DWLBC REPORT

Assessment of the groundwater resource capacity of the Peake-Roby-Sherlock Prescribed Wells Area

2008/16

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Assessment of the groundwater resource capacity of the Peake–Roby–Sherlock Prescribed Wells Area

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Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

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Report DWLBC 2008/16

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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EXECUTIVE SUMMARY

The Peake-Roby-Sherlock Prescribed Wells Area (PRS PWA) was prescribed under the Natural Resources Management Act (2004) on the 27th October 2005 in response to a sudden increase in groundwater extractions in the area. As part of the Water Allocation Plan, this assessment of the capacity of the groundwater resource is required under Sec 155 of the Act. Consideration of the social and economic impacts from such extractions (as required by Sec 76 of the Act) is outside the scope of this report, and may result in the volume available for allocation being different from the capacity of the resource. There are two main aquifer systems that underlie the PRS PWA; the unconfined watertable aquifer, and the underlying confined aquifer.

Beneath the low lying Coastal Plain, the watertable lies at shallow depths within an unconfined limestone aquifer of Quaternary age. Although there is no current use due to high salinities (over 15 000 mg/L), a generous volume of 2000 ML/y should be made available for allocation for potential future extractions for purposes such as desalination or aquaculture.

In the north-eastern portion of the PRS PWA beneath the Mallee Highlands, low salinity groundwater around 2–3000 mg/L occurs in the Tertiary Murray Group Limestone aquifer at a depth of about 40–50 m. By using the same method as used in the adjoining Mallee PWA, which takes into account recharge, throughflow and use of storage, a PAV of 1215 ML/y is recommended as the maximum volume that could be allocated.

The confined aquifer comprises both the Buccleuch Group and the underlying Renmark Group. Most stock and domestic wells, some irrigation wells, and the Peake town water supply well are completed in the Buccleuch Group, or "coral" aquifer that lies at a depth of 90–100 m below ground and varies in thickness from 5–25 m. The confined aquifers are not recharged by local rainfall, but by lateral inflow of groundwater into the PRS PWA from south-western Victoria.

The three main potential impacts on the confined aquifer in the PRS PWA:

1. Downward leakage of saline groundwater from the overlying unconfined aquifer is considered a low risk to the resource on the basis of groundwater modelling and monitoring.
2. Collapse of the confining layer due to excessive drawdowns could potentially occur if extractions exceeded 5000 ML/y, with the critical drawdown and risk of depressurization only occurring within several kilometres of the centre of pumping, and would not occur over the whole region.
3. Drawdowns due to extractions over 5000 ML/y will cause inflows of saline groundwater from the west, resulting in the stock salinity limit for drinking water (5000 mg/L) being exceeded within 200 years. However, the stock limit will not be exceeded within 200 years if extractions remain below 1800 ML/y. Any determination of what constitutes an acceptable rate of rise in salinity is beyond the scope of this report.

1. INTRODUCTION

The Peake-Roby-Sherlock Prescribed Wells Area (PRS PWA) was prescribed under the Natural Resources Management Act (2004) on the 27th October 2005 in response to a sudden increase in groundwater extractions in the area. As part of the Water Allocation Plan, this assessment of the groundwater resources is required to help determine the amount of groundwater that can be allocated. The PRS PWA comprises all lands situated within the Hundreds of Peake, Roby and Sherlock (Fig. 1).

Figure 1. Location of Peake-Roby-Sherlock PWA

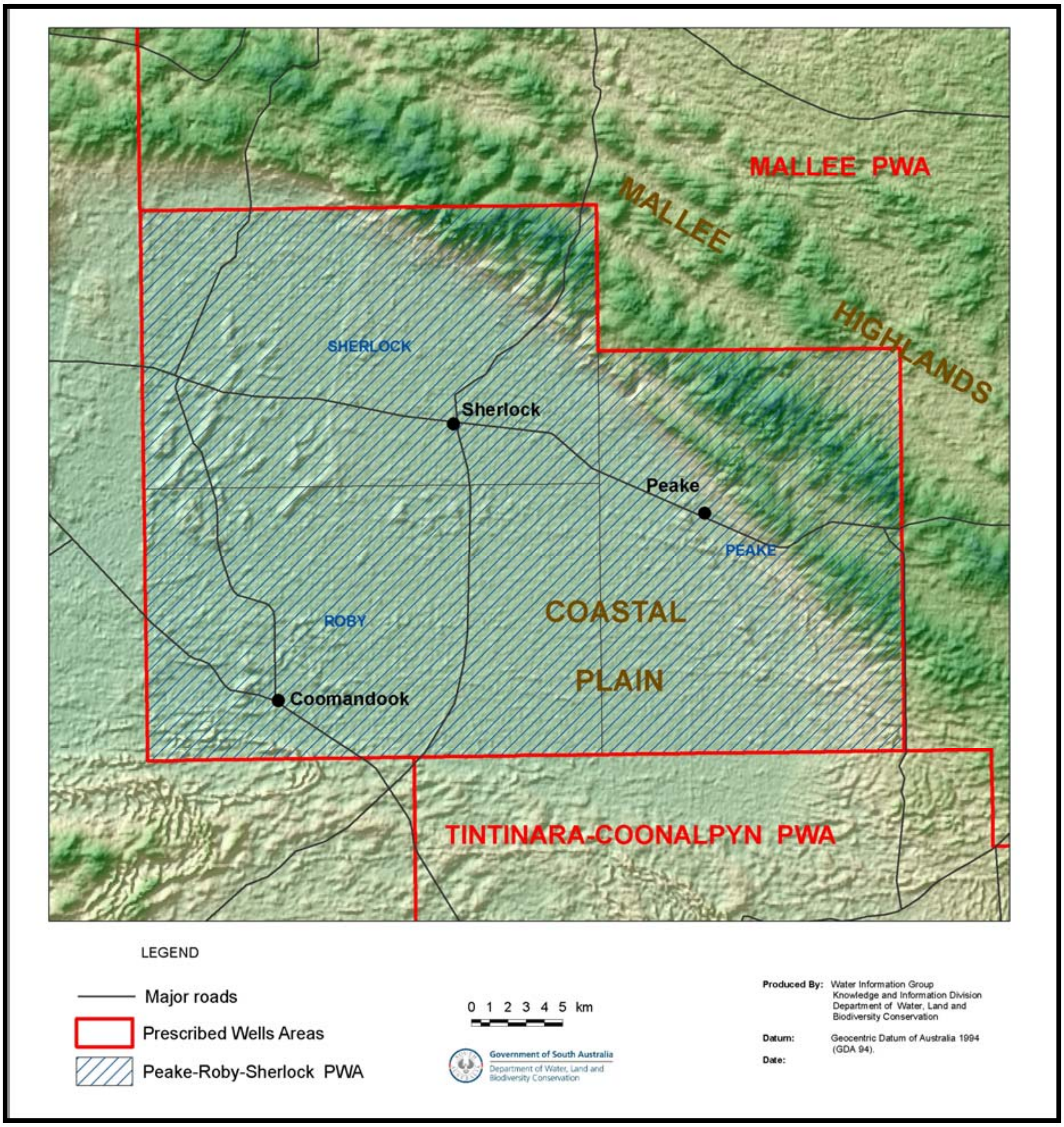

Figure 2. Topography of Peake-Roby-Sherlock PWA

About one million years ago, a marine transgression extended as far inland as the Marmon Jabuk Scarp, and eroded away much of the older Tertiary sands and limestones which underlie the Mallee Highlands to the east. When the sea retreated, it left a broad, flat low-lying area which gave rise to its description as the Coastal Plain (Fig. 2). This event has shaped the hydrogeology of the PRS PWA as it is known today. There are two main aquifer systems that underlie the PRS PWA; the unconfined watertable aquifer, and the underlying confined aquifer. Each aquifer will be discussed in turn.

2. UNCONFINED AQUIFER

The unconfined aquifer is continuous across the PRS PWA; but can be divided into two main regions – the low lying Coastal Plain and the Mallee Highlands, each with different hydrogeological characteristics. Figure 3 displays a cross section across these two regions.

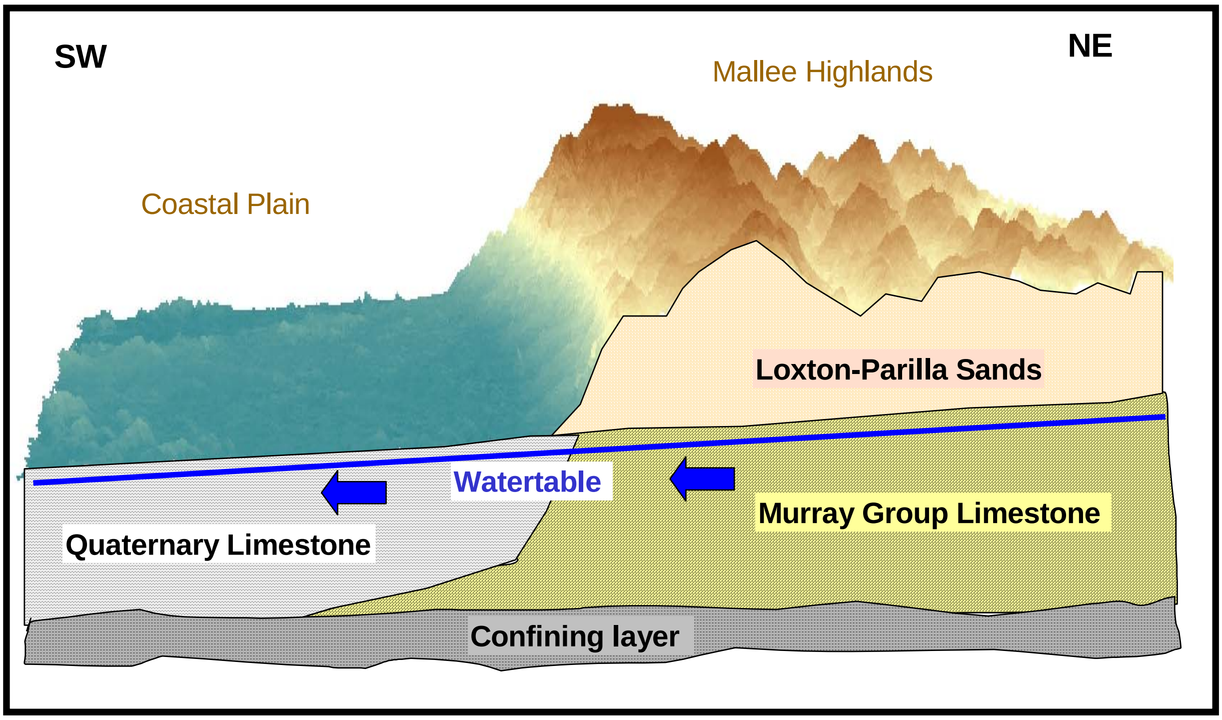

Figure 3. Geological cross section of unconfined aquifer

2.1 COASTAL PLAIN

Beneath the Coastal Plain, the watertable lies at shallow depths ranging between 3–8 m below ground level. Groundwater lies within an unconfined limestone aquifer of Quaternary age which was deposited during the marine transgression. Rogers (1980) names this unit the Coomandook Formation and describes it as a "marine fossiliferous sandy limestone, with interbedded calcareous sandy clays and sands". Groundwater movement is in a westerly direction from beneath the highlands to the east, and flows under a very low gradient at a very slow rate of a metre or so per year.

