Irrigation of a Proposed Olive Tree Plantation, Emu Springs, South Australia. An Assessment of the Hydraulic Impacts on the Groundwater Resources using a Three-Dimensional Groundwater Flow Model

REPORT BOOK 99/00017

by

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Irrigation of a Proposed Olive Tree Plantation, Emu Springs, South Australia. An Assessment of the Hydraulic Impacts on the Groundwater Resources using a Three-Dimensional Groundwater Flow Model.

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The USGS software package MODFLOW was used to construct a three-layer predictive simulation model of groundwater flow underlying Emu Springs, an area in the southern Mallee region of South Australia near Tintinara. The purpose of the model was to assess the hydraulic impacts of groundwater extraction for irrigation of a proposed 1 600 hectare olive tree plantation.

Based on assumed aquifer parameters and recharge rates, the results indicate that there is likely to be an impact on existing potentiometric heads in the area, subject to the respective level of use from these aquifers. This may impact on other groundwater users in the area of drawdown for each aquifer.

Pumping groundwater from the proposed 16 wells in the unconfined aquifer showed a long-term decline in heads A new state of equilibrium was not attained until 25 years after the commencement of extraction.

For the case where the irrigation extractions are from both the unconfined and confined aquifers, the likely cone of drawdown in the confined aquifer is spatially more extensive than that for the unconfined aquifer. The likely cone of drawdown in the unconfined aquifer is reduced under such an extraction scenario.

It is possible that some adverse groundwater quality impacts may be experienced, particularly in the case of the unconfined aquifer due to increased salt accessions to the aquifer resulting from the irrigation activity. This aspect requires further investigation and is of particular relevance to the developer in order to maintain a suitable groundwater quality for the irrigation enterprise.

INTRODUCTION

The hydraulic effects of extraction on the groundwater resources for a proposed irrigated olive tree plantation in the Emu Springs area have been assessed using a finite difference, three-dimensional predictive flow model. The Emu Springs locality and the extent of the model area are shown in Figures 1 and 2.

A three-layer model was constructed using the USGS modular software package MODFLOW, using assumed aquifer parameters based on previous studies and knowledge of the area.

An initial steady state simulation was calibrated against observed groundwater heads as the first step to creating transient flow models for the area. The transient model simulations cover a thirty year extraction period.

THE MODFLOW MODEL

The hydrogeology of the area was discretised into three layers consisting of 74 by 70, 500 metre wide, grid cells, as illustrated in Figure 3. The total area of the model domain is about 1300 km^2. AMG coordinates were used to define the model domain. Coordinates of the model were from E410000 to E445000 and N6020000 and N6057000 (zone 54).

Layer 1 represents the Tertiary Limestone Aquifer, which is considered unconfined in this area. The Lower Tertiary Aquitard is represented by Layer 2 and acts as a confining layer to the underlying Tertiary Confined Sand Aquifer (Layer 3).

The thickness of each hydrogeological unit was obtained from a previous Departmental report (Barnett, 1983).

The northern and southern borders of the model area are represented as no flow boundaries as they were parallel to the groundwater flow direction.

For all three layers, each of the eastern and western boundaries are represented by linearly grading general head boundaries, each determined from available potentiometric surface maps.

Two zones of hydraulic conductivity for Layer 1 were assumed to exist. A zone in the northeast of the model domain was assigned a hydraulic conductivity of 10 m/day. In a second zone, to the west and southwest, the hydraulic gradient flattens out and the aquifer becomes much thinner. A value of 50 m/day was assigned to this zone. Layer 2, the aquitard, was given a hydraulic conductivity of 10^{-5} m/day while Layer 3 was given a constant hydraulic conductivity of 10 m/day. An anisotropy of 10 to 1 was assumed between the horizontal and vertical hydraulic conductivities.

The specific storage for Layer 3 was calculated by dividing the storage coefficient of 10^{-4} by an average aquifer thickness of 100 m. The specific yield for Layer 1 was set at 0.1.

Vertical recharge to Layer 1 was assumed to be 15 mm per annum, with the recharge occurring between May and September.

Extraction well locations are shown on each of the steady state model runs for each aquifer (Figures 4 and 5), according to the spatial distribution of 16 extraction wells provided by the proposed developer. Extraction rates for each well were based on a monthly irrigation water requirement for 100 hectares of irrigated olive trees, multiplied by 15% to account for irrigation inefficiency and leaching losses, as shown in the table below. The water requirement data for irrigated mature olive trees were provided by PIRSA industry development officers (refer to Table 1).

Apart from the initial steady state calibration model, each of the model simulations was run for a period of thirty years. Each of these years was divided into 12 stress periods representing monthly time steps. The estimated monthly crop water requirement and monthly vertical recharge rate were then assigned to each time step for the model simulations.

A full list of input parameters for the model is presented in Appendix A.

RESULTS

MODEL CALIBRATION

A steady state model was initially calibrated against potentiometric contours, for both aquifers, obtained from Barnett (1983). The results of these runs are shown in Figures 4 and 5. A transient model was then run assuming a non-pumping thirty year simulation (ie with no existing, or the proposed extractions).

The latter model run indicated a rising head in the unconfined aquifer of about 0.1 m per annum as shown in Figure 6. This is consistent with the observed rise in the water table as shown from observation well hydrographs located in the area (Figure 7 for the location of the observation wells, and Figures 8 and 9 for the hydrographs). No change in potentiometric head for the confined aquifer was observed for this model run (Figure 6).

The model, therefore, was considered to be satisfactorily calibrated against the available hydraulic data for each aquifer system.

Note that the hydrograph results presented in this report were derived from the VMODFLOW software. There appears to be a slight problem with the software, such that instead of a symmetric serrated shape simulating the effects of seasonal extraction, some of the extraction peaks and troughs appear truncated and asymmetric which is incorrect.

MODEL SIMULATIONS (SCENARIOS)

The purpose of the modelling was to provide a predictive simulation flow model of the effects on the groundwater systems resulting from the establishment of an irrigated olive tree plantation in the Emu Springs area.

Scenario 1: Pumping from 16 wells in the Unconfined Aquifer

This scenario was modelled with all 16 wells extracting groundwater from the unconfined aquifer (Layer 1) for a thirty year simulation period.

The modelled water level response for the unconfined aquifer to the extractions is shown in Figure 10. There was no change in the modelled head in the confined aquifer (Layer 3).

The size of the modelled drawdown cone in the unconfined aquifer was about 15-18 km in diameter. The maximum drawdown in head was predicted to be 10 m, although the drawdown in the immediate area encompassing the extraction well field was generally about 6 m, as shown in Figure 11.

The modelled response to extraction for the unconfined aquifer is also illustrated in the hydrographs of three observation wells, one located in the centre of the drawdown cone, and the other two wells spaced 5 and 10 kn respectively from the centre of the cone of drawdown (Figure 12). The hydrograph for the observation well located in the centre of the cone of drawdown shows that the water levels in the unconfined aquifer reached a new equilibrium after about thirty years of pumping (Figure 12). The observation well located 5 km from the centre of the drawdown cone shows a similar, but less significant, decline in head over the thirty year simulation period (Figure 12).

No impact to the extractions was observed in the observation well located 10 km from the centre of the drawdown cone, and in fact, the groundwater level trend is still rising slightly as in the non-pumping situation (Figure 12).

Sensitivity analysis was also carried out on this model simulation to examine the uncertainty in the aquifer parameters for the unconfined aquifer (Layer 1) used in the model. Four parameters were examined to assess these effects on the predicted drawdown cone:

- The hydraulic conductivity for the unconfined aquifer was increased from 10 to 15 m/d. This caused a negligible change in the spatial size of the drawdown cone, but the maximum drawdown of the cone was reduced from ten to 5 m, as shown in Figure 13. The hydrographs for the same set of observation wells used in the first simulation also illustrate a reduced impact to the extractions (Figure 14).

- The second parameter tested was specific yield which was increased from 0.1 to 0.15. For this case, the spatial size of the drawdown cone and the maximum drawdown remained essentially the same, as shown in Figure 15. The hydrographs for the same set of observation wells used in the first simulation also illustrate little change in the impact to the extractions (Figure 16).

- The third sensitivity analysis was to increase the recharge from 15 to 20 mm per annum. The spatial size of the drawdown cone was reduced by about 15% and the maximum drawdown was 8 m, as shown in Figure 17. The hydrographs for the same set of observation wells used in the first simulation also illustrate a reduced impact to the extractions (Figure 18).

- The last parameter tested was to reduce the total extraction from the wells by 25%. Again this reduced the spatial size of the drawdown cone by about 10% and the maximum drawdown was 6 m, as shown in Figure 19. The hydrographs for the same set of observation wells used in the first simulation also illustrate a reduced impact to the extractions (Figure 20).

Scenario 2: Pumping from 8 wells in the Unconfined Aquifer

In this model scenario only eight wells were used for extraction, and the extractions for the other eight wells were turned off. Extraction was, therefore, half of that used in the Scenario 1 model. The locations of the wells used in this simulation and the predicted potentiometric contours for the unconfined aquifer for this simulation run are presented in Figure 21.

The net reduction in extraction resulted in a significant decrease in the size of the drawdown cone, as shown in Figure 22. The maximum drawdown at the end of the thirty year pumping scenario was 4 m, although the drawdown in the immediate area encompassing the extraction well field was generally about one metre.

The hydrographs for the same set of observation wells used previously also illustrate this reduced impact to the lower extractions. The hydrograph for the observation well located in the centre of the cone of drawdown shows that the water levels in the unconfined aquifer reached a new equilibrium after about ten years of pumping (Figure 23), and then even commence to rise as in the non-pumping situation. No impact to the extractions was observed in the observation well located 10 km from the centre of the drawdown cone (Figure 23).

Scenario 3: Pumping from 12 wells in the Unconfined Aquifer and 4 wells in the Confined Aquifer

In this scenario, the impacts of extraction from both the unconfined aquifer (12 wells) and confined aquifer (4 wells) were assessed. The locations of the extraction wells are shown in Figure 24. This extraction scenario achieves the required level of irrigation development.

The modelled water level response for the unconfined aquifer (Layer 1) to the extractions is shown in Figure 24.

The size of the modelled drawdown cone in Layer 1 was about 11-13 km in diameter, as presented in Figure 25, and the drawdown in the immediate area encompassing the extraction well field was generally about 3 m with a maximum drawdown of about 7 m.

The modelled response to extraction for the unconfined aquifer is also illustrated in the hydrographs of the same set of three observation wells used for previous simulations (Figure 25). The hydrograph for the observation well located in the centre of the cone of drawdown shows that the water levels in the unconfined aquifer reached a new equilibrium after about fifteen years of pumping (Figure 26). No impact to the extractions was observed in the observation well located 10 km from the centre of the drawdown cone (Figure 26).

The predicted potentiometric contours for the confined aquifer (Layer 3) for this simulation run are presented in Figure 27.

As water pumped from the confined aquifer comes from confined storage, the drawdown effects are much more significant than that of the unconfined aquifer, but the recovery, however, is much quicker.

The elliptical shape of the drawdown cone in the confined aquifer shows some interference from the model boundary conditions (Figure 28). The hydrographs will therefore under estimate total drawdown. Also note that the drawdown cone is only to 3 m, with the zero drawdown contour exceeding the size of the model area.

The hydrographs for the same set of observation wells used previously show that the heads in the confined aquifer recover after each seasonal extraction period and there is no long-term decline in head (Figure 29).

It must be further noted that the model presents an idealised confined aquifer situation, and little is known of the true aquifer properties of the confined aquifer in this area.

A summary of the drawdown impacts for all the model simulations is presented in Appendix B.

CONCLUSIONS

The results of the modelling show the magnitude of the hydraulic impacts which could result from the groundwater extractions for the proposed 1600 hectare irrigated olive plantation.

It is stressed that the simulations presented are based on assumptions of aquifer parameters and recharge rates, and these may not necessarily be correct and would need to be determined from field investigations (ie drilling and aquifer testing).

Nevertheless, the results indicate that there is likely to be an impact on existing potentiometric heads in either or both the unconfined and confined aquifers present in the area, subject to the respective level of use from these aquifers.

For the case where all the irrigation extractions are from the unconfined aquifer, the likely cone of drawdown could extend to a distance of about 7.5 km from the well field. A preliminary assessment of such drawdown impacts to existing unconfined aquifer groundwater users indicates that about 9 known wells may be affected (it is stressed that the current status of these wells is not known and the presence of any other wells would need to be confirmed).

Pumping groundwater from the proposed 16 wells in the unconfined aquifer showed a long-term decline in heads and that the unconfined aquifer system reached a new equilibrium state by the end of the thirty year extraction period.

For the case where the irrigation extractions are from both the unconfined and confined aquifers, the likely cone of drawdown in the confined aquifer is spatially more extensive than that for the unconfined aquifer. A preliminary assessment of such drawdown impacts to existing confined aquifer groundwater users, based on the extent of the 3 metre drawdown in head, indicates that about 4 known wells may be affected (it is stressed that the current status of these wells is not known and the presence of any other wells would need to be confirmed). The likely cone of drawdown in the unconfined aquifer is reduced under such an extraction scenario.

