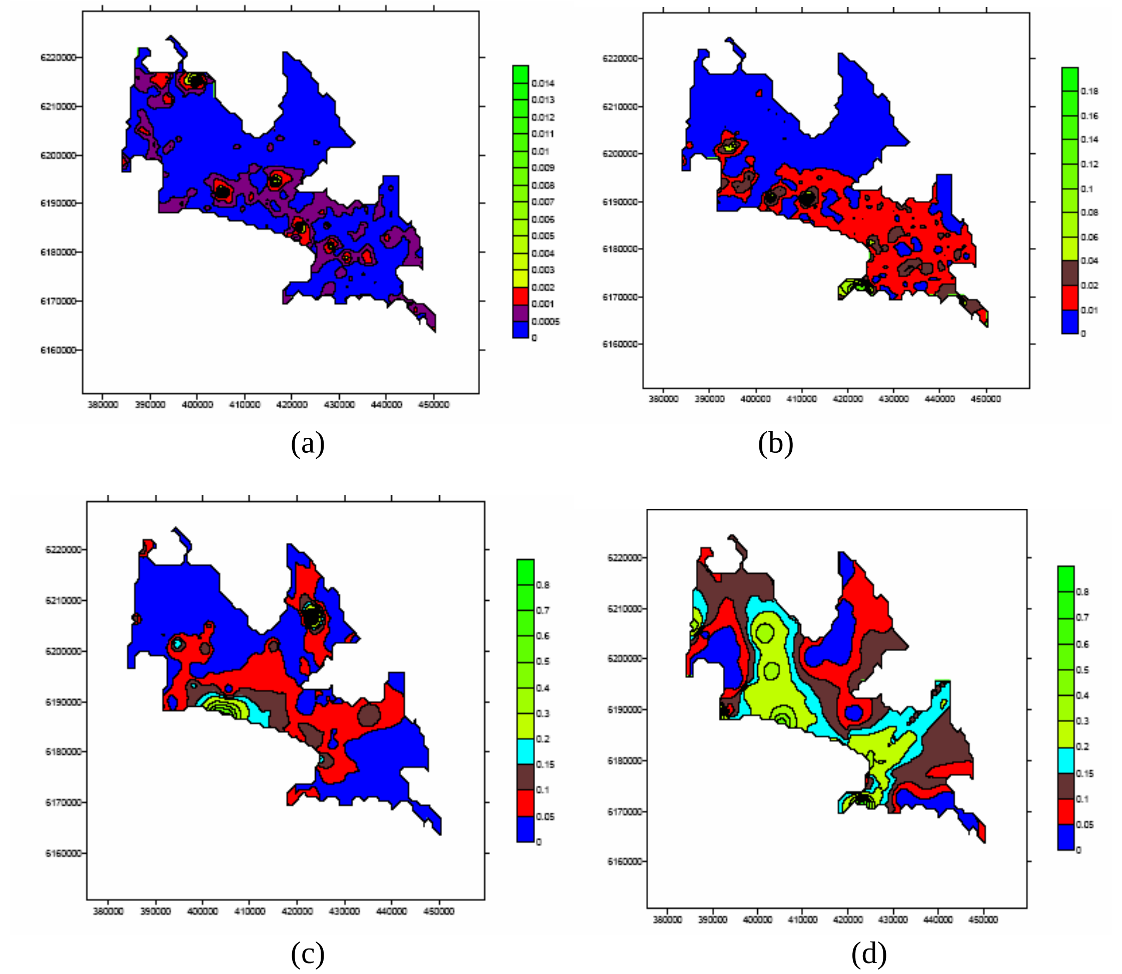


Figure E-6 Calibrated vertical conductivity (m/day) for model layers (a) Upper Shepparton (b) Lower Shepparton (c) Calivil and (d) Renmark Formations