The salinity distribution (Fig. 4) shows some interesting features which strongly reflect the extent and impact of the marine transgression. This has resulted in high groundwater salinities over 15 000 mg/L below the Coastal Plain with consequently, no current use of the resource. These high salinities have caused significant problems over the years to older stock and domestic wells intersecting the underlying confined aquifer by causing corrosion of uncemented steel casing. This has resulted in leaking wells supplying water contaminated by saline water from the unconfined aquifer.

The unconfined aquifer is recharged predominantly locally by rainfall which infiltrates directly into the aquifer through the soil profile.

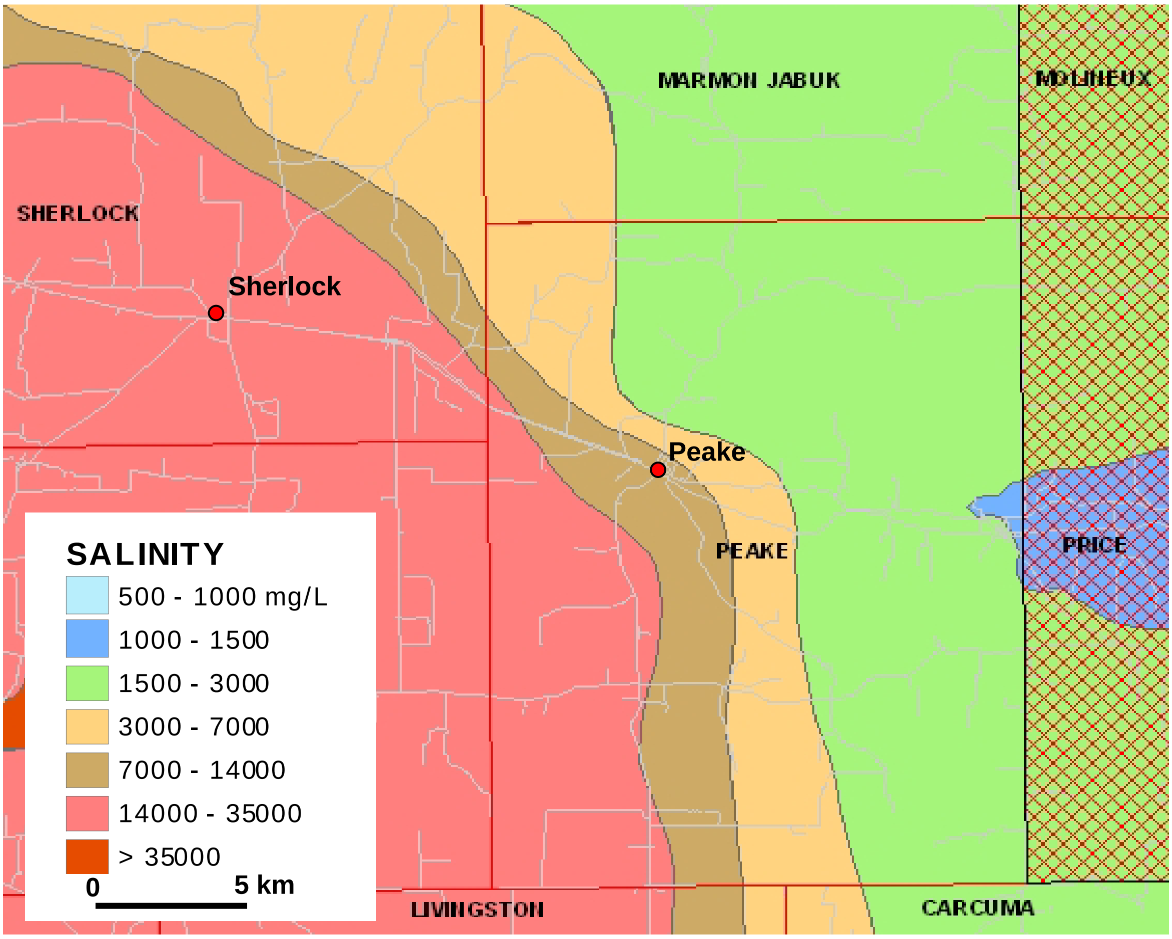

Figure 4. Salinity distribution in the unconfined aquifer

2.2 MALLEE HIGHLANDS

Only a few kilometres to the east of the Coastal Plain, low salinity groundwater in the range of 2–3000 mg/L lies at a depth of about 40–50 m beneath the Mallee Highlands in the Tertiary Murray Group Limestone aquifer (Figs 2 and 3). This groundwater which is mostly used for stock and domestic purposes, also moves slowly in a westerly direction. Much further to the east in the Mallee PWA, this aquifer is extensively used for irrigation. The limestone is overlain by up to 70 m of sands and clayey sands of the Loxton-Parilla Sands unit.

3. CONFINED AQUIFER

The confined aquifer comprises both the Buccleuch Group and the underlying Renmark Group. Most stock and domestic wells, some irrigation wells, and the Peake town water supply well have been drilled down into the confined aquifer because of the high salinities in the overlying shallow aquifer.

The most widely used aquifer is the Buccleuch Group, which consists of a consolidated bryozoal limestone or "coral" that lies at a depth of 90–100 m below ground and varies in thickness from 5–25 m. This aquifer is confined by a thick layer of black carbonaceous clay up to 20 m thick. The coral layer lenses out toward the east, coincidentally where the terrain rises toward the Mallee Highland. Below this coral, sand layers within the Renmark Group lie at a depth of about 130 m and may be developed for supplies, with wells requiring sandscreens. There are very few wells in the PRS PWA that develop this sand aquifer, which attains a thickness of up to 25 m. Figure 5 depicts an east-west cross section through the confined aquifer which shows the variable thickness of the aquifers and confining layers.

Although the coral and sand confined aquifers are separated by sandy clays varying in thickness from 2–20 m, there will be leakage between them on a regional scale over a time frame of months to years. This leakage will be enhanced by extractions from either aquifer.

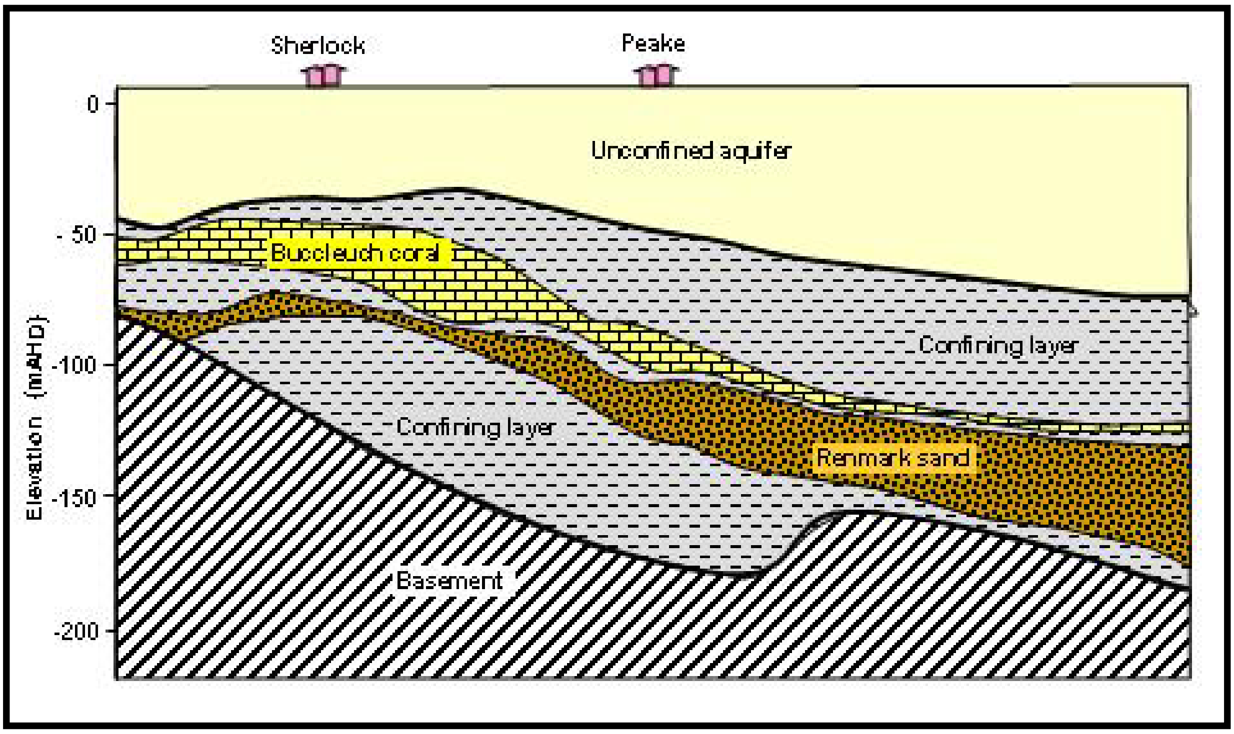

Figure 5. Geological cross section of confined aquifer

Because the Buccleuch and Renmark Group confined aquifers are confined, they are not recharged by local rainfall. The main recharge source is lateral inflow of groundwater into the PRS PWA from south western Victoria where local recharge does occur because the confined aquifer is shallower and receives downward leakage from the overlying unconfined aquifer.

Figure 6. Regional potentiometric surface and flowpath for confined aquifer

Figure 6 shows the long flowpaths for the confined aquifer in which groundwater flows downgradient from the recharge areas in southwest Victoria, to the discharge areas near the River Murray and the Lower Lakes. Within the PRS PWA, groundwater movement in the confined aquifer was generally from east to west before the commencement of irrigation.

Confined aquifer salinities, as shown in Figure 7, show a steady increase towards the west. To the southwest of Sherlock, the salinities are mostly too high for stock and reticulated water is used for stock and domestic supplies.