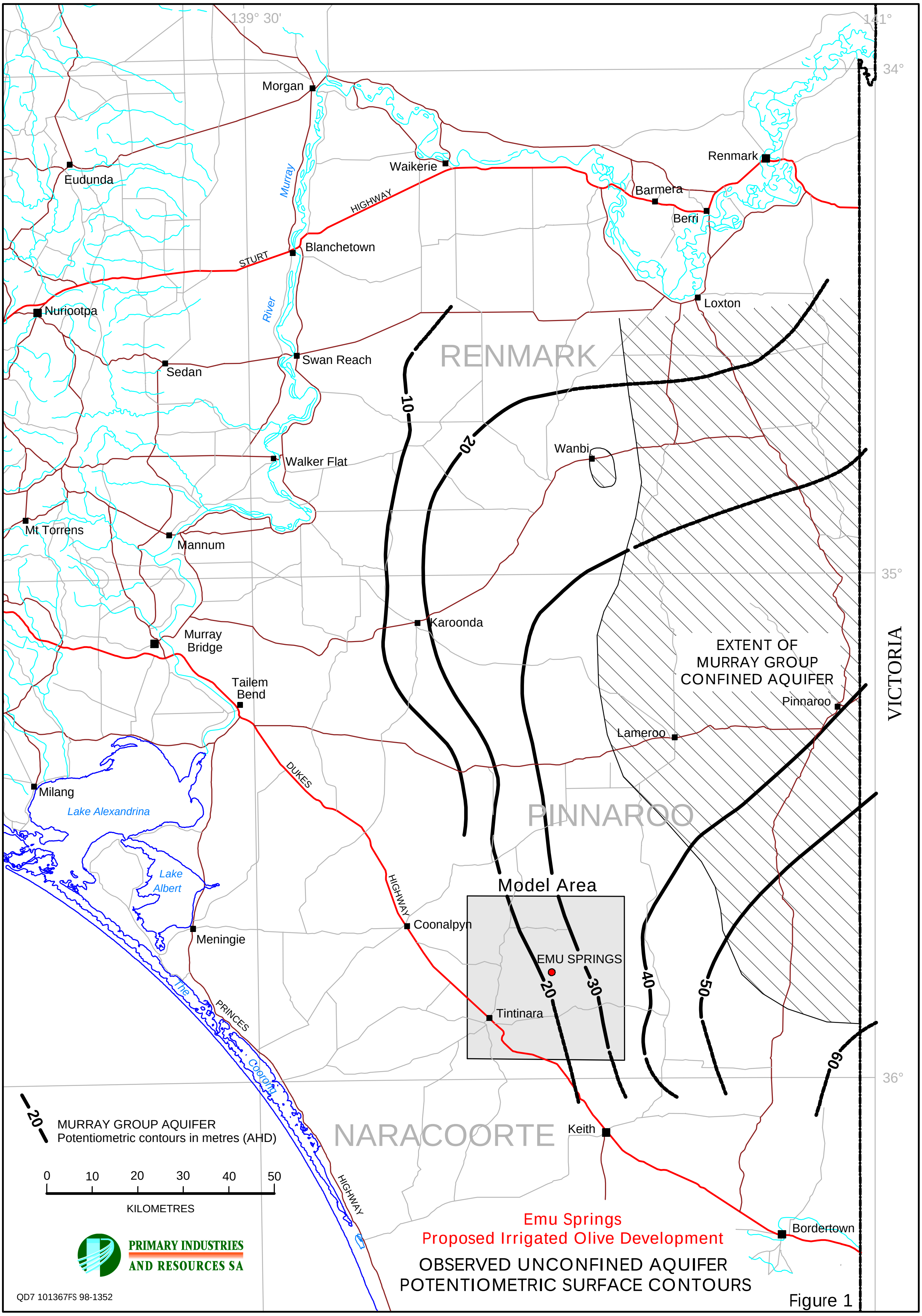
It should also be noted that it is possible that some adverse groundwater quality impacts may be experienced, particularly in the case of the unconfined aquifer due to increased salt accessions to the aquifer resulting from the irrigation activity. This aspect requires further investigation and is of particular relevance to the developer in order to maintain a suitable groundwater quality for the irrigation enterprise.

REFERENCES

Barnett, S. 1983. Murray Basin Hydrogeological Investigation, Data Assessment – Mallee Region. *SA Department of Mines and Energy Report Book,* 83/18.

TABLE 1: IRRIGATED OLIVE WATER REQUIREMENTS

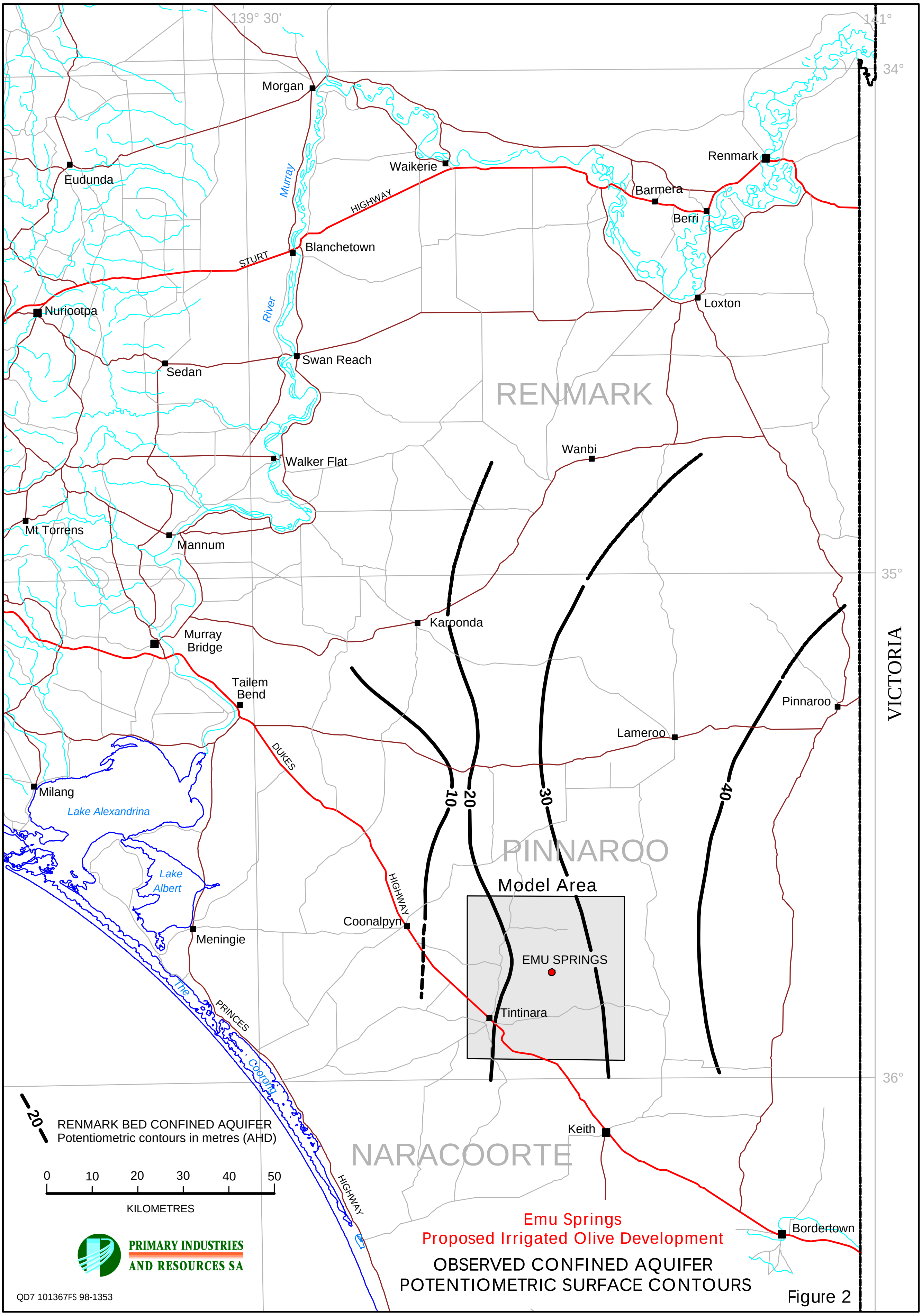
IRRIGATED OLIVE WATER REQUIREMENTS		
Month	**Irrigated Crop Water Requirement (mm)**	**Irrigation Water Requirement For 100 ha (ML)** (assuming an additional water requirement of 15% for irrigation efficiency and leaching)
January	115	132
February	96	110
March	65	75
April	26	30
May	0	0
June	0	0
July	0	0
August	0	0
September	10	12
October	36	41
November	72	83
December	101	116
TOTAL	**521**	**599**