E-4 Model Results

E-4.1 Prediction of Groundwater Levels

Calibrated water levels were compared with the observed water levels for 124 observation bores of period September-95 to August-00. The model output shows a good agreement between the observed and simulated heads. The overall trend of the observed groundwater hydrograph is closely followed by the modelled data. The overall difference between the average of observed and simulated heads ranges from less than 0.5 m to 1.0 m, which indicates a close agreement between observed and simulated water elevations. Detailed piezometric data and numerical model results have shown overall decline in the groundwater levels in the region. This decline is attributed to improved land and water management practices as well as relatively dry climate over the last decade. Some areas within the MIA e.g. Yenda, Murrami and some parts of the Kooba and Benerembah areas have very limited groundwater outflow capacities. These areas are likely to result in shallow watertable and soil salinity problems if irrigation and winter cropping efficiency is not managed within the regional groundwater flow capacity.

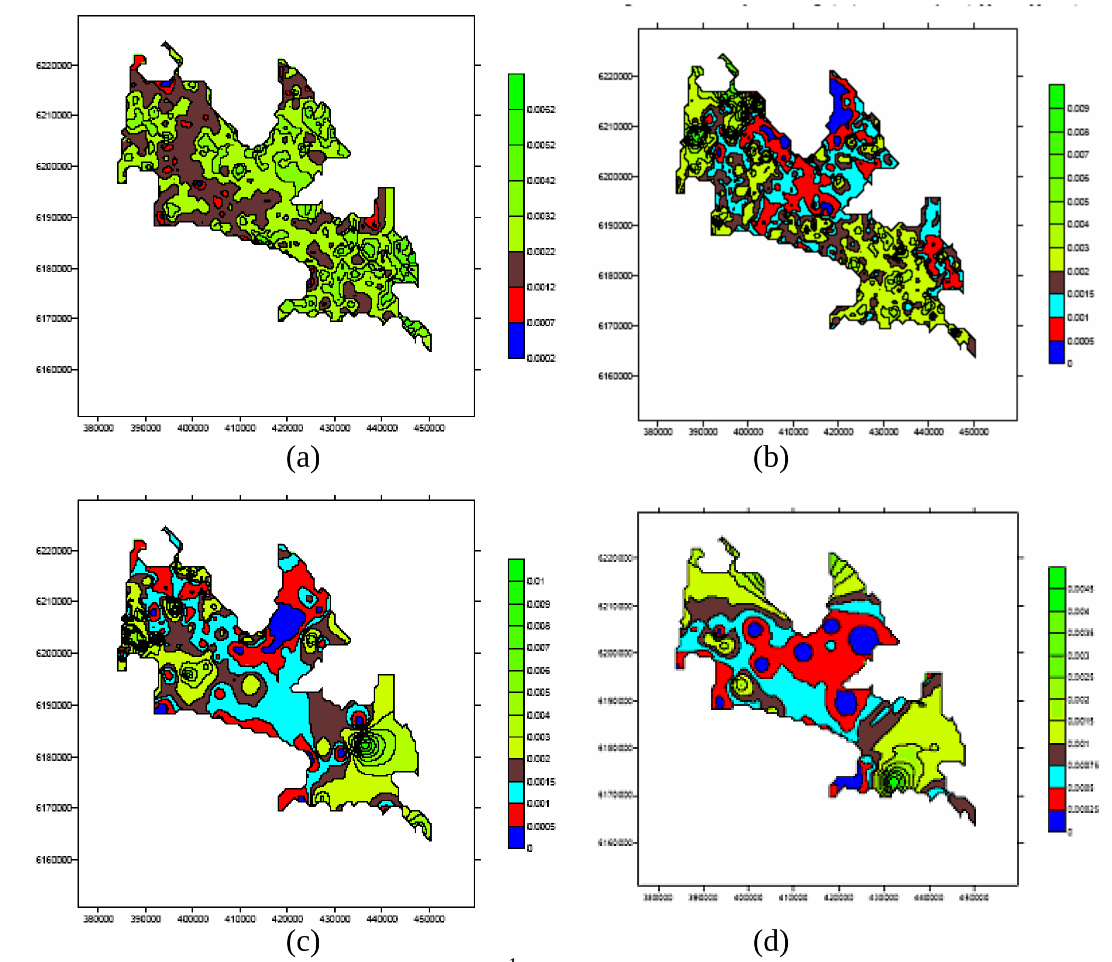


Figure E-7 Calibrated specific storage (m^{-1}) for model layers (a) Upper Shepparton (b) Lower Shepparton (c) Calivil and (d) Renmark Formations