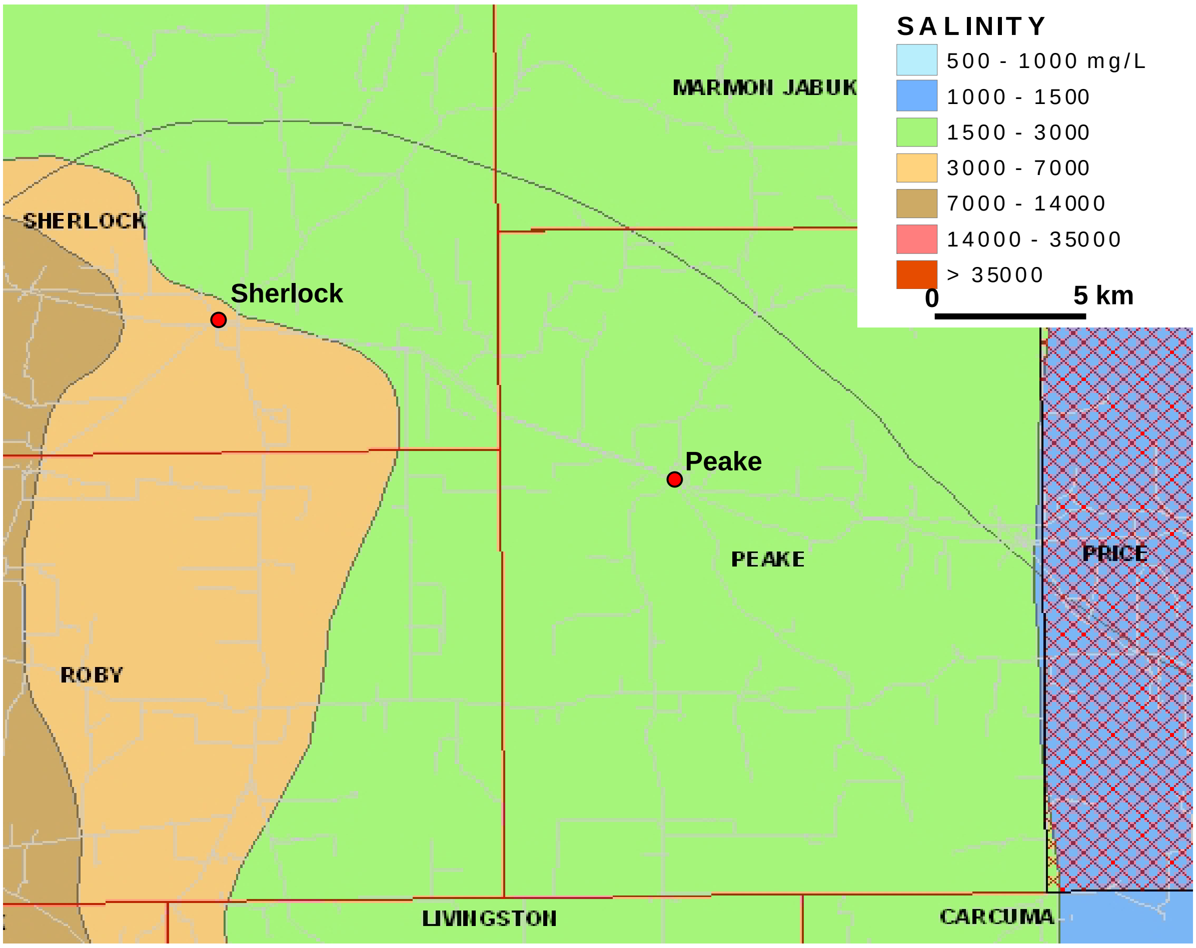

Figure 7. Salinity distribution in the confined aquifer

4. GROUNDWATER MONITORING

DWLBC have been monitoring groundwater levels in the PRS PWA since 1989 when concerns were expressed about rising watertables in the southwest of the area. Initially, the network was established on a regional scale, but when interest in establishing irrigation in the Peake area first became apparent in 2000, the network was expanded. The dramatic increase in development in 2004 prompted an intensification of the network and commencement of salinity monitoring.

Where possible, recently drilled wells with pressure cemented PVC casing were selected for monitoring to ensure long term integrity of the data collected, without the risk of casing corrosion causing inaccurate or unrepresentative readings.

All observation well data for PRS PWA can be obtained from the OBSWELL database via the web at this address;

http://applications01.pirsa.sa.gov.au:102/new/obsWell/SearchGroup/startSearch - here

The network name of PEAKE should be entered to examine or download observation well data (water levels and salinity).

4.1 UNCONFINED AQUIFER

There are currently 17 observation wells which monitor the unconfined aquifer within (or immediately adjacent to) the PRS PWA (Fig. 8). Most of these were established in 1987 to monitor rising watertables on the low-lying Coastal Plain due to the clearance of native vegetation. There are also some shallow Landcare wells which are monitored sporadically.

Figure 9 shows water level hydrographs from observation wells located on the Coastal Plain. The cumulative deviation from mean rainfall (in blue) measures the difference between the actual measured rainfall and the long term average rainfall on a monthly basis. An upward trend in this line indicates above average rainfall, and conversely, a downward trend indicates below average rainfall.

From Figure 9, the shallow watertable can be seen rising in response to episodic wet years (such as 1992–93 and 1996). Otherwise, there has been significant periods of below average rainfall since 1990 which has resulted in a slow decline in watertable levels. Prior to this time, regional watertables had been rising at 5–10 cm/y due to the increase in recharge following extensive clearing of native vegetation. This watertable rise had resulted in dryland salinity affecting hundreds of hectares in the Cooke Plains area (Barnett, 1992).

Hydrographs for observation wells in the Mallee Highlands in Figure 10 show a very gradual rising trend of 1–5 cm/y due to clearing, despite the below average rainfall discussed earlier, and the considerable depth to the watertable. Vegetation clearance will also cause a long term increase in groundwater salinity as salt previously stored in the root zone of the mallee vegetation is flushed down to the watertable by the increased recharge (Cook, Telfer and Walker, 1993).

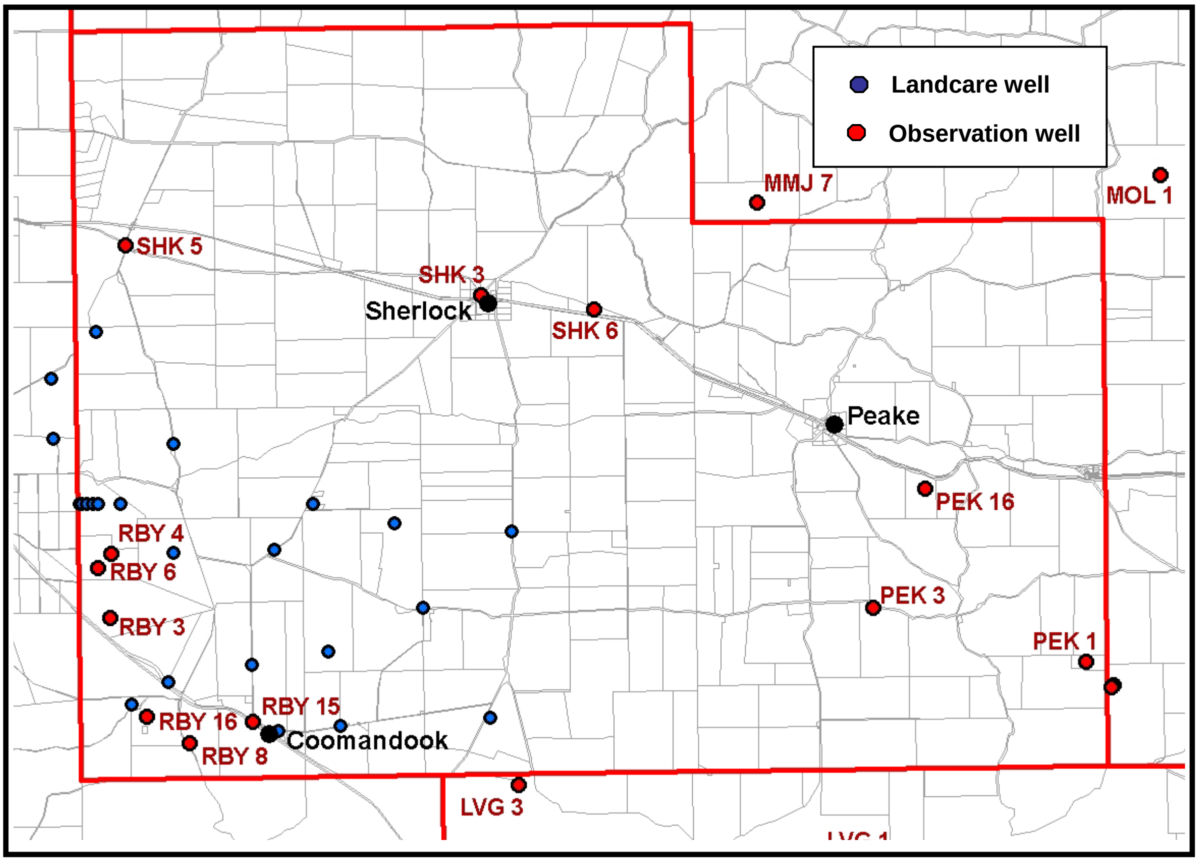

Figure 8. Unconfined aquifer observation network

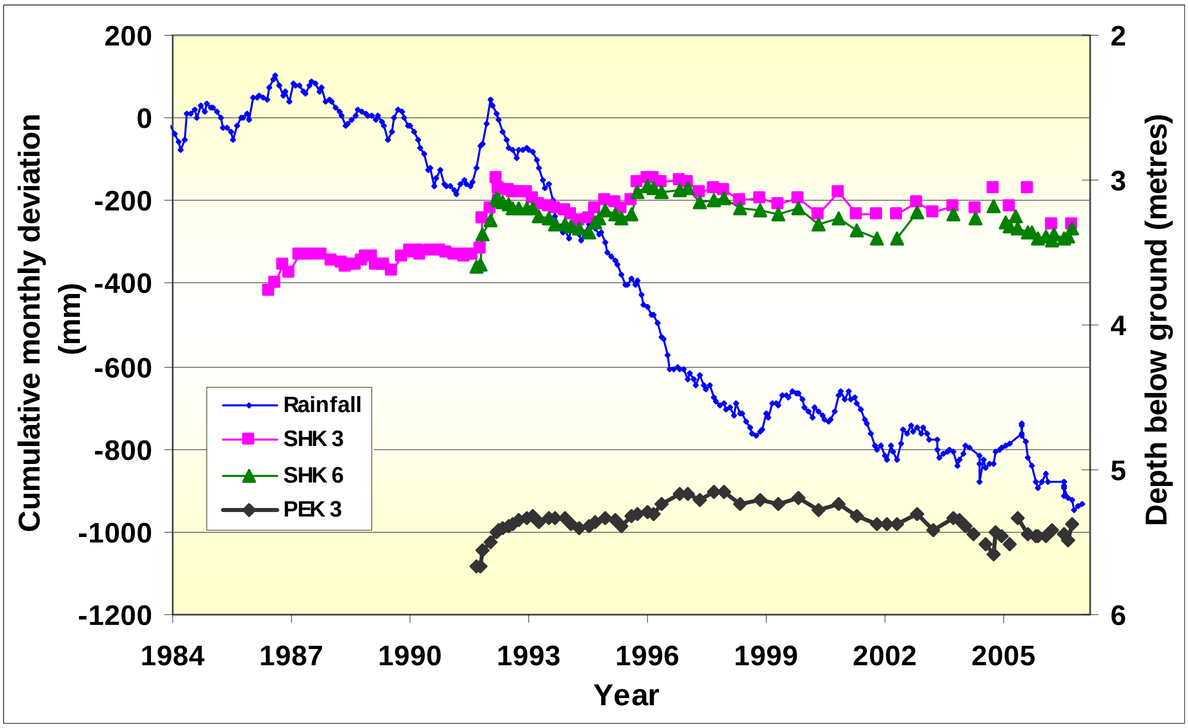

Figure 9. Coastal Plain hydrographs

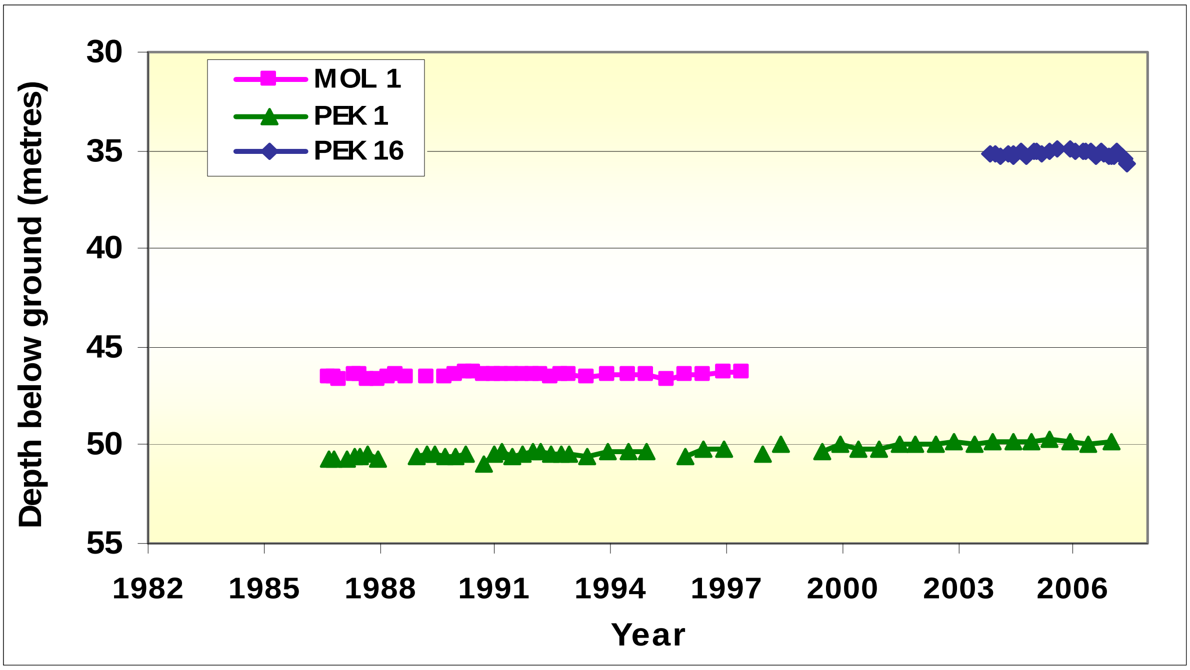

Figure 10. Mallee Highland hydrographs

It is important to note that PEK 16, which is located close to the area of maximum drawdown in the underlying confined aquifer, shows no evidence of any impacts indicating downward leakage caused by confined aquifer extraction.