Emu Springs
Proposed Irrigated Olive Development

OBSERVED UNCONFINED AQUIFER POTENTIOMETRIC SURFACE CONTOURS

Figure 1



Emu Springs
Proposed Irrigated Olive Development

OBSERVED CONFINED AQUIFER POTENTIOMETRIC SURFACE CONTOURS

Figure 2

Model grid and
well locations

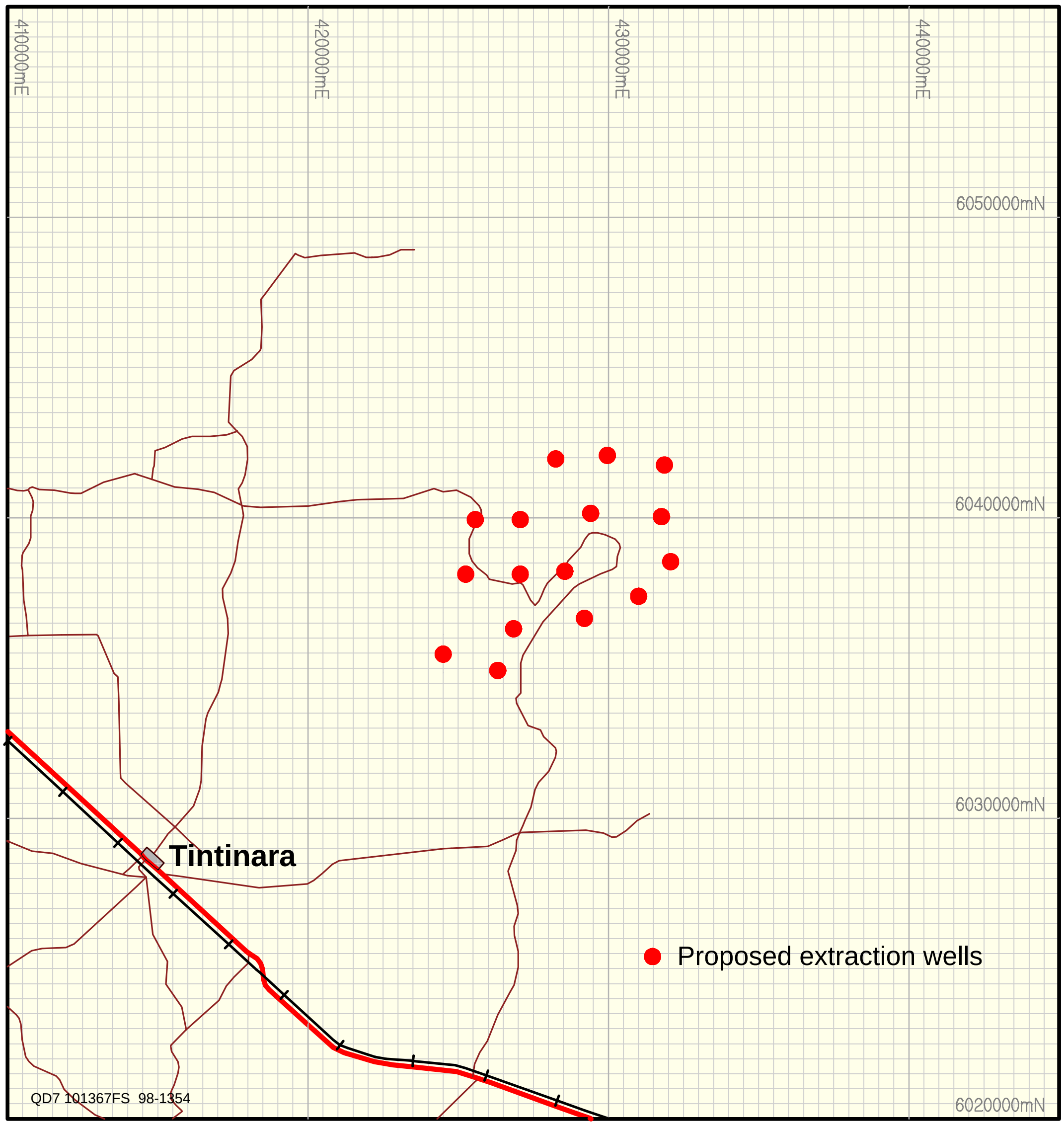


Figure 3

Steady state unconfined aquifer
potentiometric surface contours

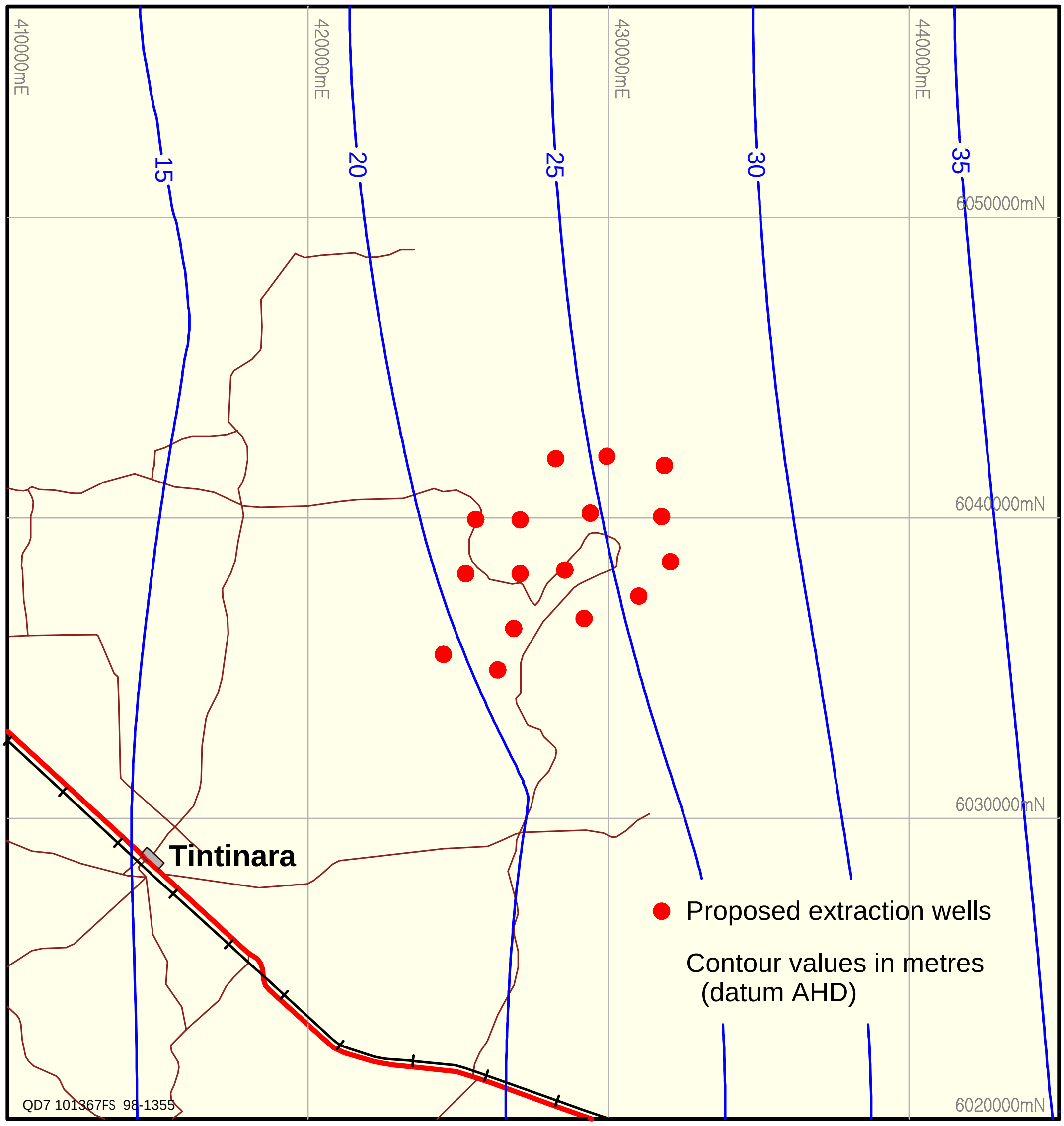


Figure 4

Steady state confined aquifer potentiometric surface contours

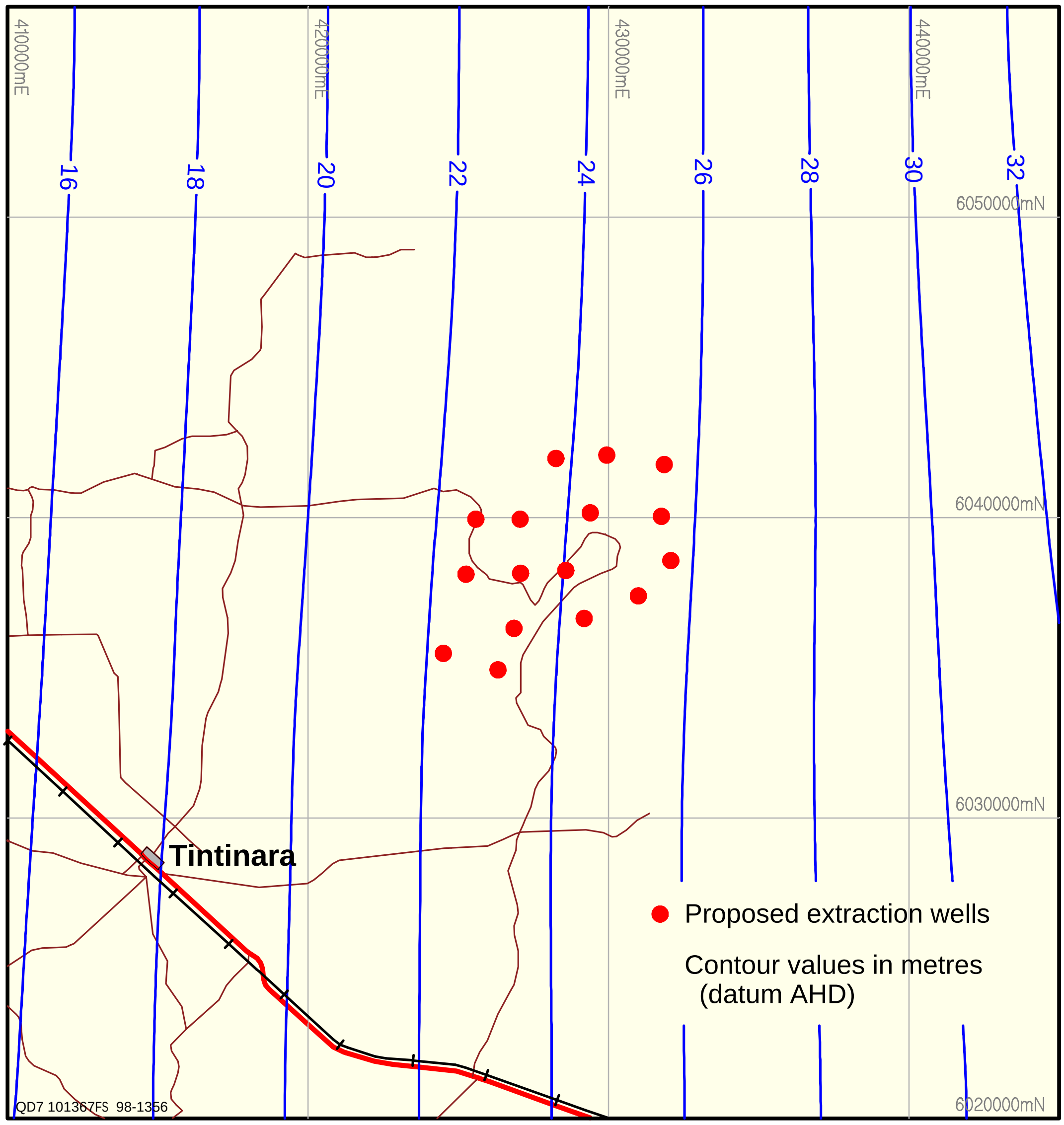


Figure 5

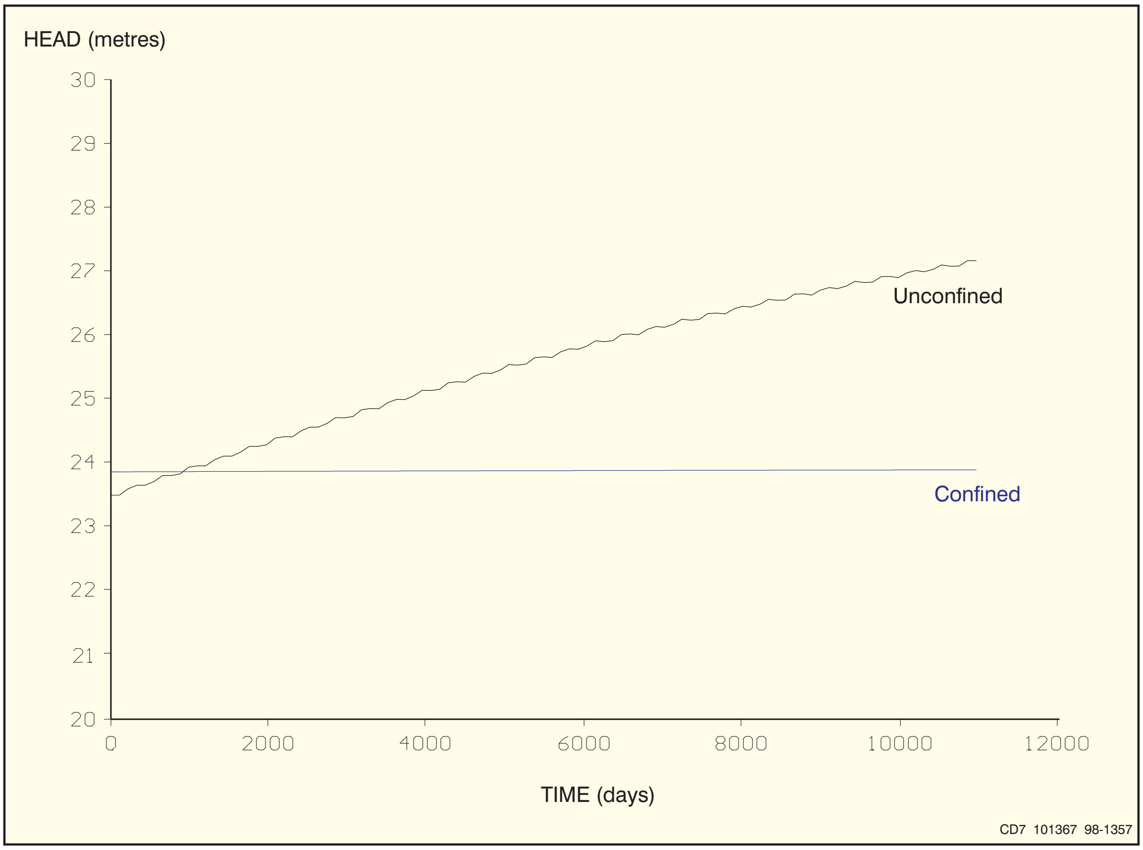


Figure 6 *Modelled transient non-pumping hydrographs for both the unconfined and confined aquifers*

Location of PIRSA observation wells in the area

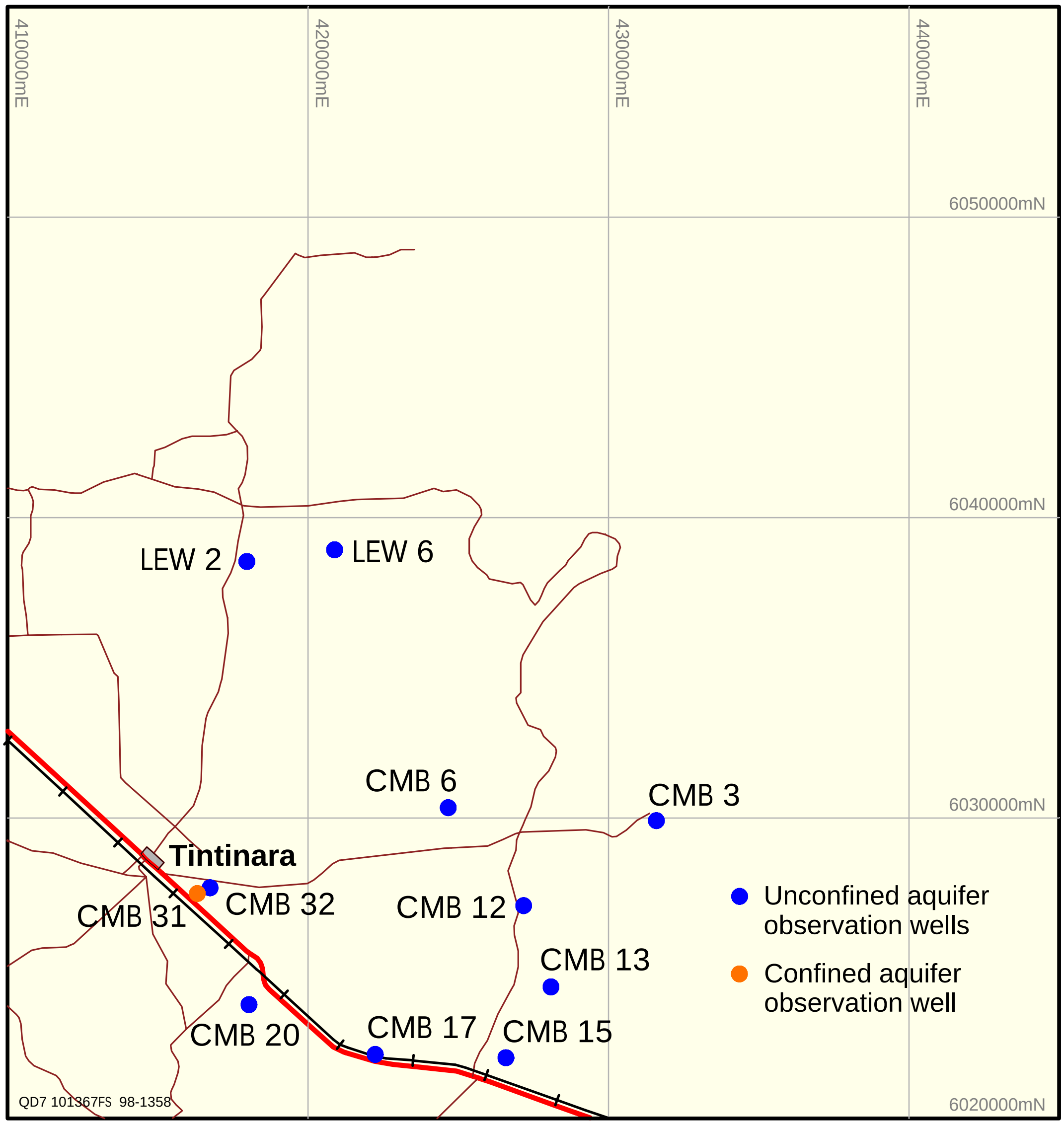


Figure 7

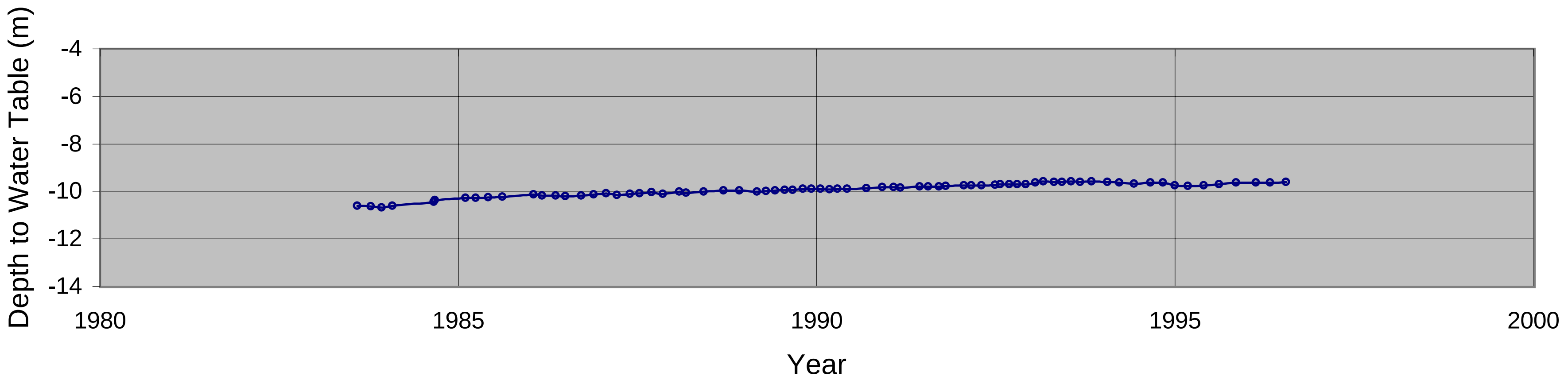


FIGURE 8   Hydrograph for Observation Well CMB006

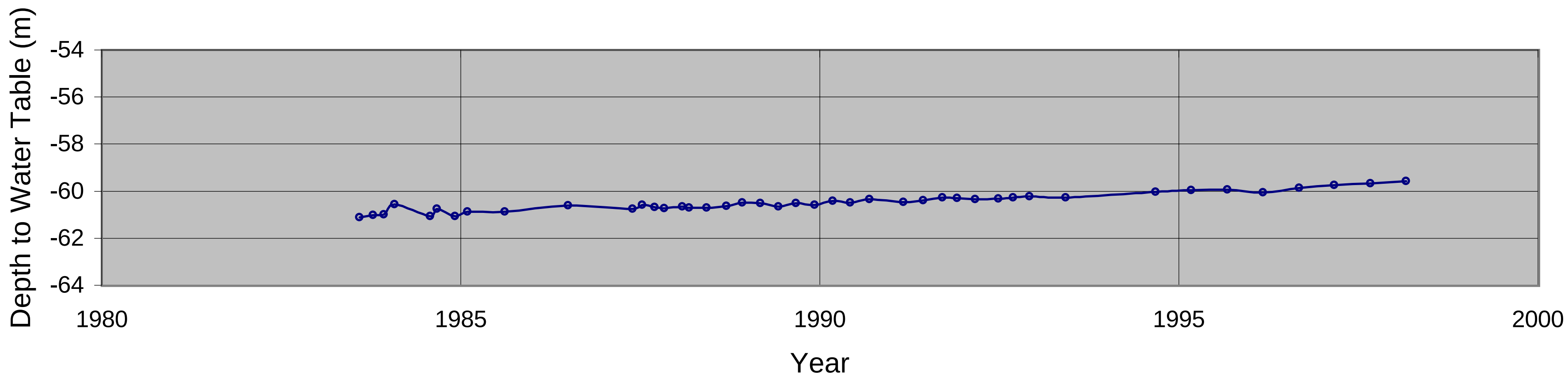


FIGURE 9 Hydrograph for Observation Well LEW006

Scenario 1 - Modelled unconfined aquifer potentiometric surface contours after thirty years of extraction