E-4.2 Spatial Distribution of Groundwater Levels

Spatial assessment of the "goodness" of fit between modelled and measured groundwater level contour plans is performed by comparing the modelled contours with the interpolated measured groundwater levels (Figure E-8). Water level contours for different stress periods (September 1995-August 2000) show that the model replicates groundwater contours in the whole MIA very well particularly for the shallow layers (upper and lower Shepparton). There is a bit discrepancy in the deeper layers due to lack of piezometric data. Since the model generates the interpreted direction of the groundwater flow and approximated water levels, there was no systematic over- or under-prediction of heads in most parts of the modelled area. Spatial distribution of computed and observed water level contours is shown in Figure E-8.

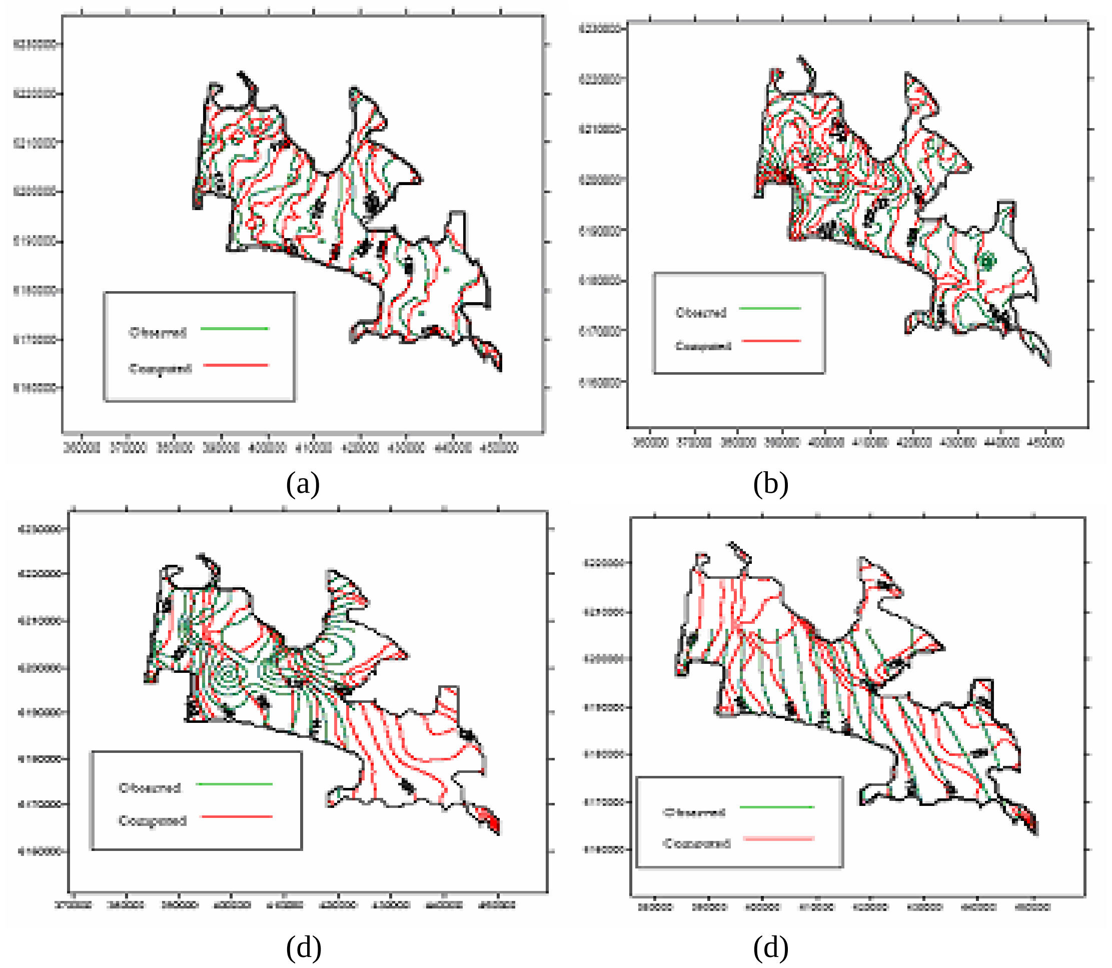


Figure E-8 Spatial distribution of computed and observed water level contours (Sep. 1999) for model layers (a) Upper Shepparton (b) Lower Shepparton (c) Calivil and (d) Renmark Formations

E-5 Model Performance

The quantitative calibration performance was assessed using statistics of piezometric head residuals. It is not possible to draw absolute quantitative comparisons for groundwater level contours, because contours are the result of interpolations between data points, and are therefore subjective. Quantitative measures of the average error of the model are reported in Table E-2. A scattergram was plotted that showed occurrence of all points with a small degree of scatter about the line of perfect fit (a 45° line through the origin representing an unattainable perfect calibration). All the plotted points were not grouped consistently indicating over- and under-prediction of head levels. The coefficient of determination (R^2) is also calculated as 0.99, which indicates a very high degree of correspondence between the modelled and interpolated observations.

Table E-2 Statistical Calibration Performance Measures

Description	Equation	Comments	Model Results
Sum of Residuals (SR)	$\sum_{i=1}^{n} Wi \mid hi - Hi \mid$ [m] Wi= weighting (range 0 to 1)	Weighting can be (subjectively) applied at selected points to help account for confidence in the data quality. SR is not intuitive, as it varies with sample size	1480