There has been no salinity monitoring carried out in the unconfined aquifer due to high salinities and low levels of extraction.

4.2 CONFINED AQUIFER

There are currently 16 observation wells monitoring pressure levels in the confined aquifer in the PRS PWA, as shown in Figure 11.

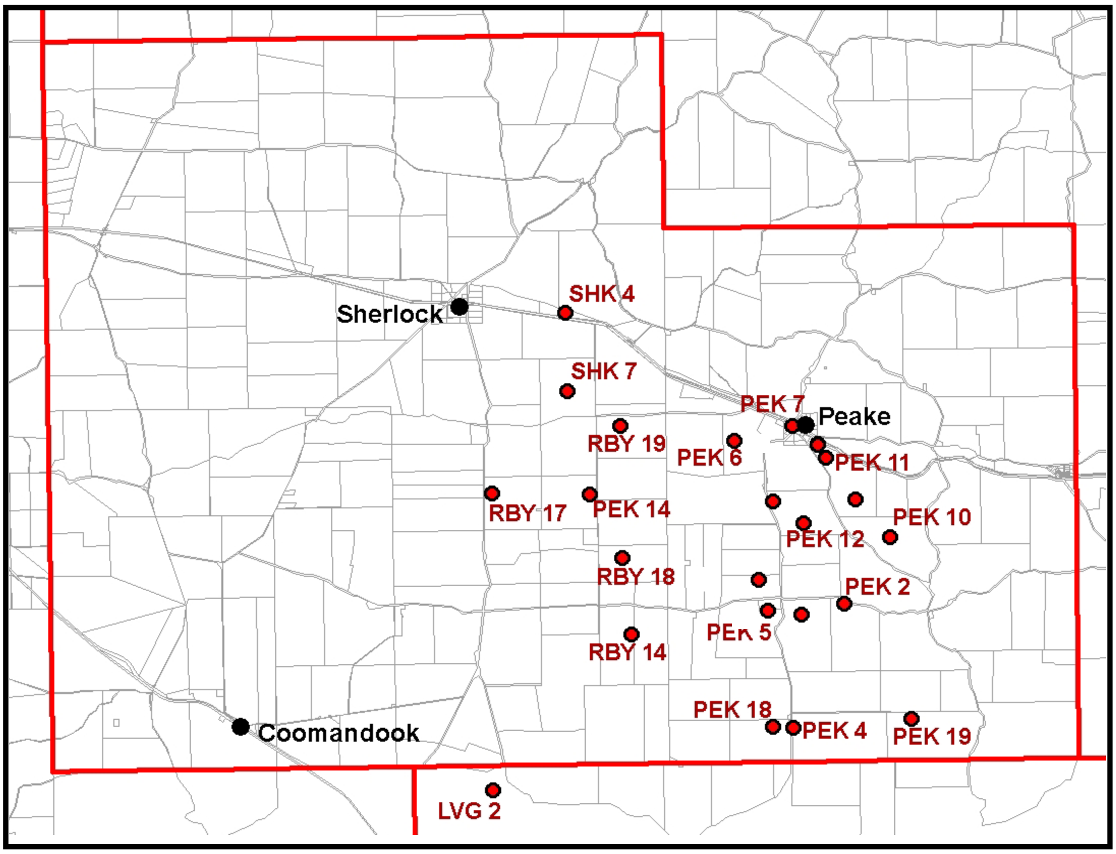

Figure 11. Confined aquifer pressure level network

These wells were selected to obtain representative water level readings because they have either been recently constructed with pressure cemented PVC casing, or have been rehabilitated with a cemented PVC liner.

Contours of the drawdown in confined pressure levels between 2002 (prior to irrigation expansion) and April 2008 are shown in Figure 12. Over this period, the maximum decline in pressure levels ranged up to 20 m.

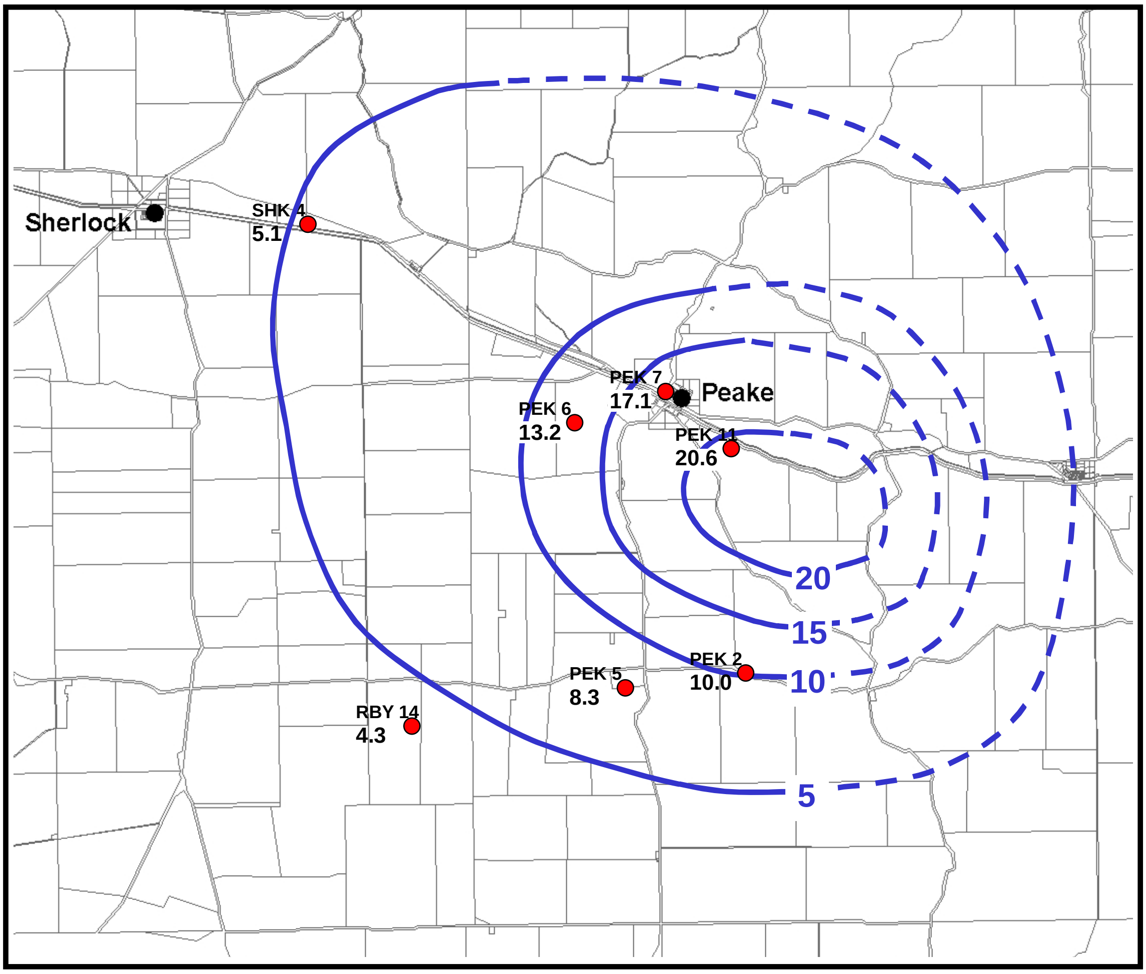

Figure 12. Contours of drawdown from 2002 pre-irrigation levels to April 2008

Figure 13 presents water level hydrographs from various observation wells:

- PEK 7 (the Peake town water supply well) which is representative of the impacts on properties within 3 km of the area of concentrated pumping.
- PEK 5, which is representative of wells at a distance of 6 km.
- RBY 14, which is representative of wells at a distance of 10 km.
- SHK 4, which is representative of wells at a distance of 15 km.

Large seasonal variations in pressure levels are shown, with the drawdowns decreasing with distance from the irrigation. The results also indicate the drawdowns are beginning to stabilise, with the rate of increase of the maximum drawdown level from year to year decreasing, and the difference between recovered groundwater levels from year to year also decreasing. This gradual approach to a new equilibrium is consistent with trends observed in the Mallee PWA (Barnett, 2006).