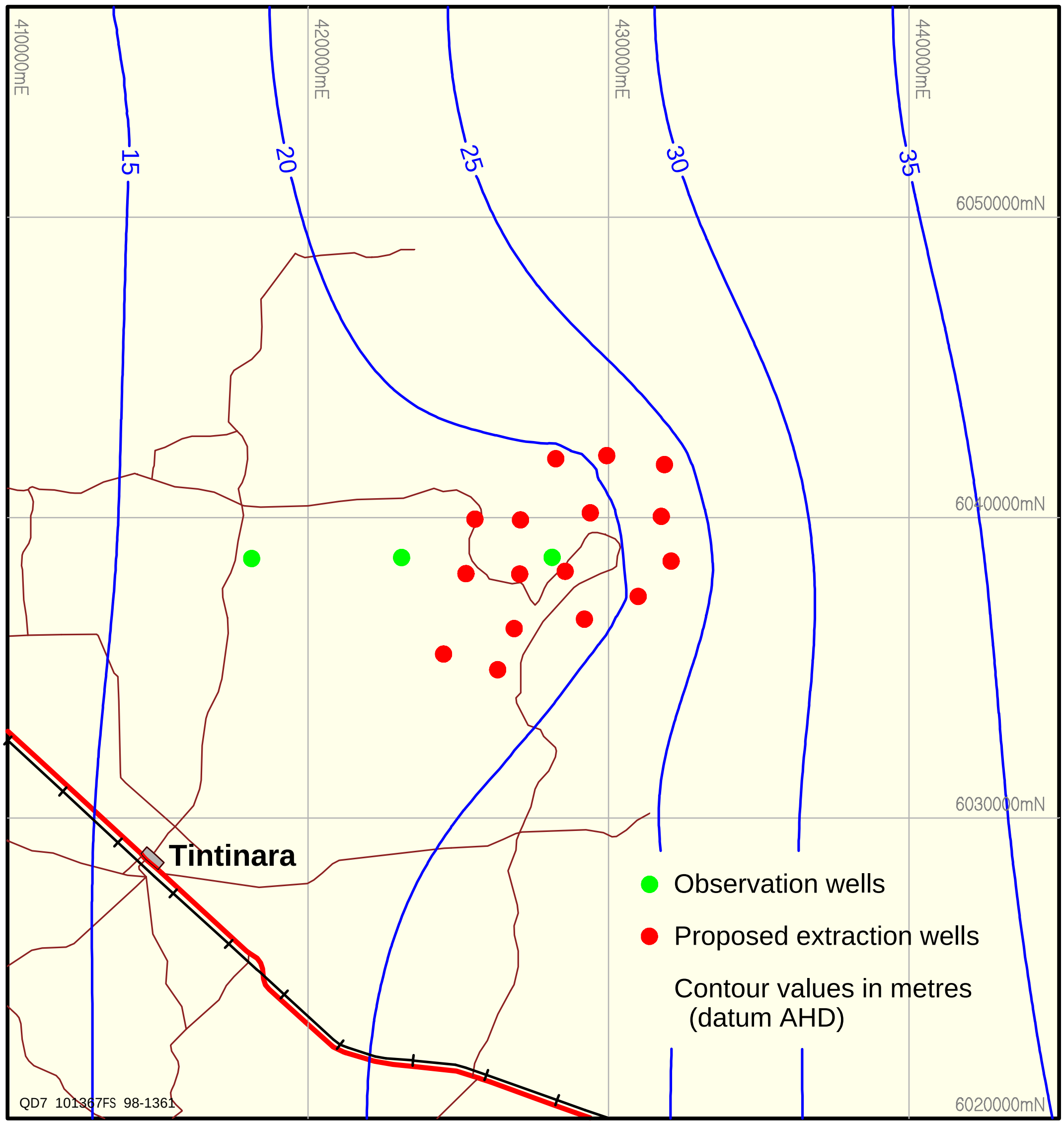


Figure 10

Scenario 1 - Modelled drawdown cone
in the unconfined aquifer after thirty years extraction

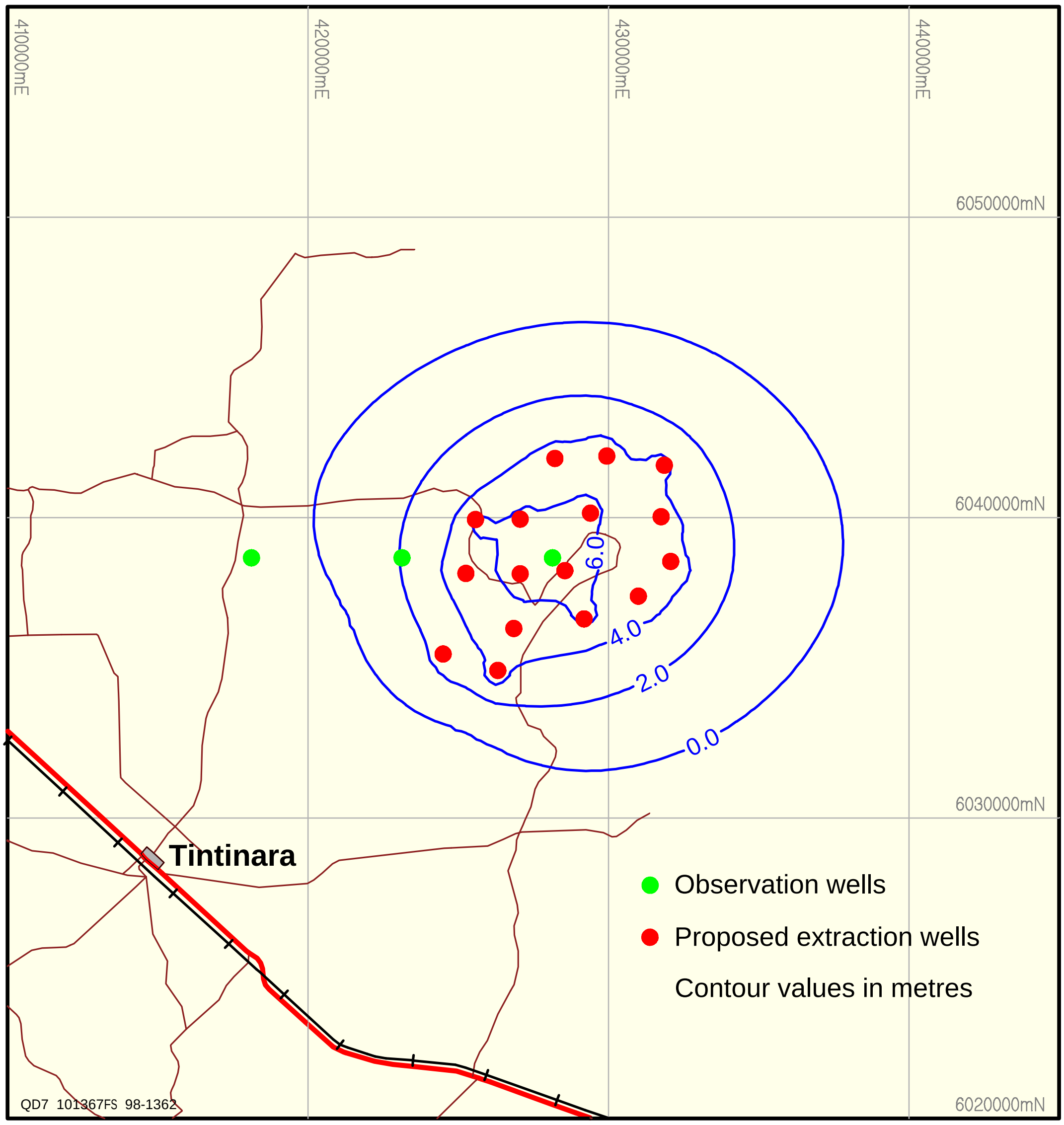


Figure 11

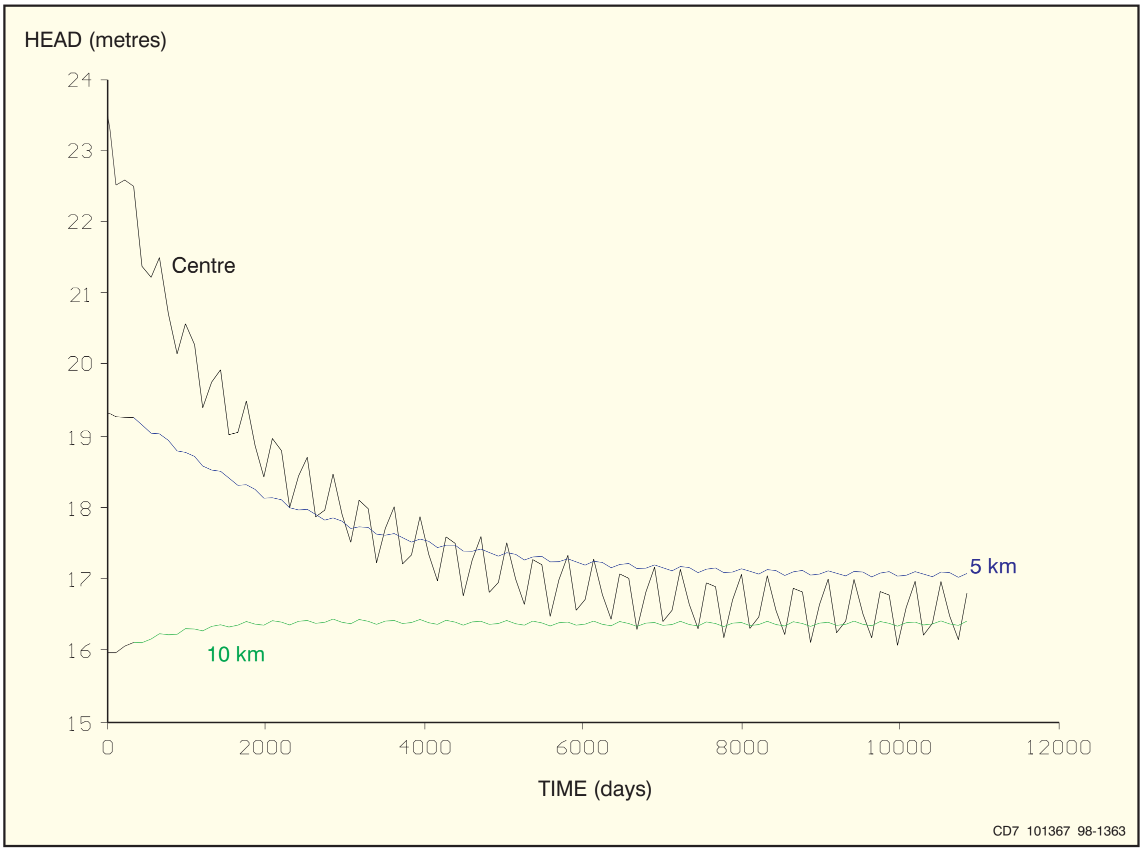


Figure 12 *Scenario 1 - Modelled hydrographs of drawdown against time in the unconfined aquifer*

Sensitivity Analysis: K=15 m/d - drawdown cone in the unconfined aquifer after thirty years extraction