Mean sum of Residuals $MSR = \frac{SR}{n}$	$\frac{1}{n}\sum_{i=1}^{n} Wi \mid hi - Hi \mid$ [m]	Independent of sample size, but depends on the range in the measured values	0.56
Scaled Mean Sum of Residuals (SMSR)	$\frac{100.MRS}{\Delta H} = \frac{100.SR}{n.\Delta H}$ [%] ΔH= range of measured heads across model domain	SMSR is an intuitive relative measure which is independent of sample size and independent of the measurement range	1.41
Sum of Squares (SSQ)	$\sum_{i=1}^{n} [Wi(hi - Hi)]^2$ [m²]	The unit [m²] indicate that this is not an intuitive measure of performance. Depends on the sample size	1416
Mean Sum of Squares $MSSQ = \frac{SSQ}{n}$	$\frac{1}{n}\sum_{i=1}^{n} [Wi(hi - Hi)]^2$ [m²]	Not an intuitive measure of performance but it is independent of the sample size	0.53
Root Mean Square $RMS = \sqrt{MSSQ} = \sqrt{\frac{SSQ}{n}}$	$\sqrt{\frac{1}{n}\sum_{i=1}^{n} [Wi(hi - Hi)]^2}$ [m]	An absolute measure that is problem-dependent (i.e. its value is affected by the range in the measured values). It is usually thought to be the best error measure if errors are normally distributed	0.75
Root Mean Fraction Square (RMFS)	$100\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[Wi\left(\frac{hi - Hi}{Hi}\right)\right]^2}$ [%] Weight apply to the friction not to the residual	This measure is affected by magnitude of Hi, which is determined by the datum. Model boundary conditions may constrain hi. An improved performance can be contrived by changing the datum to increase Hi.	0.60
Scaled RMFS (SRMFS)	$SRMFS = RMFS\frac{\overline{H}}{\Delta H}$ [%]	$\overline{H}$ = mean of measured head values, which have a range of ΔH	1.91
Scaled RMS (SRMS)	$SRMS = \frac{100.RMS}{\Delta H}$ [%]	SRMS and SRMFS should both be low (say less than 5% or some other agreed value), indicating that the ratio of error to total head differential is small. And hence errors are only a small part of the overall model response.	1.90
Coefficient of Determination (CD)	$\frac{\sum_{i=1}^{n}\left[Wi(Hi - \overline{H})\right]^2}{\sum_{i=1}^{n}\left[Wi(hi - \overline{H})\right]^2}$ [-]	CD tends to one for perfect calibration.	0.99