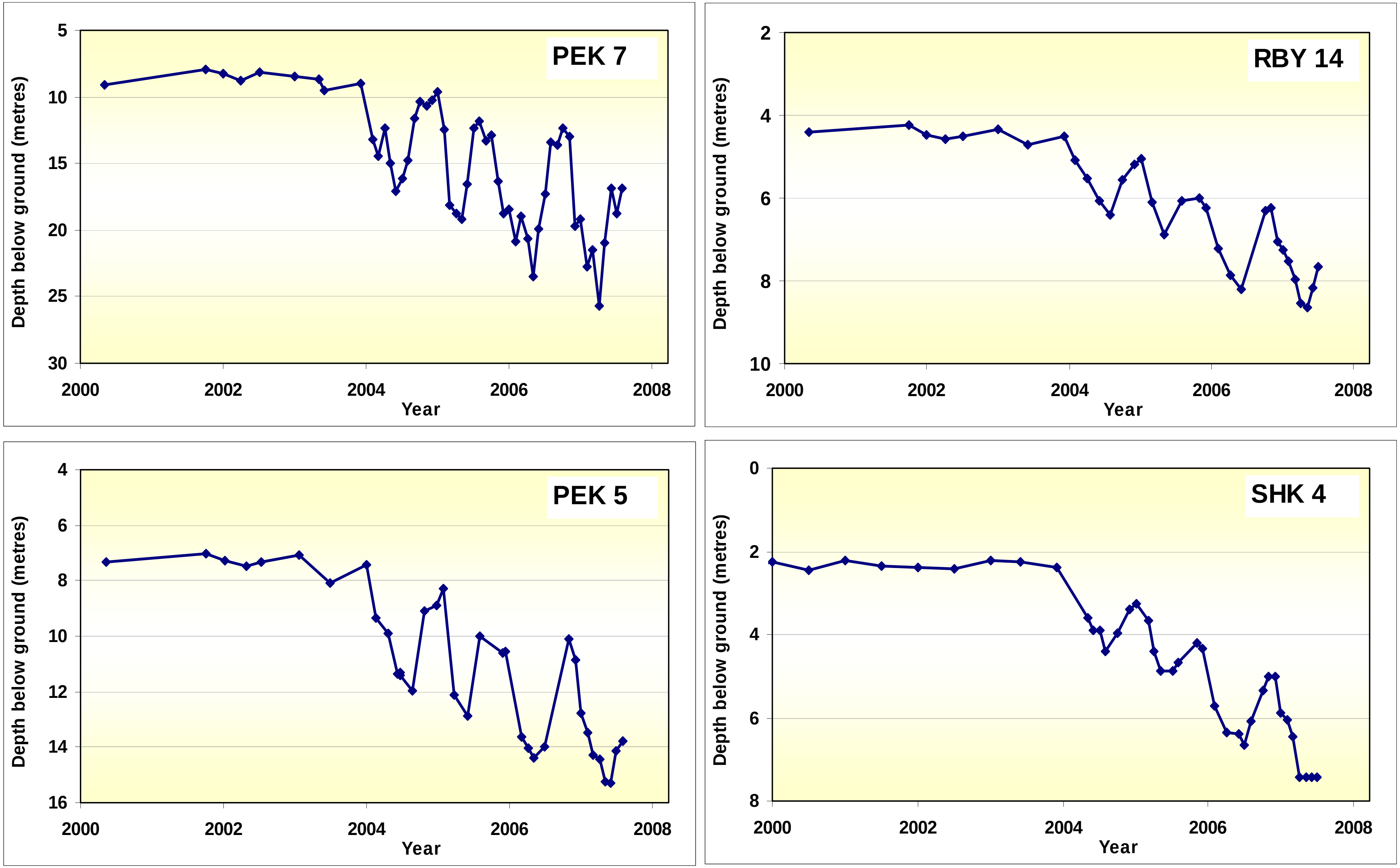

Figure 13. Confined aquifer water level hydrographs

The confined aquifer salinity network is shown in Figure 14. These private stock and domestic wells are concentrated to the west of the main extraction area where the risk of salinity increases due to flow reversal is higher. They are sampled at six monthly intervals.

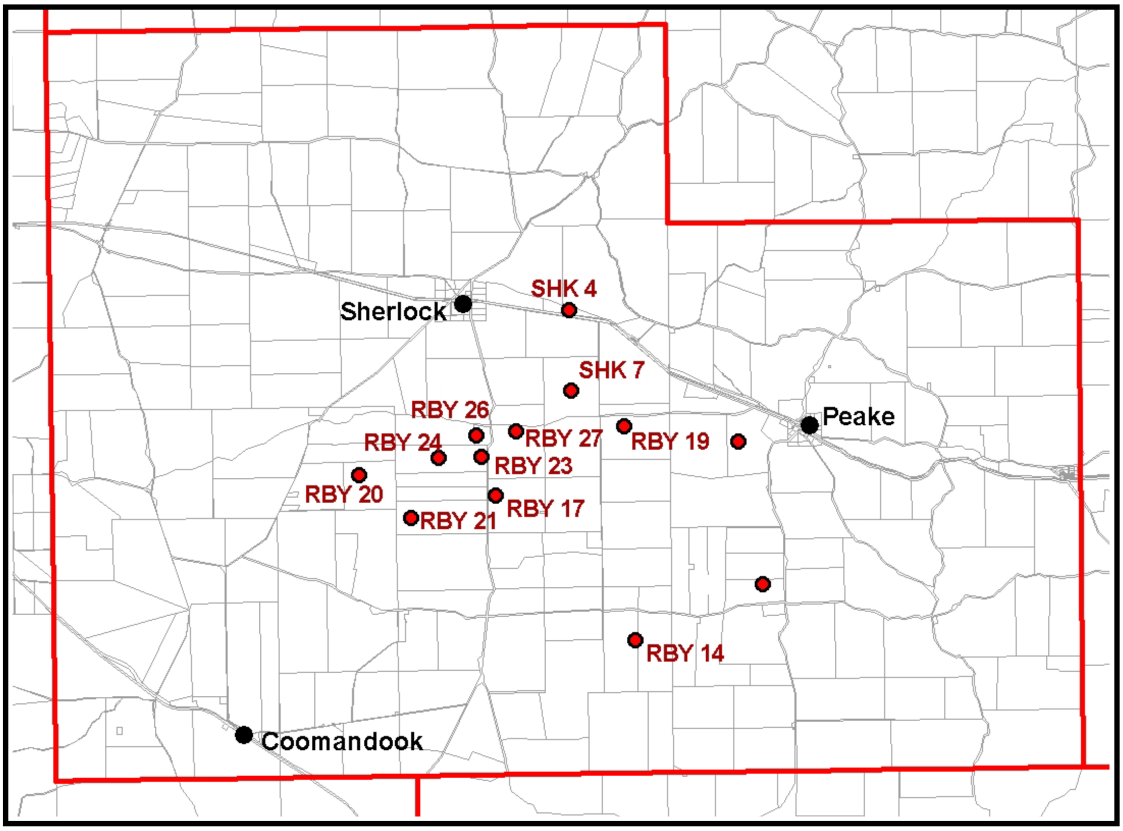

Figure 14. Confined aquifer salinity network

Monitoring trends in the 11 wells since irrigation commenced vary from a small decrease, to an increase of 4% over two years. The average increase was 2%. However, when long term trends incorporating pre-irrigation salinity values were examined, half the wells showed a decrease, with the remainder averaging an increase of only 0.2%.

As an example of how short term salinity trends can be misleading, Figure 15 gives salinity readings from a stock well (MCA 2) in the Hundred of McCallum to the northeast of Keith. The short term observed rising trend may give cause for concern, however over the full range of data shown in Figure 16, it forms part of the range of natural variations in a stable long term trend.

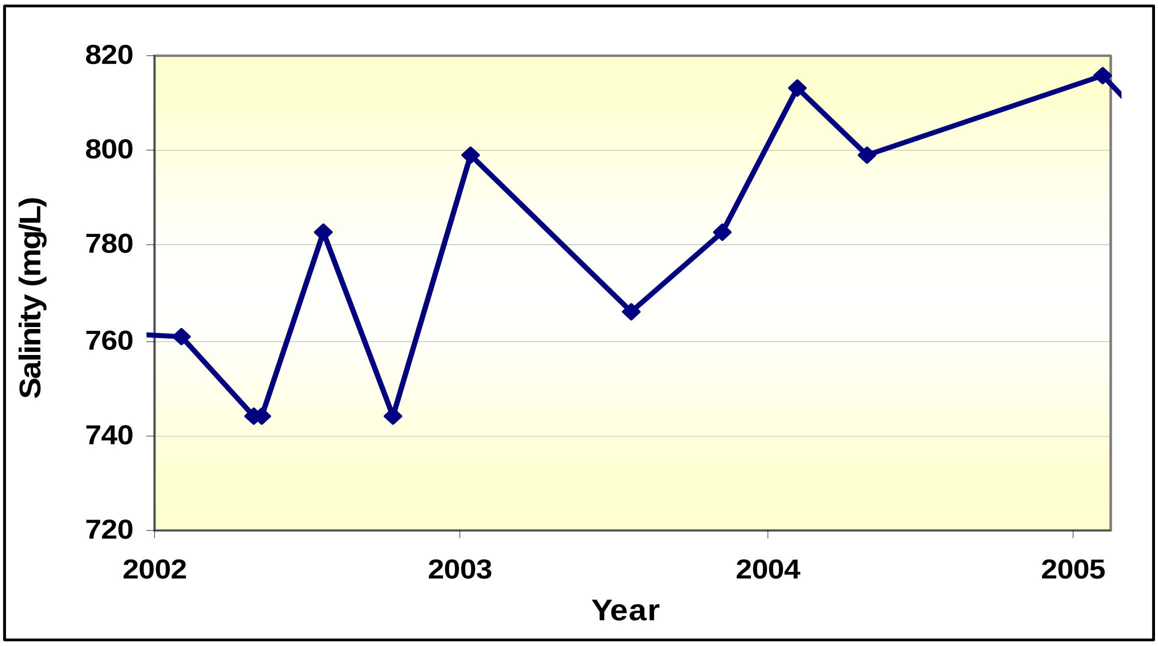

Figure 15. Short term salinity trend for MCA 2

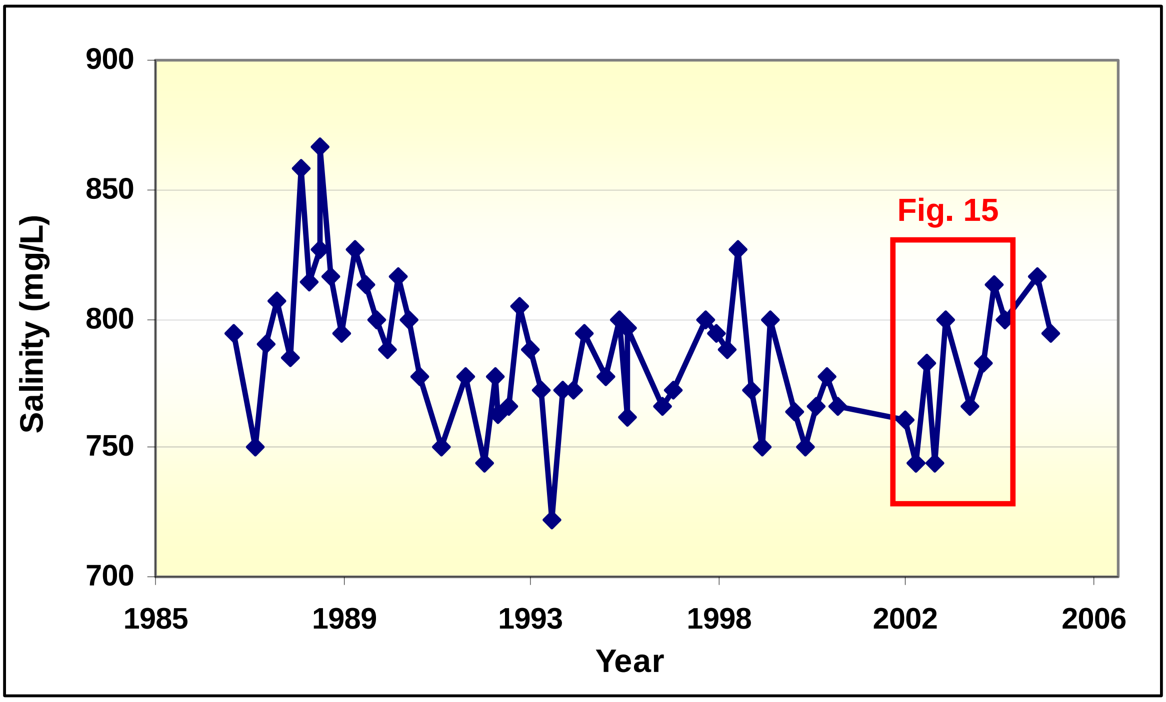

Figure 16. Long term salinity trend for MCA 2

Salinity monitoring will have to continue in the PRS PWA for several more years before any meaningful trends can be observed.

5. MODELLING RESULTS

The flow of groundwater through the pore spaces in an aquifer obeys certain rules of physics and consequently, can be calculated using mathematical equations. These equations require knowledge of the characteristics of the aquifer, such as the thickness and permeability, together with the gradient of the water pressures from high levels to low levels, which is the driving force for groundwater flow.

A groundwater model attempts to reproduce the observed groundwater levels by making hundreds of these mathematical calculations in three dimensions. In this modelling exercise for the PRS PWA, a MODFLOW three dimensional groundwater flow model was used. Appendix A presents details of the model construction and the calibration process.