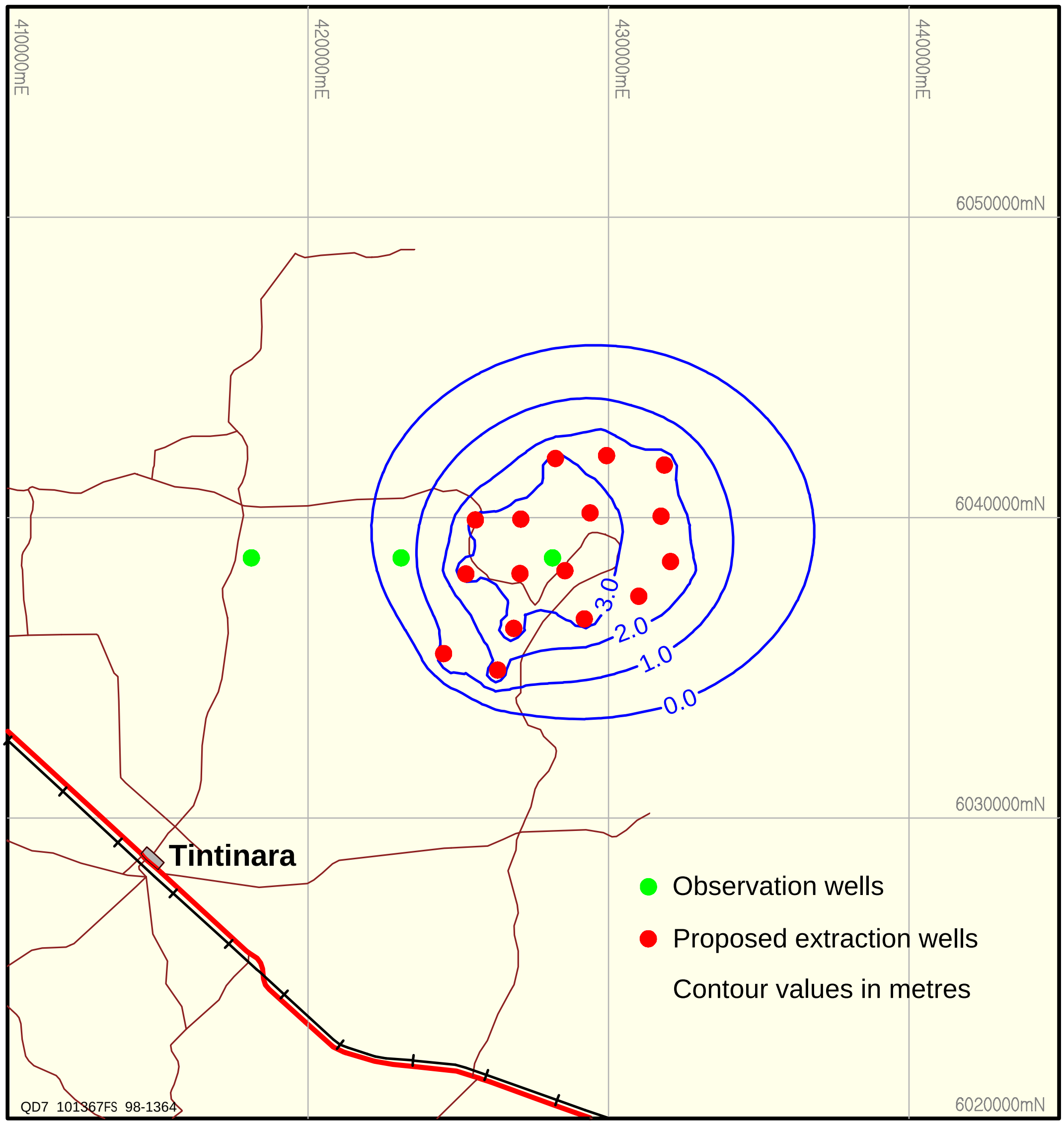


Figure 13

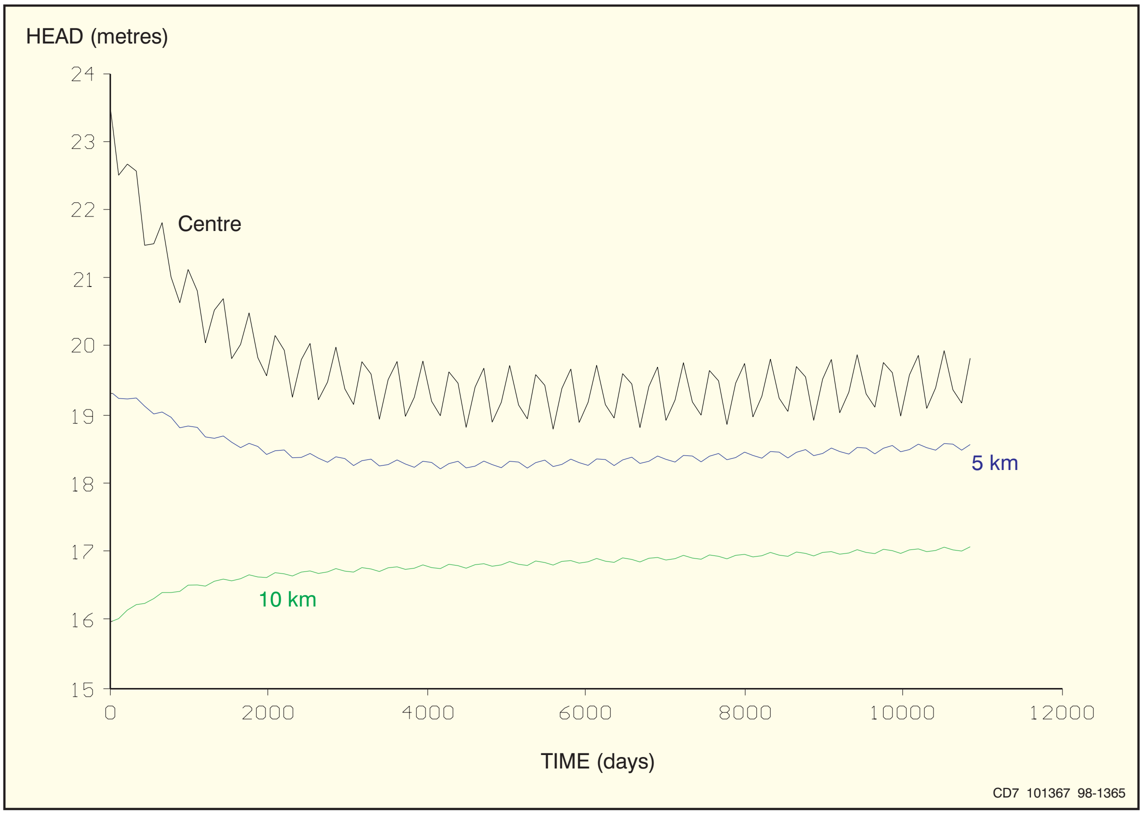


Figure 14 *Sensitivity analysis - K=15m/d - modelled hydrographs of drawdown against time for the unconfined aquifer*

Sensitivity Analysis - Sy = 0.15 - Drawdown cone
in the unconfined aquifer after thirty years extraction

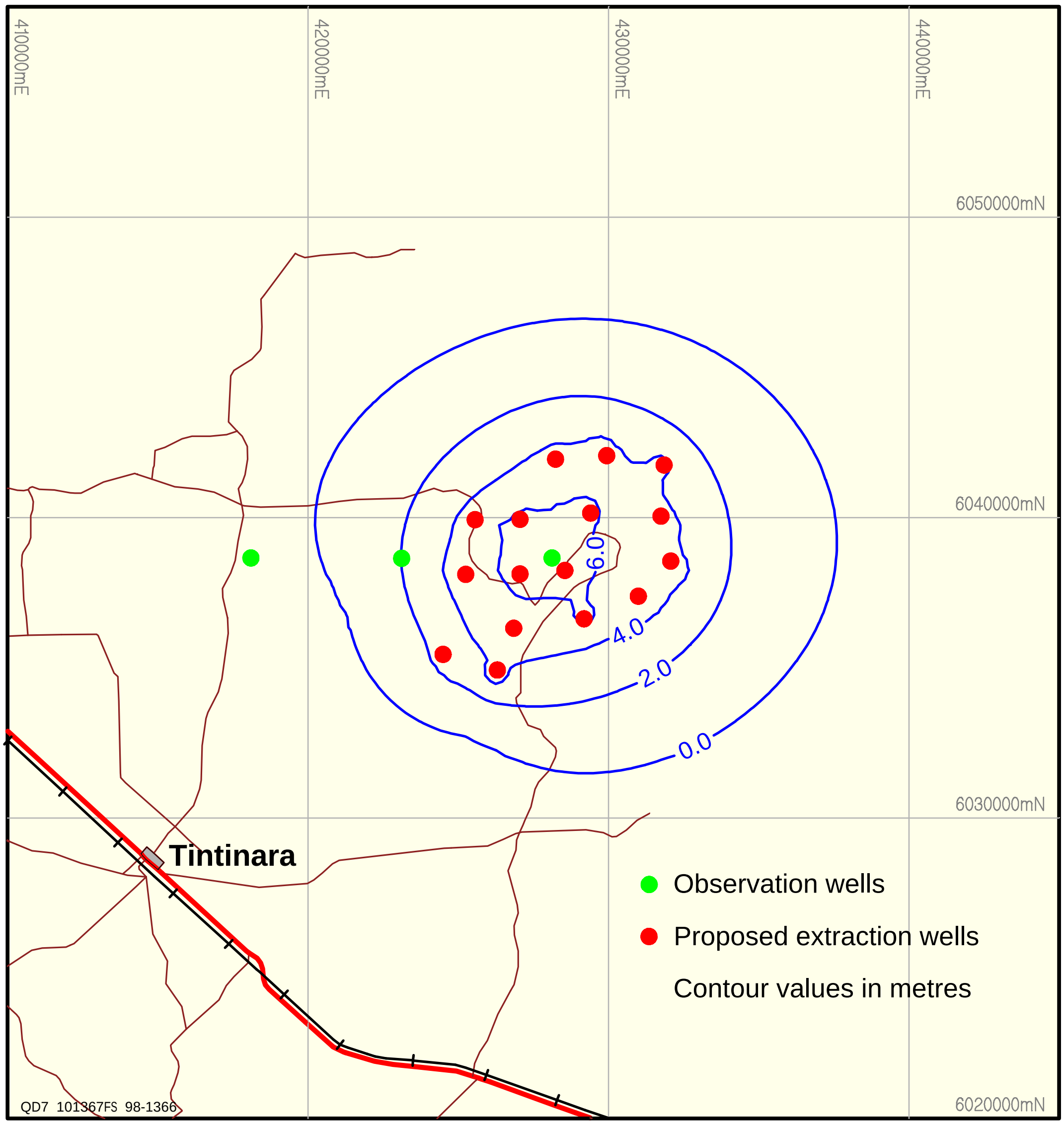


Figure 15

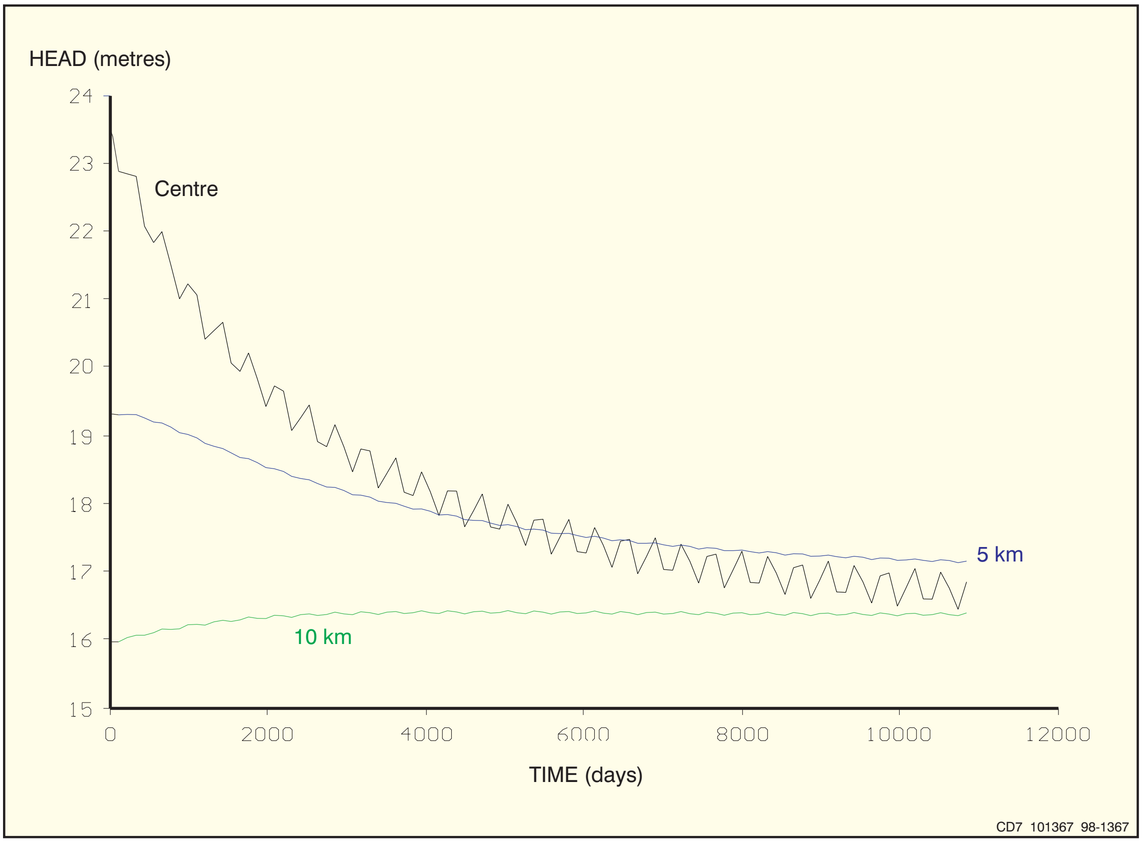


Figure 16 *Sensitivity analysis - Sy=0.15 - modelled hydrographs of drawdown against time for the unconfined aquifer*

Sensitivity analysis - recharge = 20 mm per annum -
Drawdown in unconfined aquifer after thirty years