E-6 Water Balance of the Murrumbidgee Irrigation Area

Water balance data provide both an indication of the relative magnitude of flow components as well as a means to check that the model solution has remained stable. If there is an error in the iterative solution then it is likely to show up in the water balance. For that reason it is important to check that the model change in aquifer storage by the method of total inflow-outflow. External stresses such as wells, areal recharge, evaporation, drains and streams are simulated to calculate the water budget of each irrigation district and the average values in ML/season are presented for the calibration period (September 1995-August 2000). A minus sign refers to the water released from storage and plus sign refers to the water added to the storage. The water balance results for the MIA have shown discrepancies of less than 0.01%, which is generally considered an acceptable error.

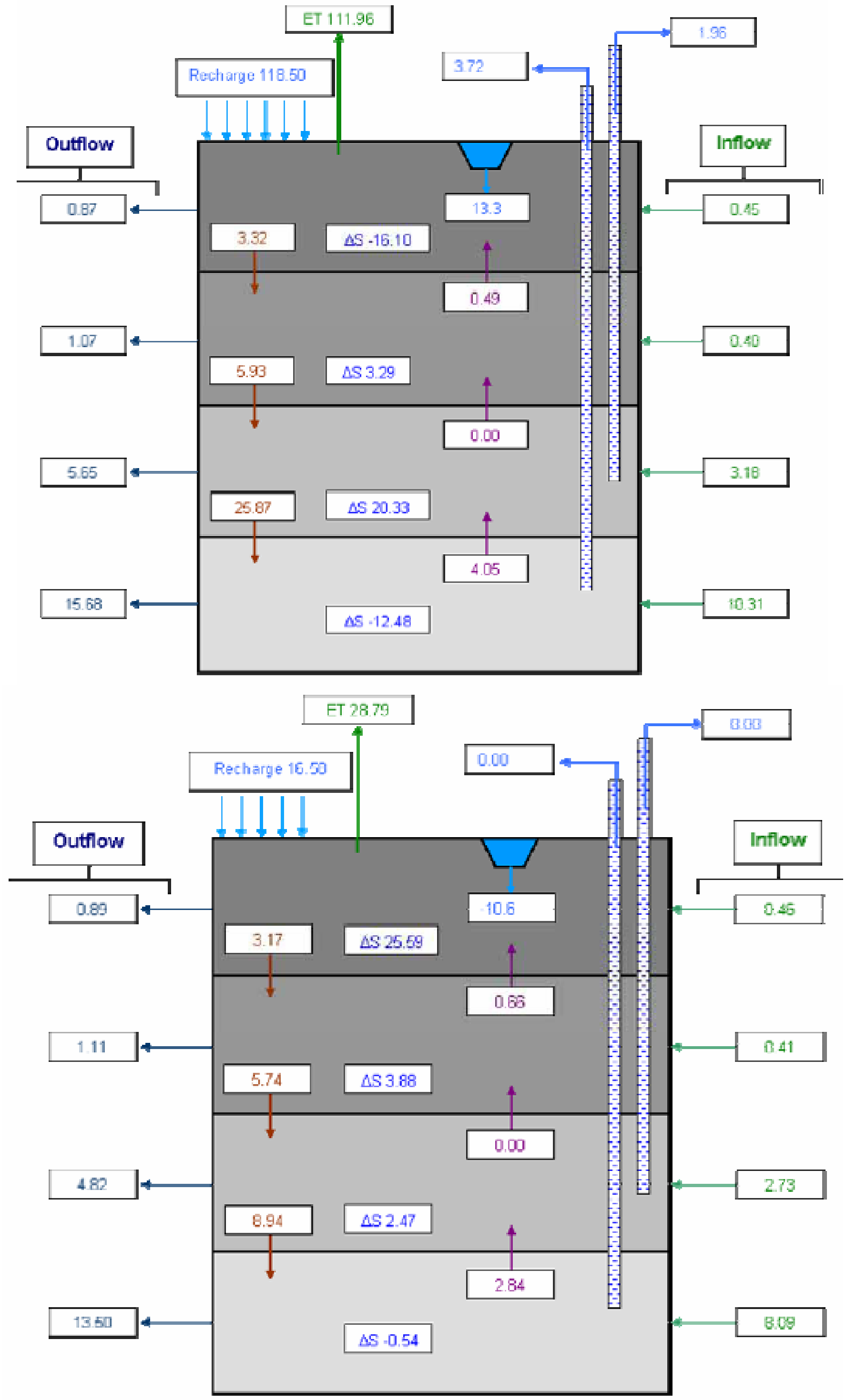


Figure E-9 Water balance (GL) of the whole MIA for (a) Irrigation (b) Non-Irrigation Periods: 1995-2000

E-7 Scenario Analysis

Using the existing groundwater conditions (Sep., 2000) as "initial conditions" a number of future scenarios up to Year 2025 were studied to simulate the future dynamic response of aquifers under the MIA.

E-7.1 Scenario-1: Dry Conditions Continued for Next 25 Years

During 2001/02 irrigation water deliveries were 917,000 ML, summer rainfall was 164 mm and winter rainfall was 165 mm. The groundwater levels will be in equilibrium after a fall of around 1 m in most of the areas. In some areas groundwater levels will rise by around 1 m e.g. under the north-west of Murrami, some parts of Yenda and South Benerembah (Figure E-10 (a)). The higher groundwater level changes are likely to be in the north-east of Yenda (2-5m). The groundwater salinity varies by less than 1000 µs/cm. The greatest groundwater salinity increases are predicted in the western part of Murrami, Yenda and in the north and south Benerembah (Figure E-11 (a)).