The groundwater model is able to calculate the distribution of groundwater pressures across the PRS PWA for a given rate of groundwater extraction. The model was used to predict the likely future changes to the groundwater system (water levels and salinity) under different rates of extraction or 'extraction scenarios', and allow comparisons between the various scenarios.

Table 1 shows the various groundwater extraction scenarios tested by the model. The prediction results were run for 20 years into the future.

Table 1. Modelled extraction scenarios

Scenario	Extraction regime
1	Current 2006–07 rates of **1170 ML/y** for 20 years
2	Increase from current rate of **1170** to full authorisation of **2205 ML/y** by 2009–10, then continued at this higher rate for 17 years
3	Increase from current rate of **1170** to an intermediate rate of **1660 ML/y** by 2008–09, then continued at this higher rate for 18 years
4	Increase from current rate of **1170** to the requested rate of **6500 ML/y** by 2010–11, then continued at this higher rate for 16 years

Scenario 1 represents the "status quo" with no increase from current extractions, whilst Scenario 4 represents the "worst case" scenario of unrestricted pumping which would be the case if no prescription process had been initiated. The results are presented by way of hydrographs (which show the variation in pressure levels at certain points), and regional drawdown contours (which show the drop in pressure levels compared to the pre-irrigation situation).

Figure 17 presents predicted pressure levels at three sites:

- PEK 7 (the Peake town water supply well) which is within 3 km of the area of concentrated pumping.
- PEK 5, which is representative of wells at a distance of 6 km.
- RBY 24, which is representative of wells at the western extent of usable groundwater below 5000 mg/L, at a distance of 15 km from the area of concentrated pumping.

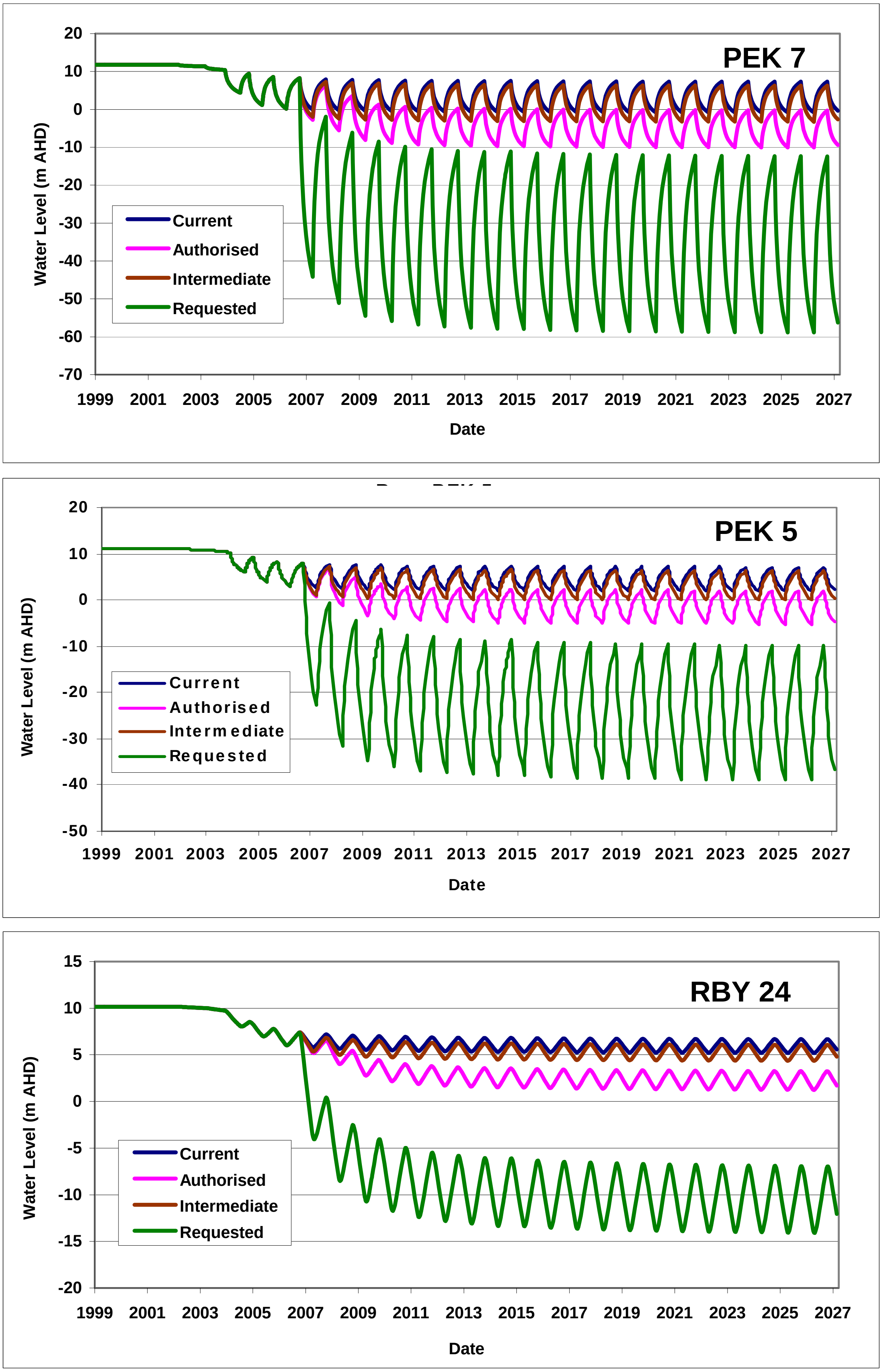

Figure 17. Predicted drawdown hydrographs in the confined aquifer

Table 2 summarises the long term drawdown predicted at each of the selected observation wells. For each scenario (or extraction rate), the drawdown decreases with increasing distance from area of concentrated pumping. Figure 18 extrapolates these results to give the predicted drawdowns for a range of extraction rates at a range of distances.

Table 2. Summary of drawdowns at selected observation wells

Scenario	Extraction rate (ML/y)	PEK 7 <3 km	PEK 5 6 km	RBY 24 15 km
1 – Current	1 170	12	9	5
2 – Authorised	2 205	22	11	8
3 – Intermediate	1 660	15	15	6
4 – Requested	6 500	70	50	24

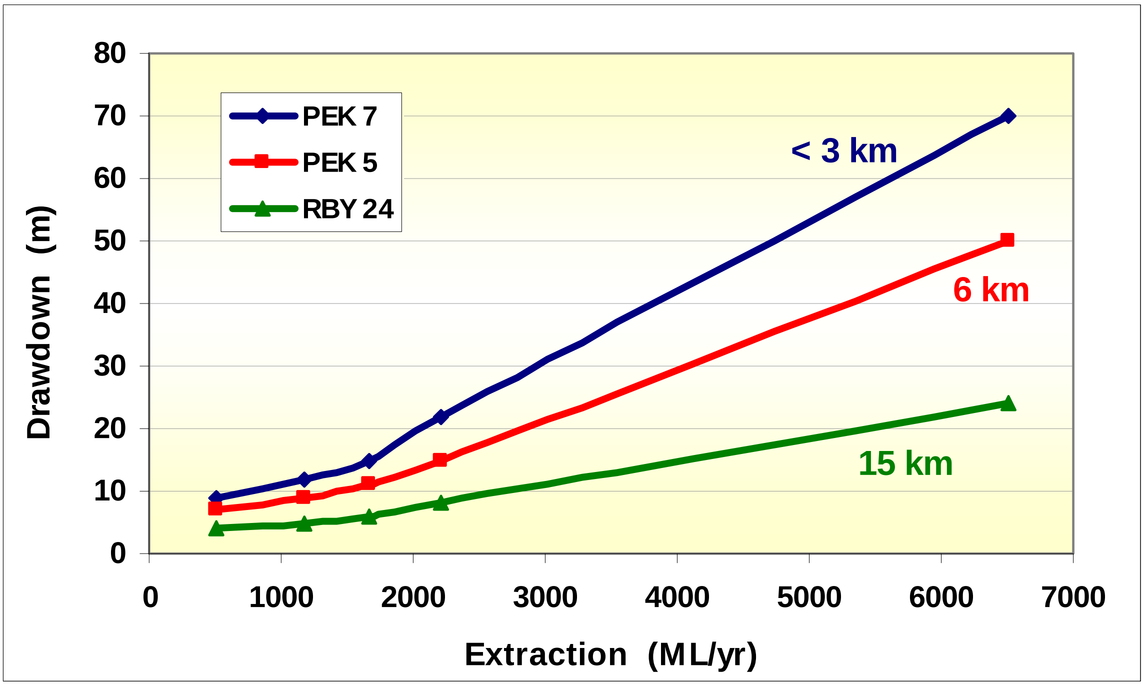

Figure 18. Predicted drawdown hydrographs in the confined aquifer

The following predicted contour plans of maximum drawdown (Figs 19 to 22), show the extent and size of the drawdown impacts after 20 years pumping for each extraction scenario.

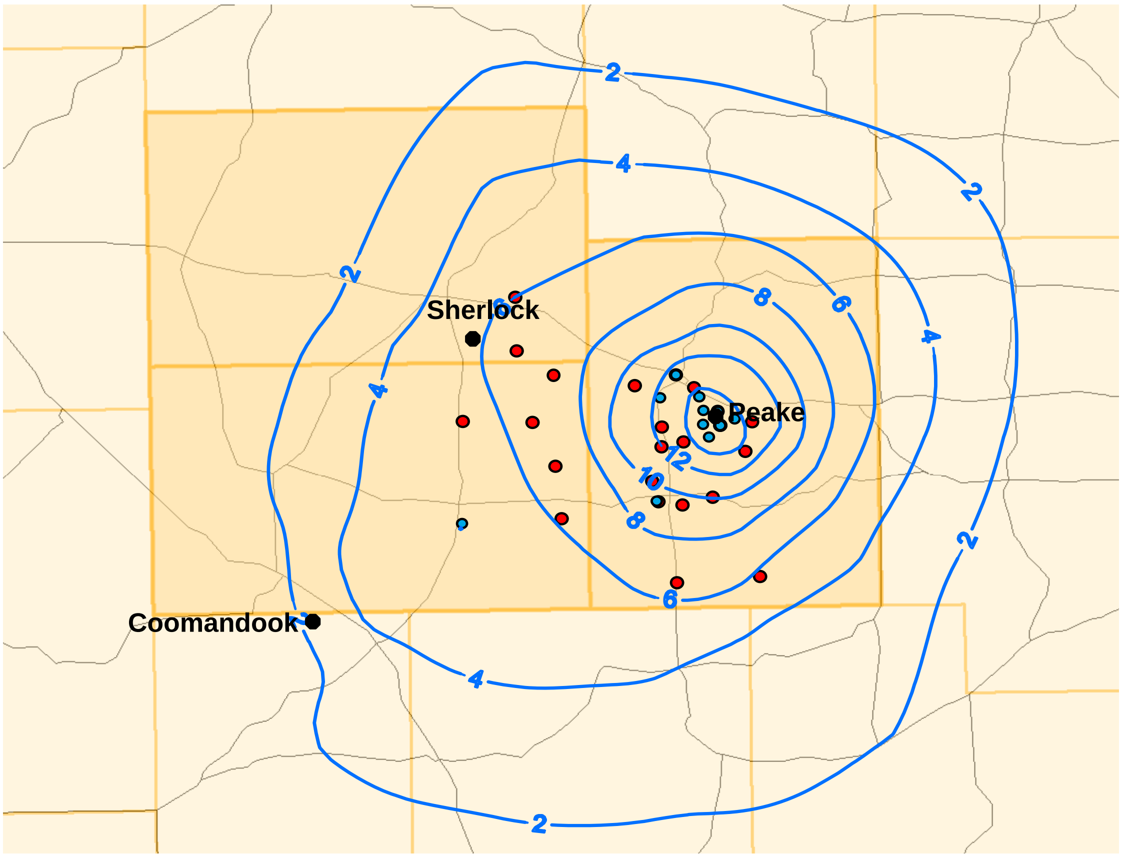

Figure 19. Predicted drawdown contours for Scenario 1 (1170 ML/y)