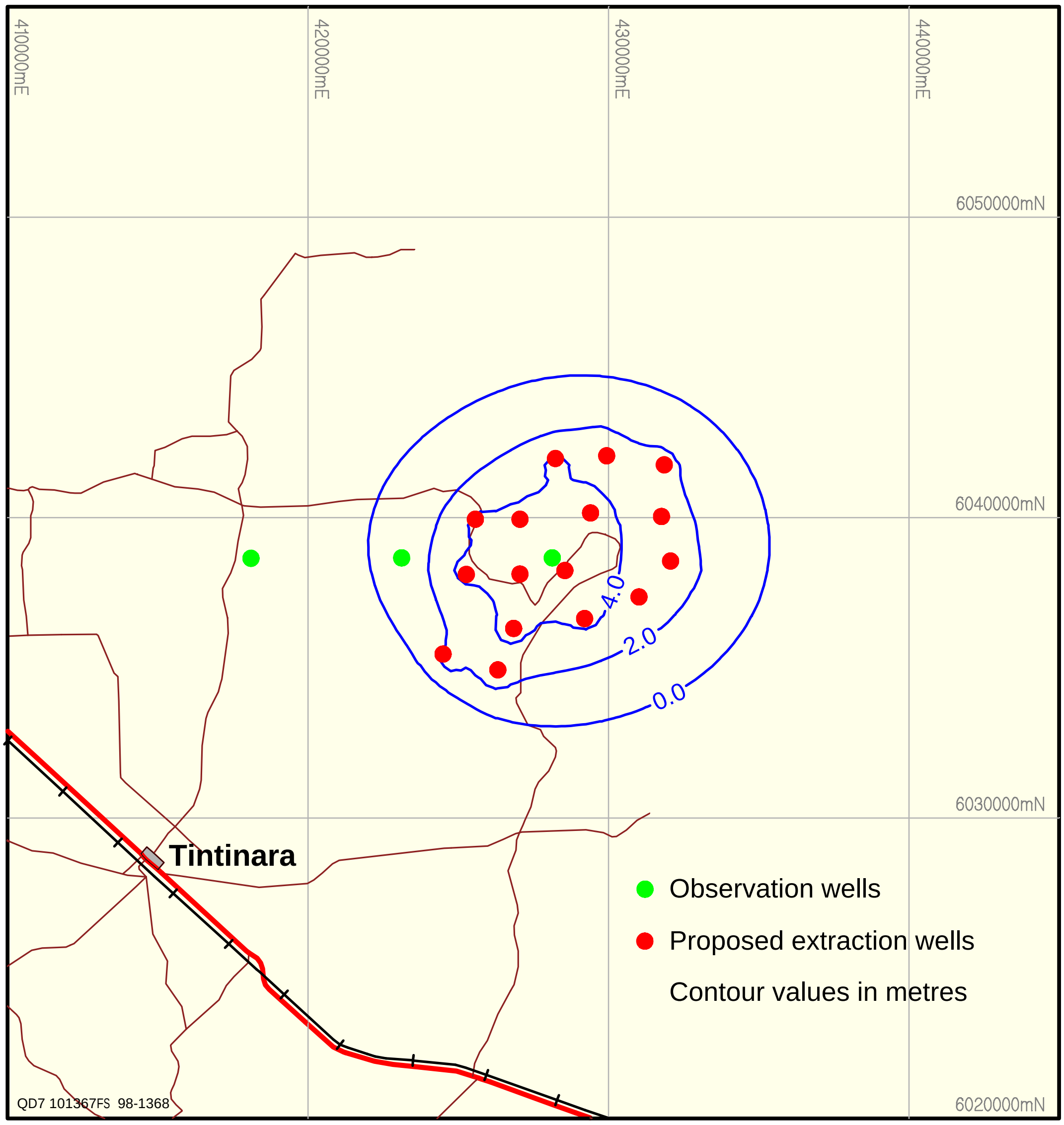


Figure 17

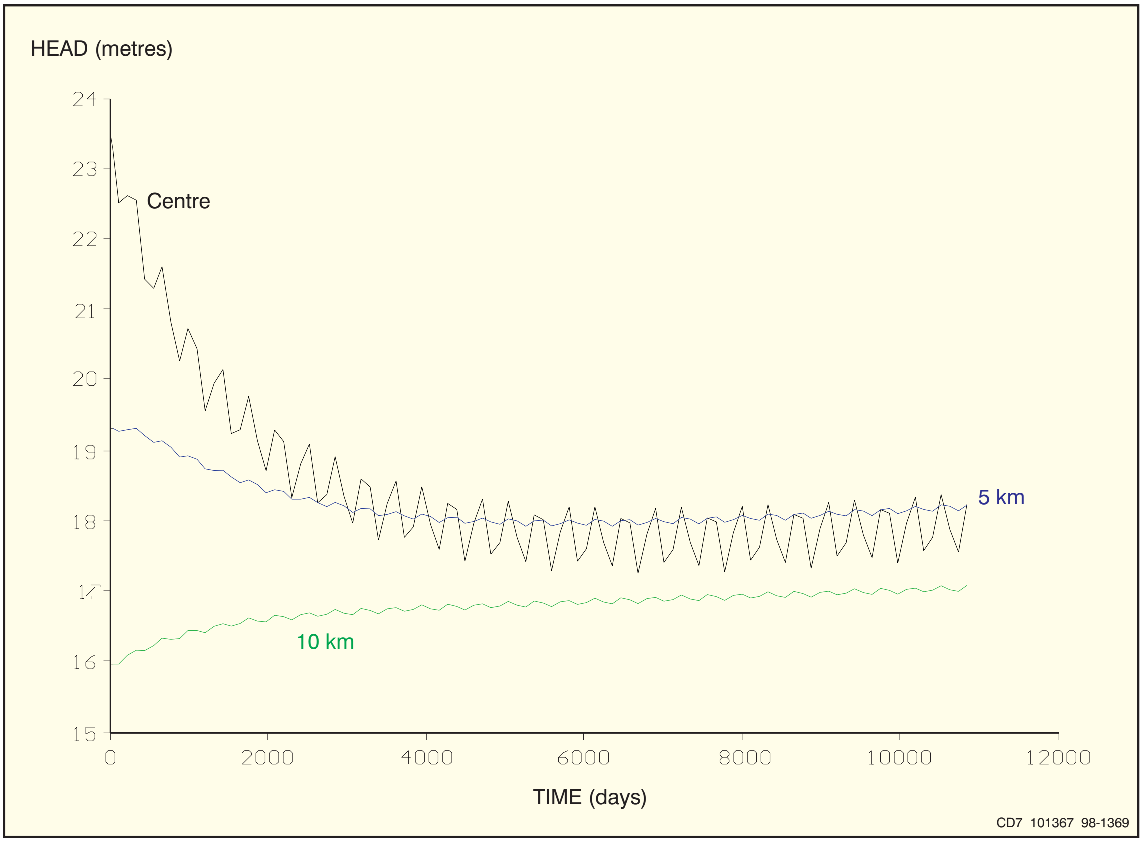


Figure 18 *Sensitivity analysis - Recharge=20mm per annum - modelled hydrographs of drawdown against time for the unconfined aquifer*

Sensitivity analysis - Extraction reduced by 25% - Drawdown cone in the unconfined aquifer after thirty years extraction

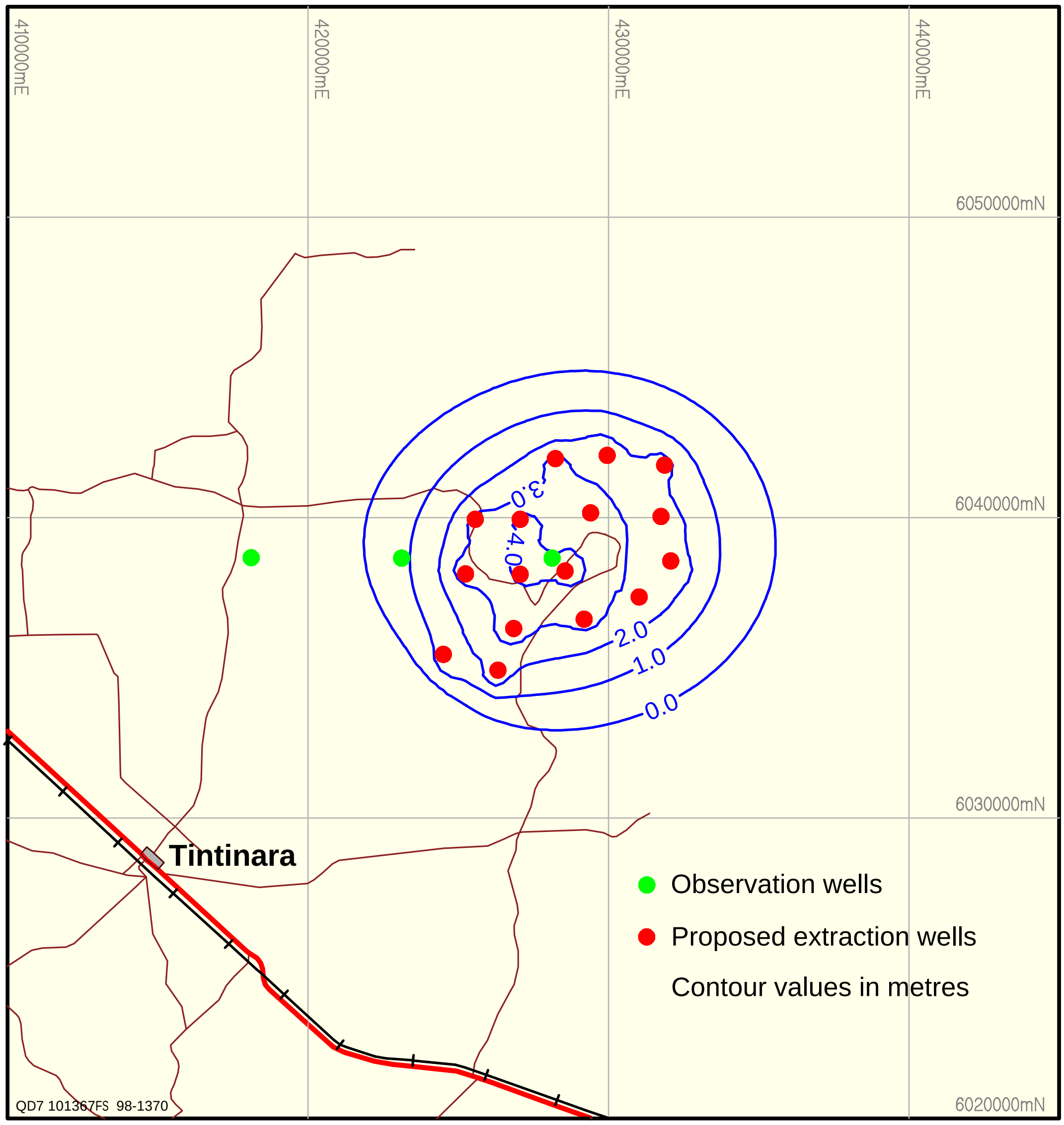


Figure 19

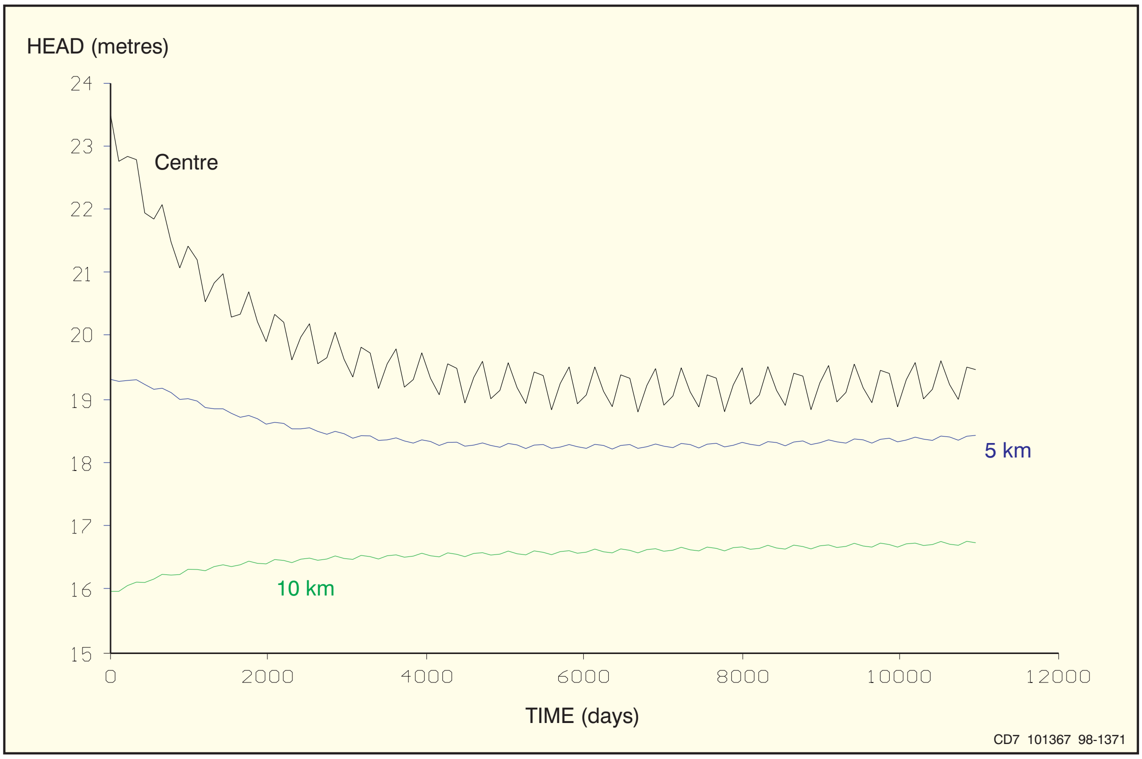


Figure 20 *Sensitivity analysis - Extraction reduced by 25% - modelled hydrographs of drawdown against time for the unconfined aquifer*

Scenario 2 - Modelled unconfined aquifer potentiometric surface contours after thirty years of extraction

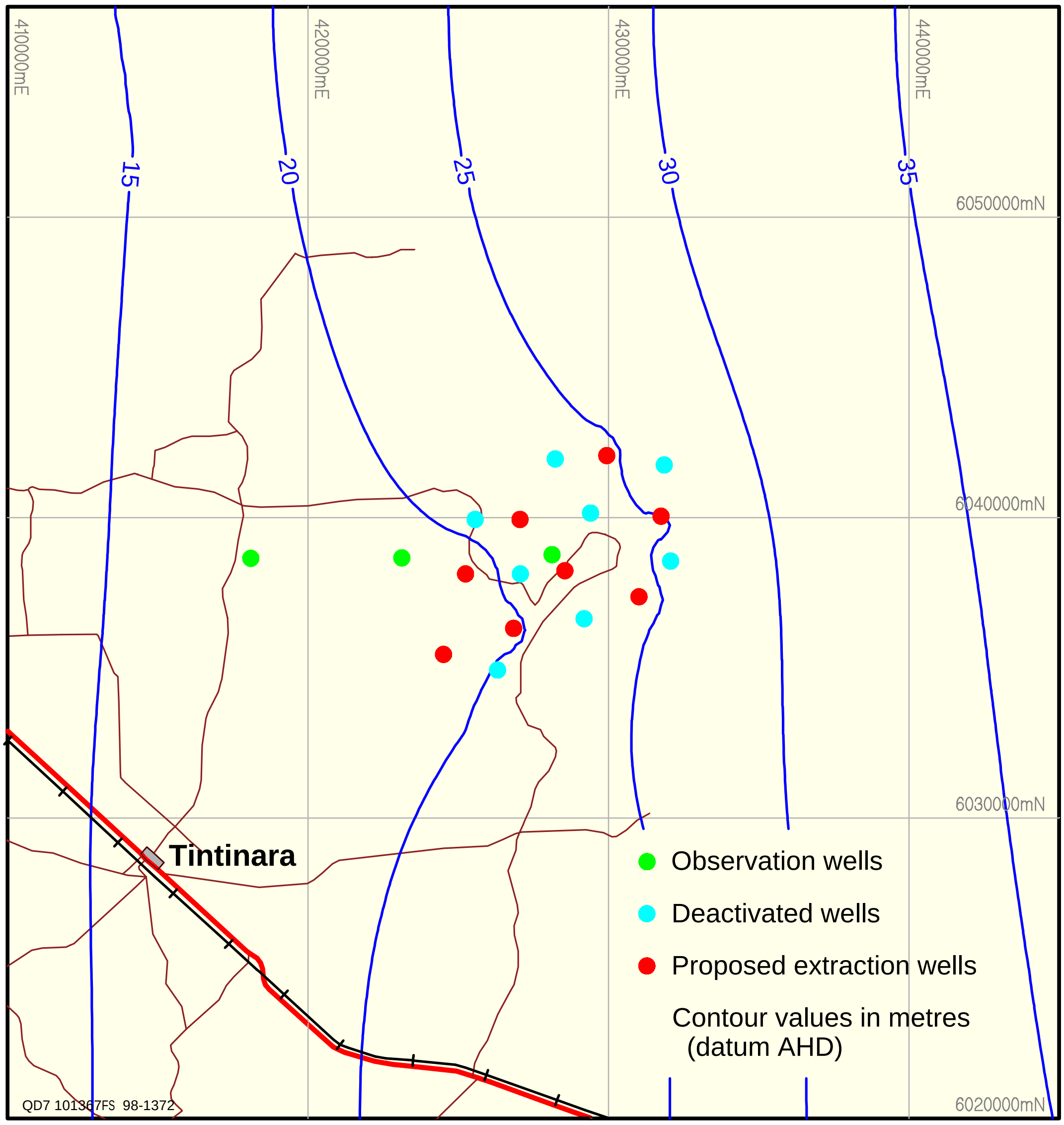


Figure 21

Scenario 2 - Modelled drawdown cone in the unconfined aquifer after thirty years extraction