E-7.2 Scenario-2: Relatively Wet Conditions Continued for the Next 25 Years

During 1992/93 irrigation allocation was 685,000 ML, summer rainfall was 398 mm and winter rainfall was 179 mm. the groundwater levels will be in equilibrium after a fall of around 1 m under most of the areas. In some areas groundwater levels will rise by around 1 m e.g. under the north-west of Murrami, some parts of Yenda and South Benerembah (Figure E-10 (b)). The greatest groundwater level changes are likely to be in the northeast of Yenda (2-5 m). The groundwater salinity levels will rise by more than 1000 µs/cm in the western part of Murrami, Yenda and in the north and south Benerembah (Figure E-11 (b)).

E-7.3 Scenario-3 and 4: 50% and 75% Reduction in Rice Area

There will be a net decline in groundwater levels during the first couple of years and then a new quasi equilibrium will be established. In most of the areas the groundwater levels will decline by around 1 m (Figure E-10 (c) and (d)). The groundwater salinity levels will rise by more than 1000 µs/cm in the western part of Murrami, Yenda and in the north and south Benerembah (Figure E-11 (c) and (d)).

E-7.4 Scenario-5 and 6: Partial and Full Reduction in Seepage from Channels

The major change in groundwater levels will occur in the Murrami and Gogelderie. The groundwater levels will be in equilibrium after a fall of around 1 m under most of the areas (Figure E-10 (e) and (f)). The groundwater salinity levels will rise by more around 1000 µs/cm in the Murrami and Gogelderie areas due to reduction of fresh quality recharge due to lesser/no seepage from channels (Figure E-11 (e) and (f)).