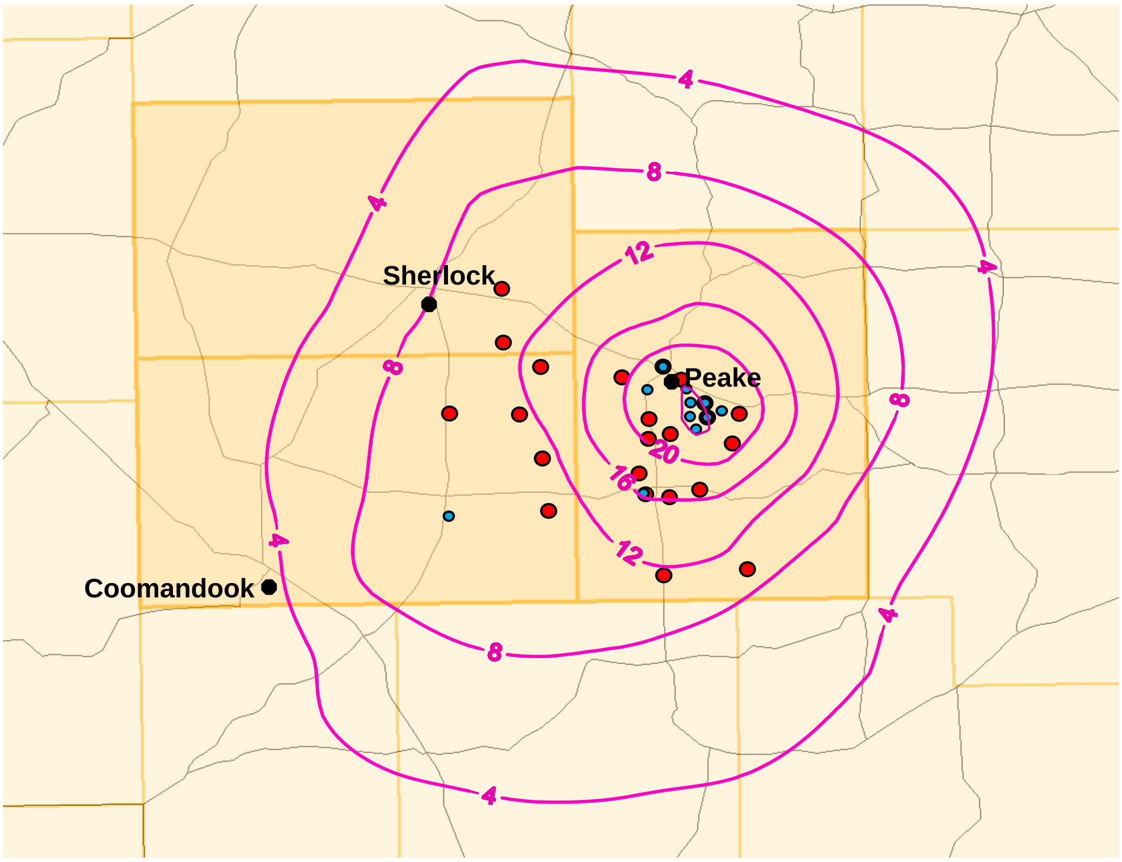

Figure 20. Predicted drawdown contours for Scenario 2 (2205 ML/y)

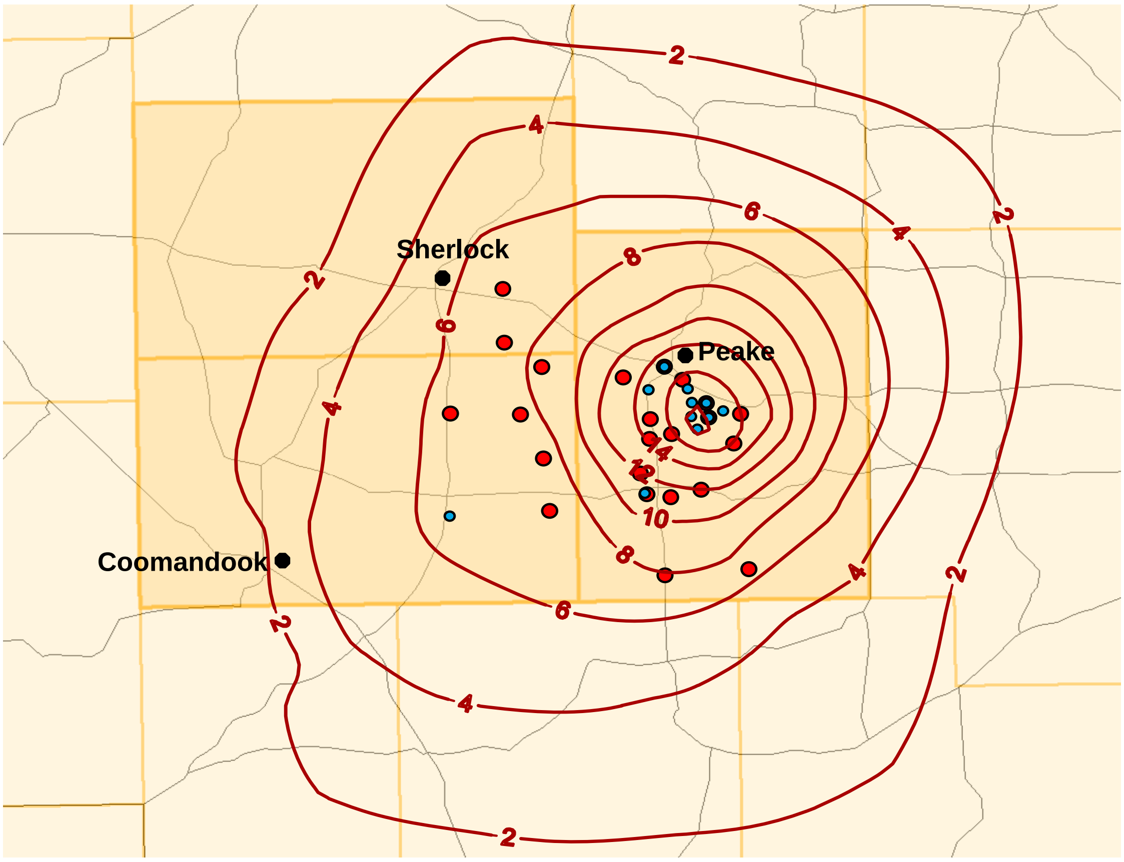

Figure 21. Predicted drawdown contours for Scenario 3 (1660 ML/y)

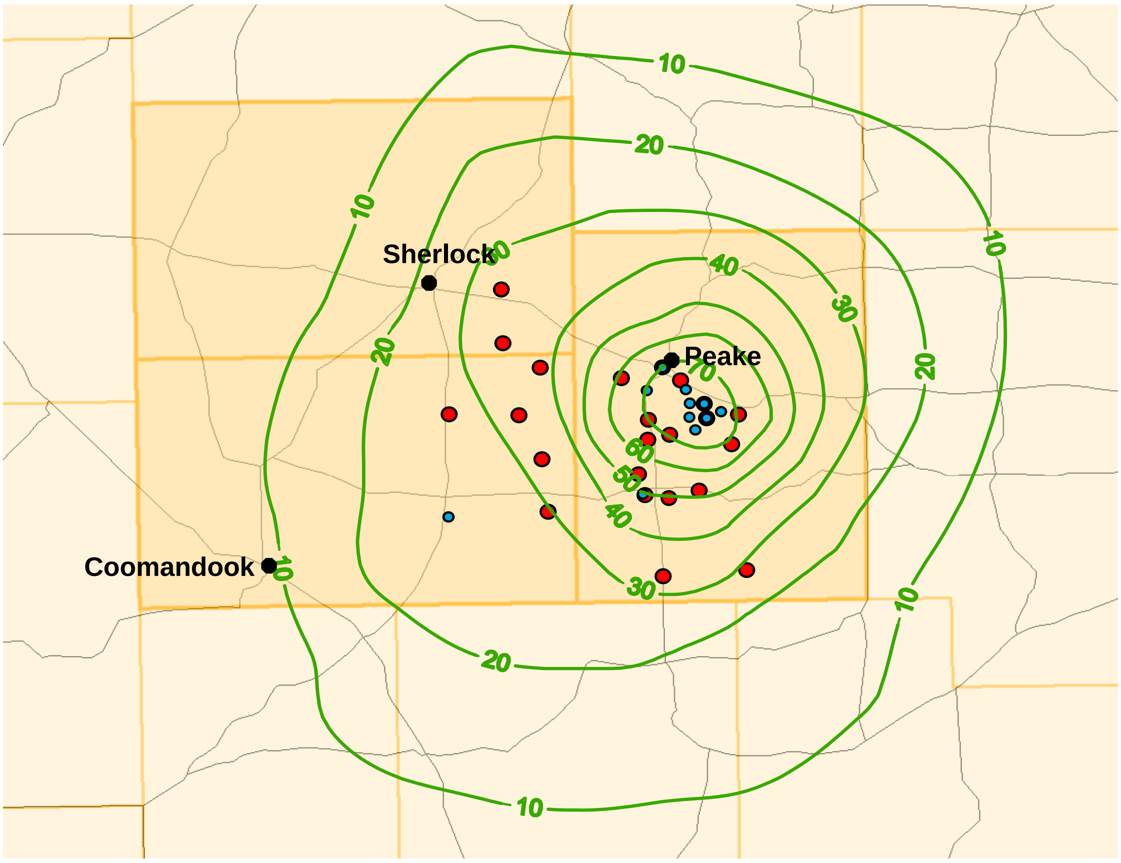

Figure 22. Predicted drawdown contours for Scenario 4 (6500 ML/y)

6. RESOURCE CAPACITY

The capacity of the resource (as required by Sec 155 of the NRM Act) is controlled by any adverse impacts on the groundwater resource that could potentially result from irrigation extractions. Consideration of the social and economic impacts from such extractions (as required by Sec 76 of the NRM Act) is outside the scope of this report, and may result in the volume available for allocation being different from the capacity of the resource.

6.1 CONFINED AQUIFER

The three main potential impacts on the confined aquifer resource in the PRS PWA are:

1. Downward leakage of saline groundwater from the overlying unconfined aquifer.
2. Collapse of the confining layer due to excessive drawdowns.
3. Drawdowns causing inflows of saline groundwater from the west.

6.1.1 DOWNWARD LEAKAGE

The drawdown of confined aquifer pressure levels will create the potential for downward leakage from the overlying unconfined aquifer if the pressure levels become lower than the watertable. The permeability of the intervening confining layer will control this leakage. The results of the groundwater modelling scenarios and water level monitoring can provide some indication of the effectiveness of the confining layer.

Table 3 presents the components of groundwater inflows to the 'coral' confined aquifer over the whole PRS PWA, as calculated by the well-calibrated groundwater model. The table shows the volumes in cubic metres per day during the irrigation season when drawdowns are at their maximum. It can be seen that lateral inflow from the east is by far the largest component, with downward leakage very small in comparison.