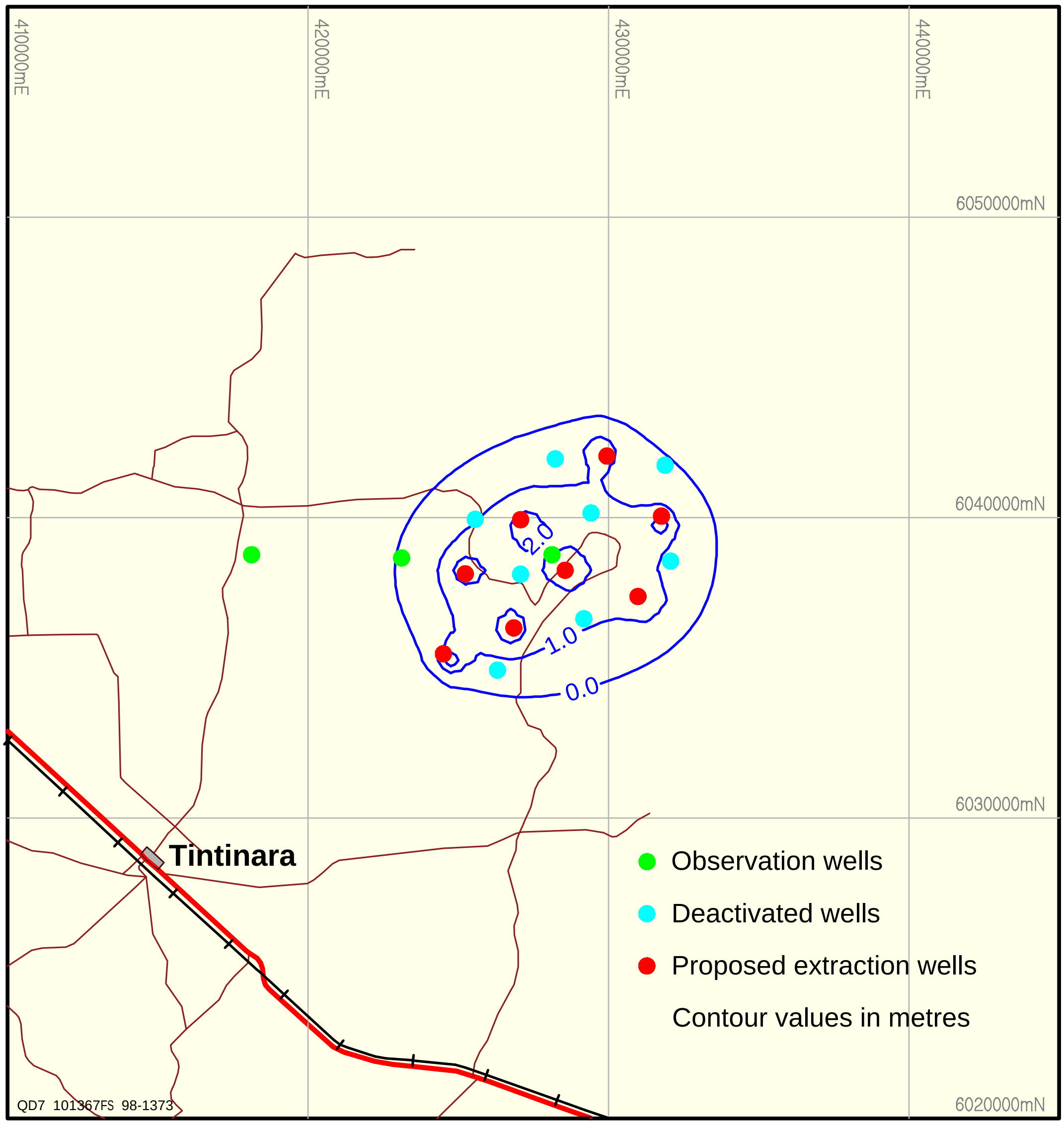


Figure 22

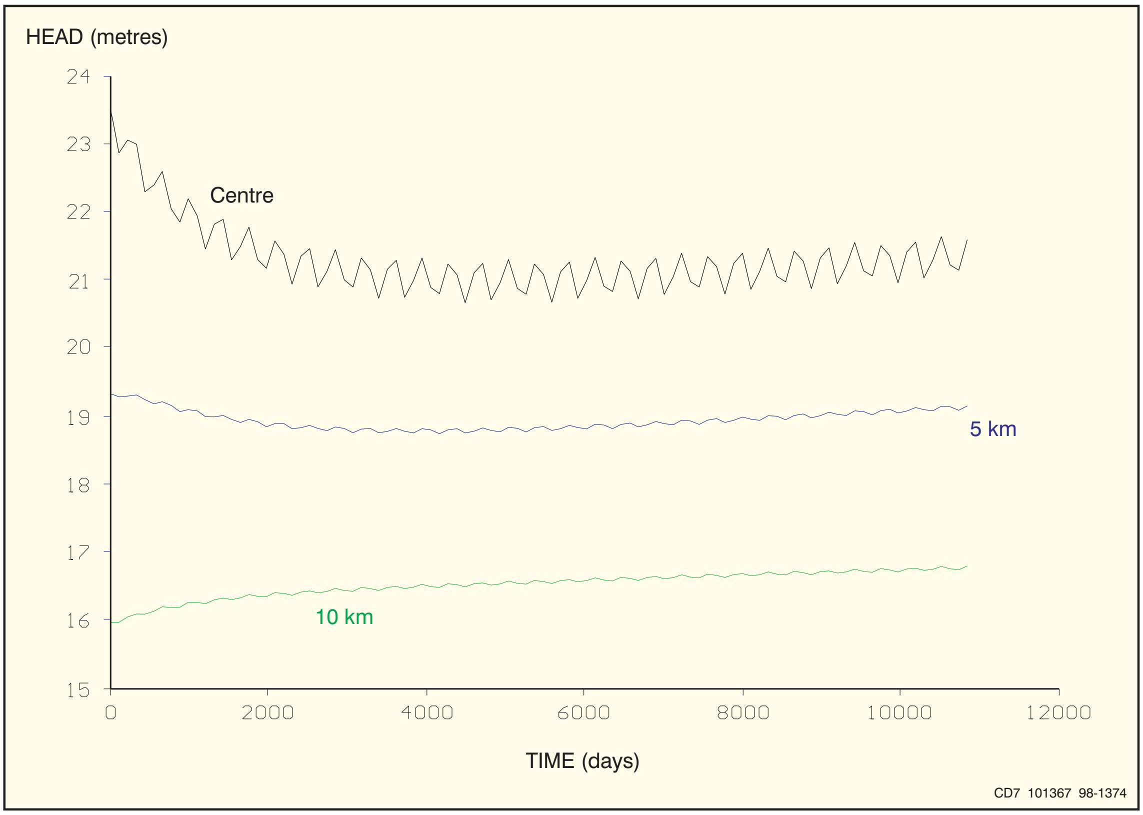


Figure 23 *Scenario 2 - Modelled hydrographs of drawdown against time for the unconfined aquifer*

Scenario 3 - Modelled unconfined aquifer potentiometric surface contours after thirty years extraction

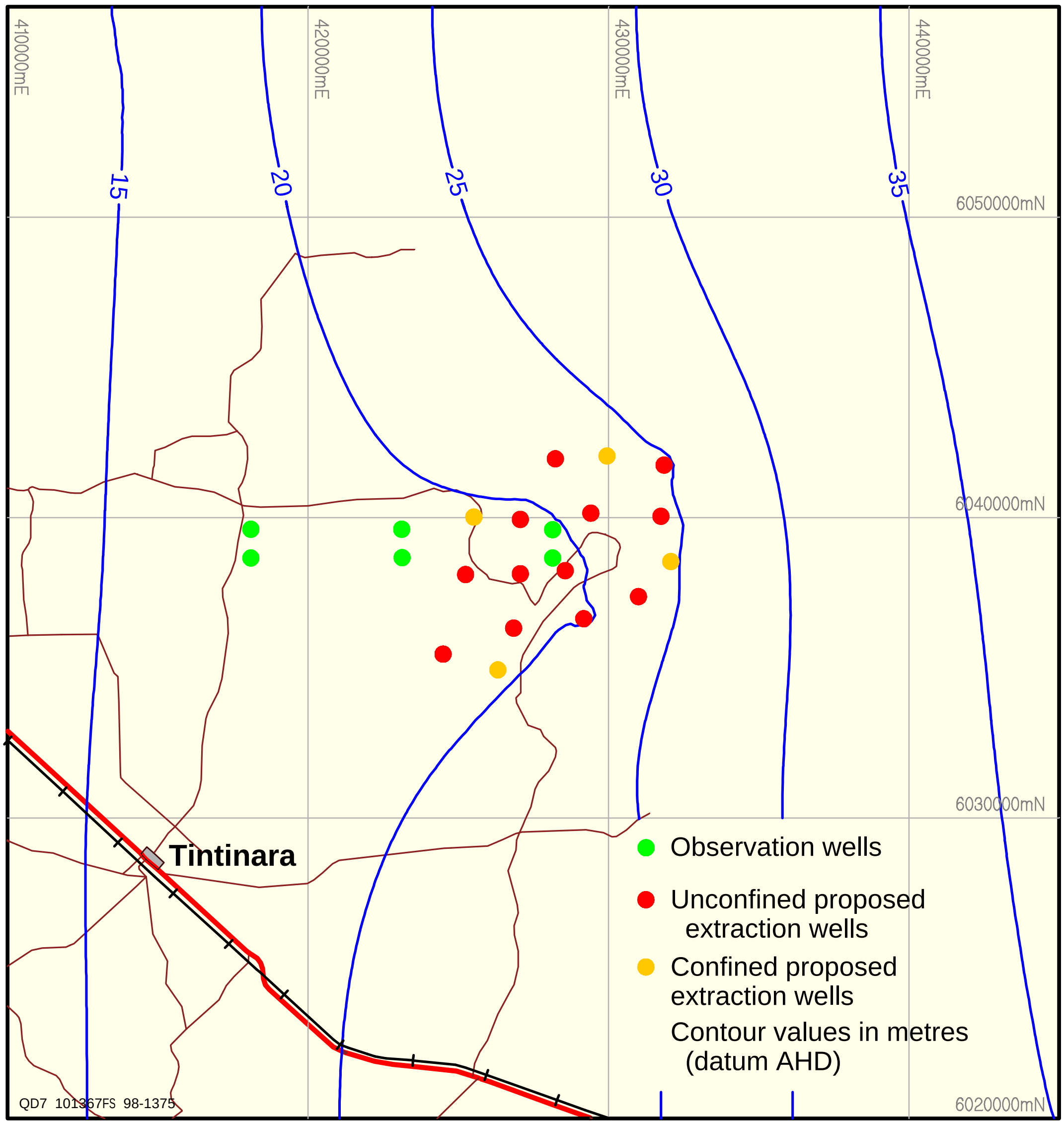


Figure 24

Scenario 3 - Modelled drawdown cone in the unconfined aquifer after thirty years of extraction

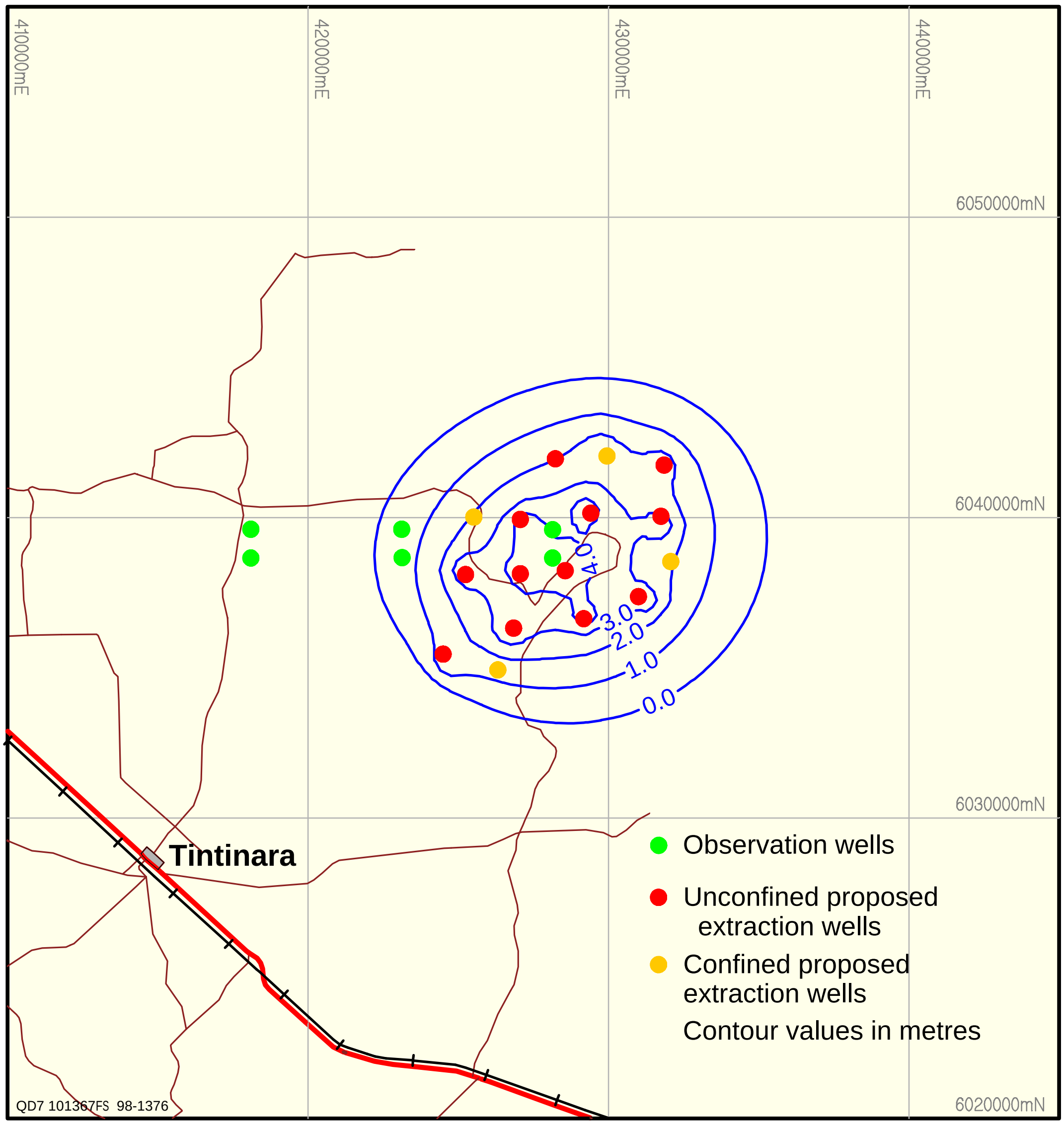


Figure 25

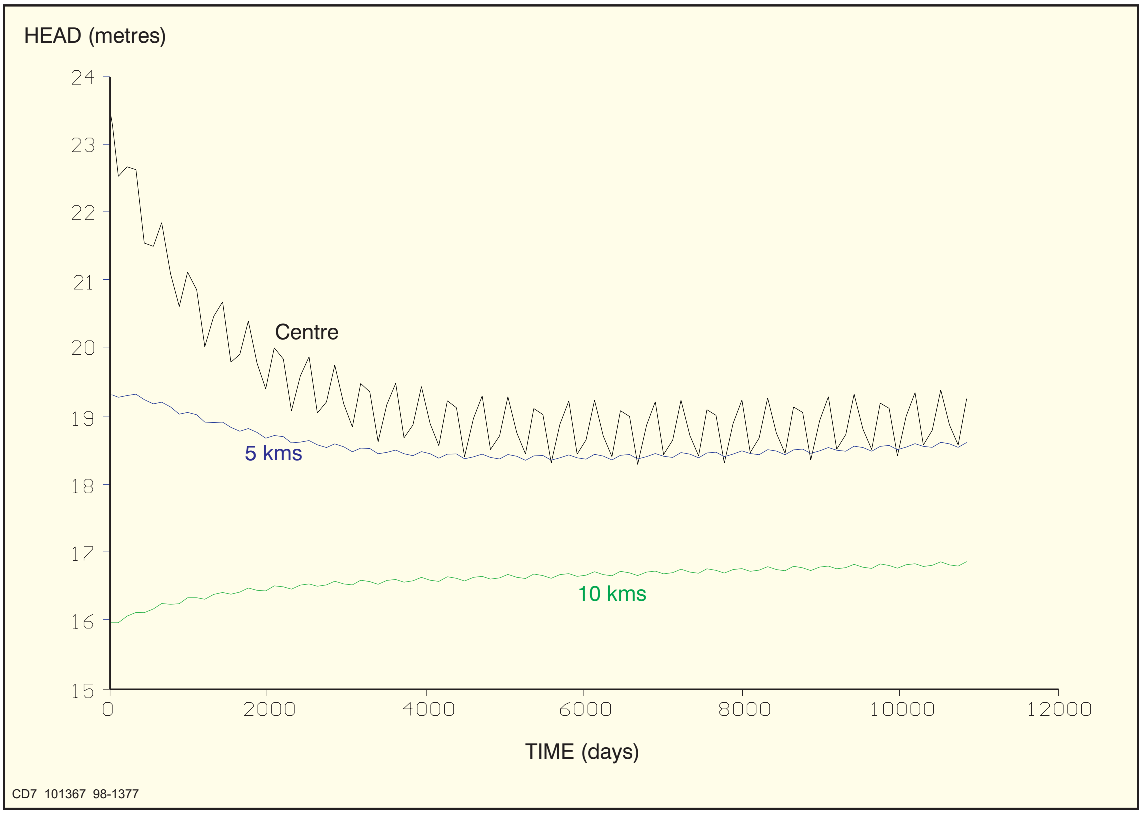


Figure 26 *Scenario 3 - Modelled hydrographs of drawdown against time in the unconfined aquifer*