E-8 Regional Groundwater Trends

1. The groundwater levels in south west of North Benerembah are declining due to the impact of groundwater pumping. The groundwater outflow rates are higher at the edge of the area

as compared with the areas close to the Barren Box swamp. Areas close to the Barren Box swamp need to be managed within the groundwater outflow capacity by reducing net recharge to 0.15 to 0.35 ML/ha during the irrigation season.

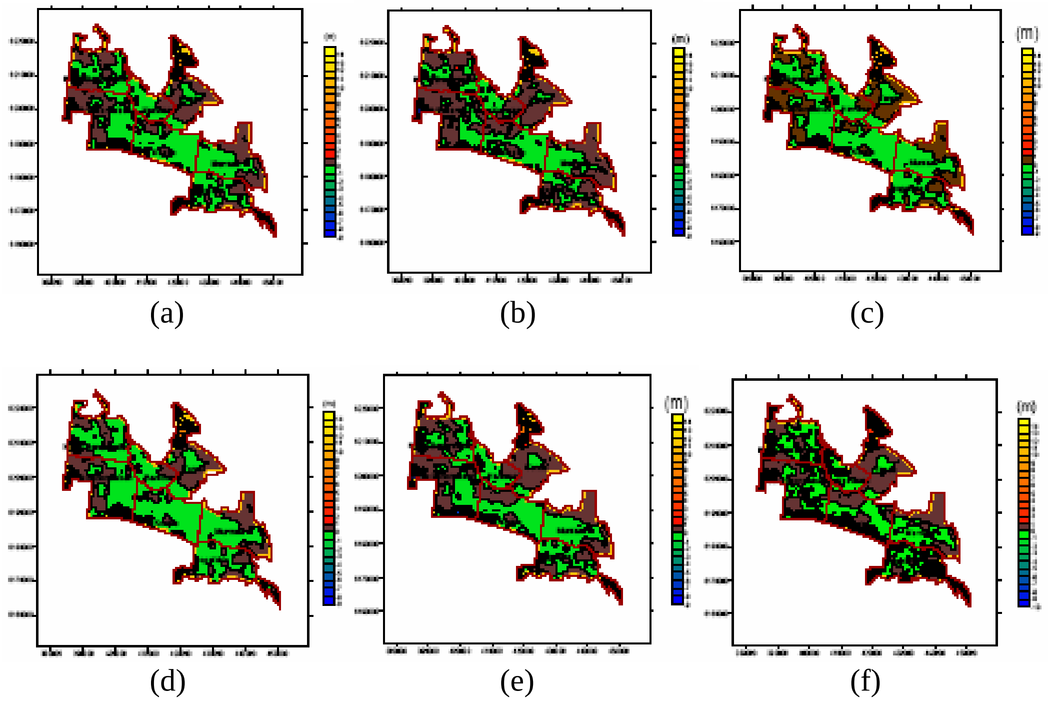


Figure E-10 Predicted groundwater level changes from 2000 to 2025 under scenarios of (a) dry conditions, (b) wet conditions, (c) 50% reduction in rice area, (d) 75% reduction in rice area, (e) partial reduction in seepage, and (f) full reduction in seepage