Scenario 3 - Modelled confined aquifer potentiometric surface after thirty years of extraction

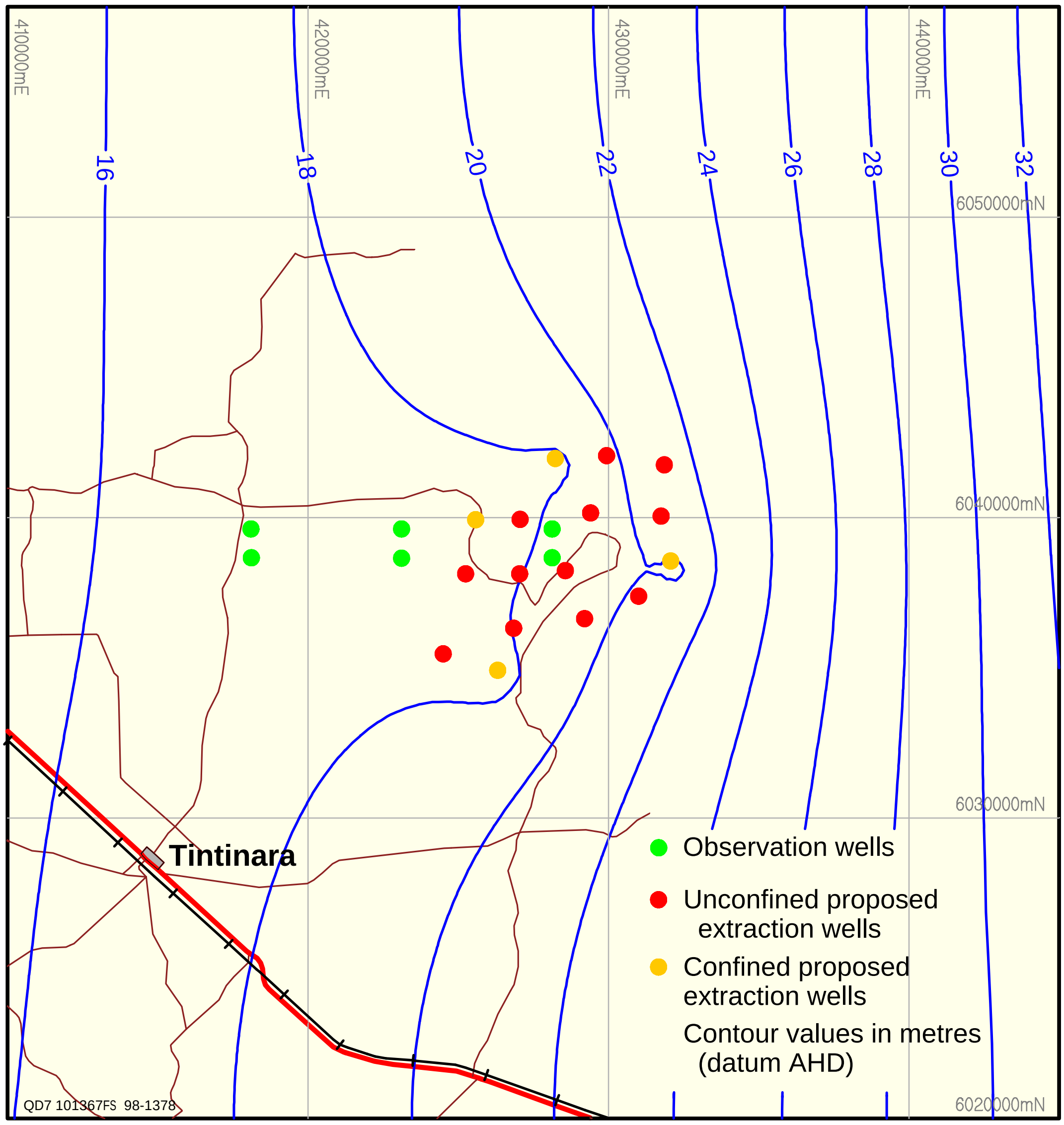


Figure 27

Scenario 3 - Modelled drawdown cone in the confined aquifer after thirty years extraction

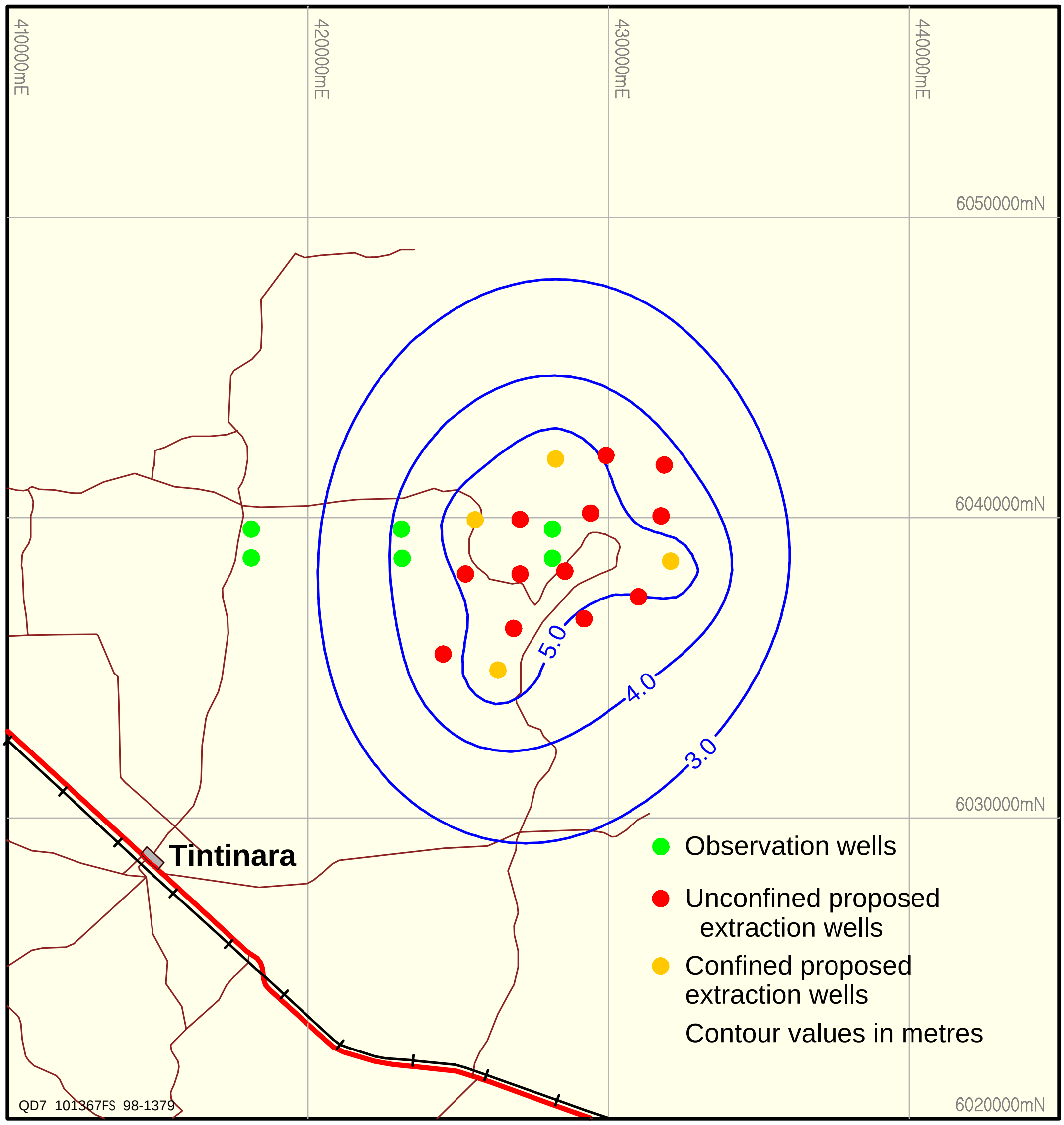


Figure 28

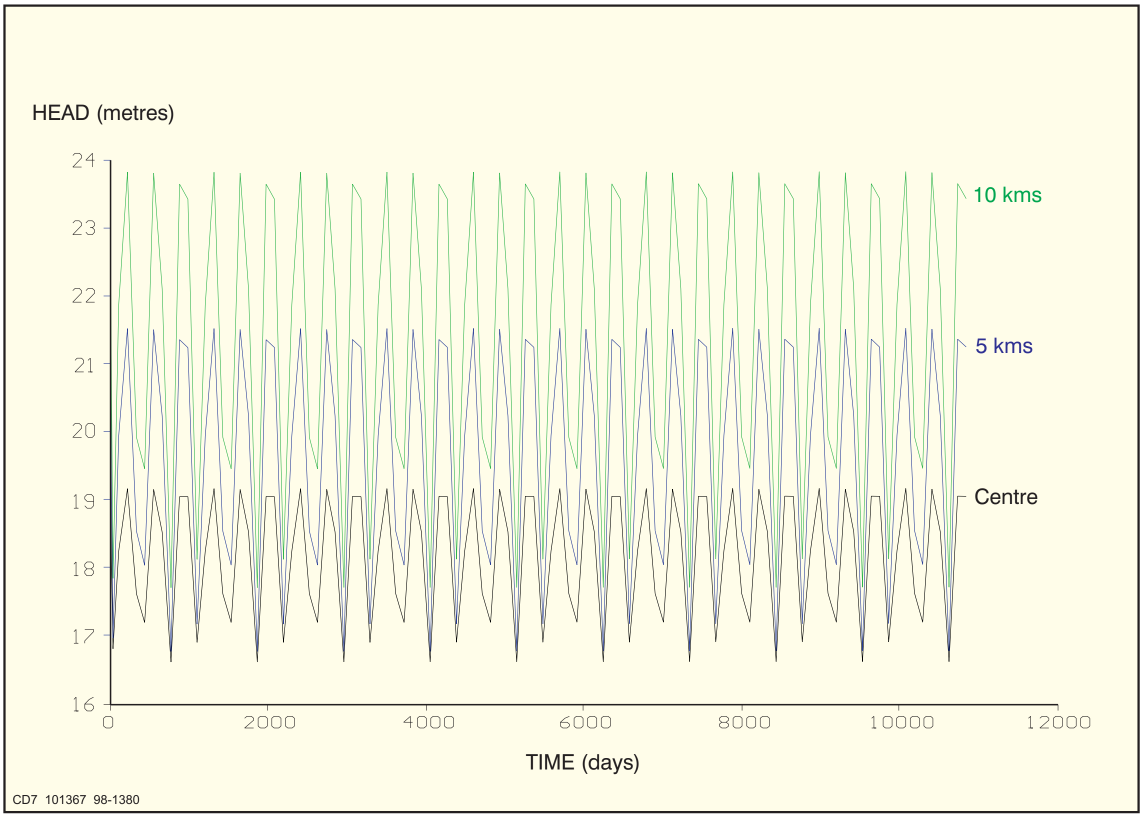


Figure 29 *Scenario 3 - Modelled hydrographs of drawdown against time in the confined aquifer*

Appendix A

MODEL PARAMETERS

MODEL PARAMETERS

Aquifer parameters

Layer 1

Zone 1
Kx = 10 m/d
Ky = 10 m/d
Kz = 1 m/d

Zone 2
Kx = 50 m/d
Ky = 50 m/d
Kz = 5 m/d

Sy = 0.1

Layer 2

Kx = 10-5 m/d
Ky = 10-5 m/d
Kz = 10-6 m/d

Sy = 0.1, Ss = 10-6

Layer 3

Kx = 10 m/d
Ky = 10 m/d
Kz = 1 m/d

Boundary Conditions

Northern and southern boundaries: No flow in all layers.
Eastern Boundary: General Head Boundary
Layer 1: linear gradation between 37.5 AHD in the north to 35 m AHD in the South.
Layer 2: linear gradation between 34 AHD in the north to 32 m AHD in the South.
Layer 3: linear gradation between 33 AHD in the north to 31 m AHD in the South.
Western Boundary: General Head Boundary
Layer 1: linear gradation between 14 AHD in the north to 13 m AHD in the South.
Layer 2: linear gradation between 14 AHD in the north to 13 m AHD in the South.
Layer 3: linear gradation between 15 AHD in the north to 16 m AHD in the South.

Recharge

Annual vertical recharge of 15 mm per annum between the months of May to September inclusive.

Extractions for each extraction well

Month	Daily Irrigation Water Requirement (kL)
January	4260
February	3942
March	2416
April	985
May	0
June	0
July	0
August	0
September	394
October	1335
November	2759
December	3751

Appendix B

SUMMARY OF THE DRAWDOWN IMPACTS
FOR THE MODEL SIMULATIONS

EXTRACTION SCENARIO	DIAMETER OF CONE OF DRAWDOWN (km)	DRAWDOWN (m)	DRAWDOWN IN IMMEDIATE AREA OF WELL FIELD (m)	COMMENTS
1. All extraction wells in the unconfined aquifer	**15-18**	**10**	**6**	**Unconfined Aquifer**
Sensitivity Analysis				
Hydraulic conductivity increased by 50% to 15 m/d	13-15	5	3	Unconfined Aquifer
Specific yield increased by 50% to 0.15	15-17	10	6	Unconfined Aquifer
Vertical recharge increased by 50% to 20 mm per annum	11-13	8	4	Unconfined Aquifer
Extractions reduced by 25%	12-14	6	3	Unconfined Aquifer
2. 8 extraction wells in the unconfined aquifer	**9-11**	**4**	**1**	**Unconfined Aquifer**
3. 12 wells in the unconfined and 4 wells in the confined aquifer	**11-13**	**7**	**3**	**Unconfined Aquifer**
	16-19	**8**	**5**	**Confined Aquifer – 3 m contour**