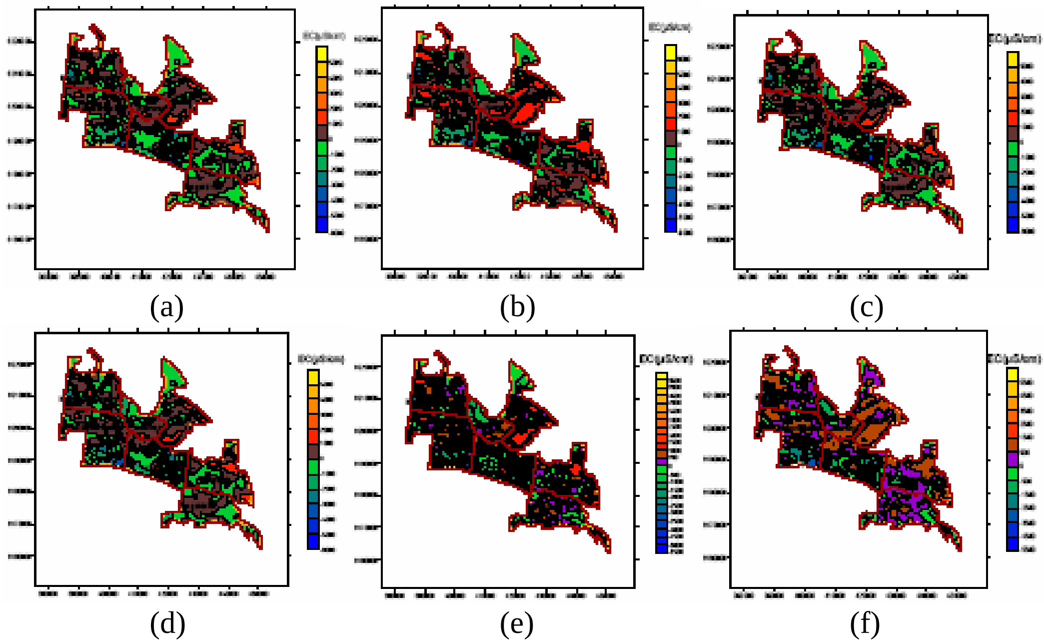


Figure E-11 Predicted groundwater salinity changes from 2000 to 2025 under scenarios of (a) dry conditions, (b) wet conditions, (c) 50% reduction in rice area, (d) 75% reduction in rice area, (e) partial reduction in seepage, and (f) full reduction in seepage

2. In Hanwood region, the groundwater levels are declining due to dry climate conditions and the impact of groundwater pumping in the Murrumbidgee catchment. The groundwater outflow rates are around 0.15 to 0.2 ML/ha/6 months. In terms of long term scenarios groundwater levels can rise in the south-west of this area and therefore on farm recharge should be reduced in this part of the area.
3. In Yenda region, the groundwater levels fluctuate within 3 m from the ground surface. The piezometers are very responsive to rainfall and local recharge events. Due to the landlocked nature of local hydrogeology there is a risk of groundwater rise and soil salinisation if drainage is not continued.
4. In South Benerembah region, the groundwater levels are continuously declining due impact of groundwater pumping. The longer term scenarios show a small rise in the north of the area which can be controlled through better land and water management within South and North Benerembah area.
5. In Kooba region, the groundwater levels in the south-west of the area are continuously declining, however groundwater levels fluctuate within 3 m in the north of the region. The northern part needs to be carefully managed by keeping irrigation and rainfall recharge within the groundwater outflow capacity i.e. around 0.15 ML/ha/six months.
6. In Murrami region, the groundwater levels fluctuate within 3 metres indicating lower groundwater outflow capacity of the underlying aquifers. The scenario analysis shows that the western part has a possibility of groundwater and salinity rise in the future. The channel seepage should be controlled on a priority basis. The irrigation and rainfall recharge needs to be reduced to less than 0.10 ML/ha/six months.
7. In the Gogelderie area, the groundwater is showing a gradual decline in the southern part due to deeper groundwater pumping. The groundwater levels are relatively static or showing a lower rate of decline in the northern part. The scenario analysis shows that this area can show further decline in watertable if channel seepage is reduced.

E-9 Final Word

This model has been calibrated and used to simulate possible management scenarios. As with any model there is a need to keep this model updated and use it with other tools such as SWAGMAN Farm to convey modelling results and help determine sustainable irrigation levels on a year to year basis. The model is ready to formulate different land and water management options and to help determine on farm actions required to meet regional targets.