Table 3. Comparison of groundwater inflow components (m^3/d)

Flow component	Current 1170 ML/y 2007	Scenario 1 1170 ML/y 2027	Scenario 2 2205 ML/y 2027	Scenario 3 1660 ML/y 2027	Scenario 4 6500 ML/y 2027
Lateral inflow	3075	3225	5335	3140	14 570
Upward leakage from Renmark Group	895	755	1995	1145	7300
Downward leakage from unconfined limestone	30	30	75	40	290

In addition, there is no evidence from any observation wells of any impacts on the unconfined aquifer due to extraction from the underlying confined aquifer. Figure 23 shows unconfined aquifer hydrographs for PEK 16 (located close to the area of maximum drawdown) and PEK 3 (located adjacent to confined well PEK 2). If downward leakage was significant, there would be some downward trend observed in the unconfined aquifer water levels.

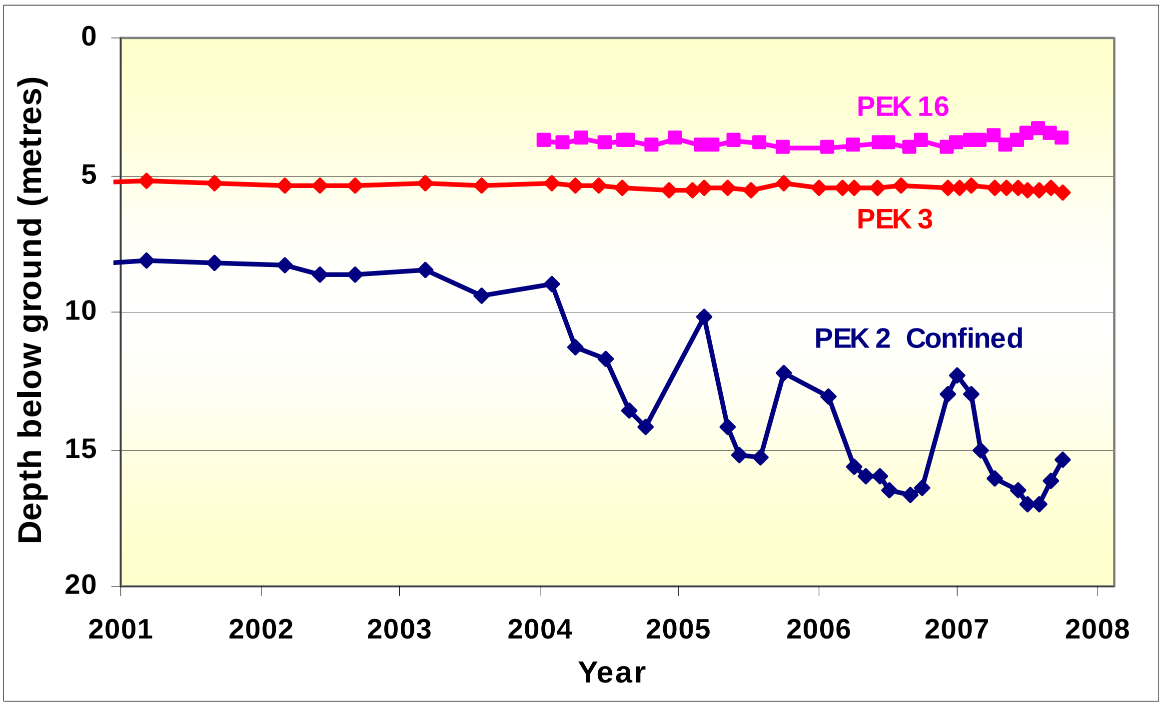

Figure 23. Unconfined hydrographs near centre of extraction

The greatest risk for downward leakage would occur where the drawdown in pressure levels is greatest, ie near the centre of concentrated extractions. In this area, the salinities in the unconfined aquifer are not saline but are about 5000 mg/L. It is concluded on the available evidence from modelling and monitoring that downward leakage is only a small risk to the confined groundwater resource.

6.1.2 COLLAPSE OF CONFINING LAYER

If drawdowns due to extractions are large enough, the pressure level for the confined aquifer may fall below the confining layer, and possibly even below the top of the confined aquifer itself. This process of depressurisation can give rise to the drying out and consolidation of the confining layer above the aquifer and also reduces the hydrostatic pressure from below supporting the confining layer against the weight of the overlying unconfined aquifer and the groundwater contained within it. This could result in fracturing of the confining layer and downward leakage from the overlying unconfined aquifer into the confined aquifer. Figure 24 shows a simplified example of how this could occur.

If a confined sand aquifer is depressurised, the consolidation and compaction of the sand grains can lead to the overlying low permeability confining sediments collapsing and blocking the sandscreens. In some parts of the world where the unconsolidated sands, silts and clays extend to the ground surface, the compaction can lead to land subsidence. This is extremely unlikely to occur in the Peake area because both the unconfined aquifer and the confined 'coral' aquifer consist of consolidated limestone.

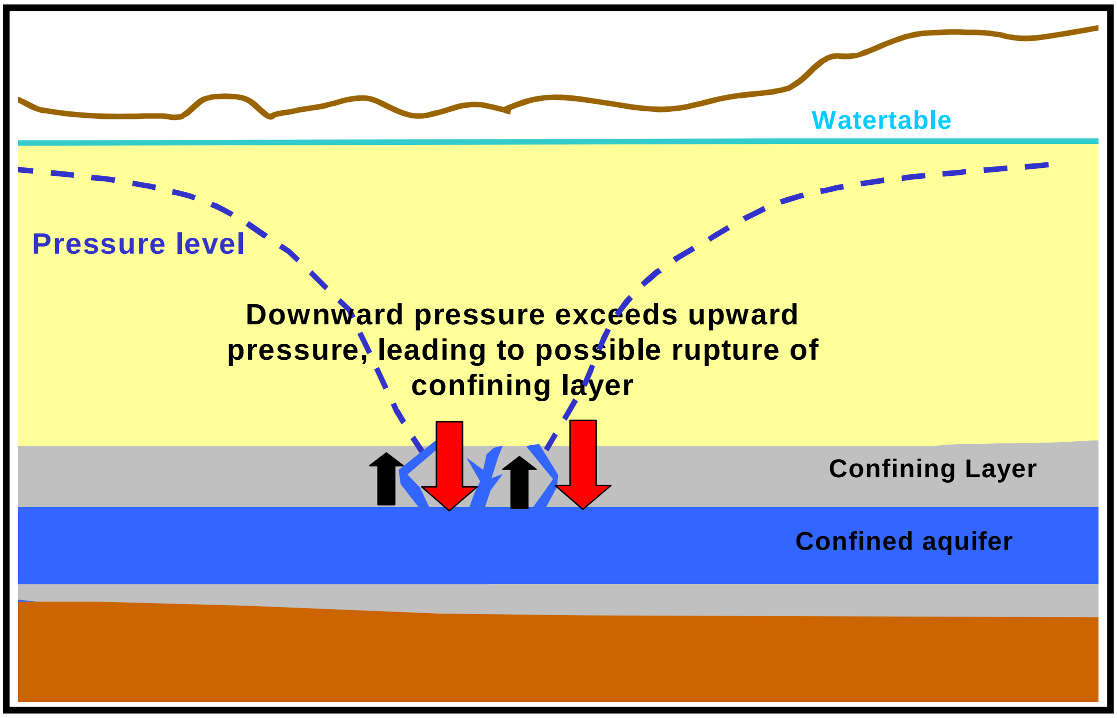

Figure 24. Process of depressurisation

Perhaps the best way of understanding this process is to consider the reverse situation which is known as "floor heave" in open cut coal mines excavated in sedimentary basins. In these situations, there are often confined aquifers underlying the coal seams. As material is removed from the open cut mine, the downward overburden pressure on the confining layer is reduced. If too much is removed, and the upward confined aquifer pressure exceeds the overburden pressure, the confining layer (or mine floor) fractures and the mine will be flooded, with the water level filling up to the confined pressure level as if in a huge borehole (Fig. 25).

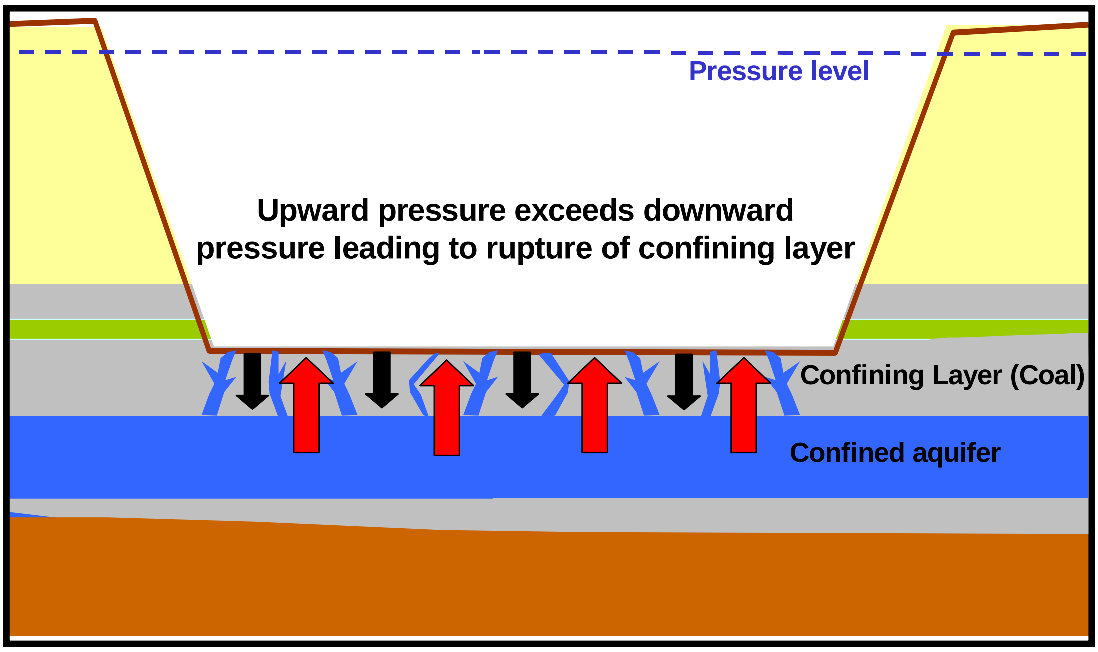

Figure 25. Process of "floor heave" in an open cut mine

Geological logs from the irrigation wells in the center of pumping indicate the top of the confining layer to lie at an elevation of about –60 m AHD. Given that drawdowns in the pumped wells could be up to 20 m greater than the regional drawdown, a conservative limit for regional drawdowns as predicted by the model to prevent a risk of depressurisation would be an elevation of –40 m AHD i.e. a drawdown of 55 m from pre-irrigation levels. Examination of Figure 17 shows that this limit would be reached if extractions exceeded 5000 ML/y.

This limit of 5000 ML/y is consistent with conclusions from a modelling exercise carried out by Aquaterra (2006), which stated that “abstraction in the order of 4000 ML/y by Draycott is not recommended” on the assumption that extractions totaling 1000 ML/y by other users would be occurring close by.

If extractions did exceed the limit, the critical drawdown and risk of depressurization would only occur within several kilometres of the centre of pumping, and would not occur over the whole region.

6.1.3 SALINITY INCREASES DUE TO FLOW REVERSAL

Before irrigation commenced, groundwater flow was from east to west in a direction from low salinity to high salinity (Fig. 26). For the situation after irrigation commenced, Figure 8 shows the direction of groundwater flow in blue, the potentiometric surface contours in m AHD in black, and the salinity pattern. Drawdowns during the irrigation season have changed the groundwater flow direction, with components of flow now entering the Peake area from the south, west and northwest.

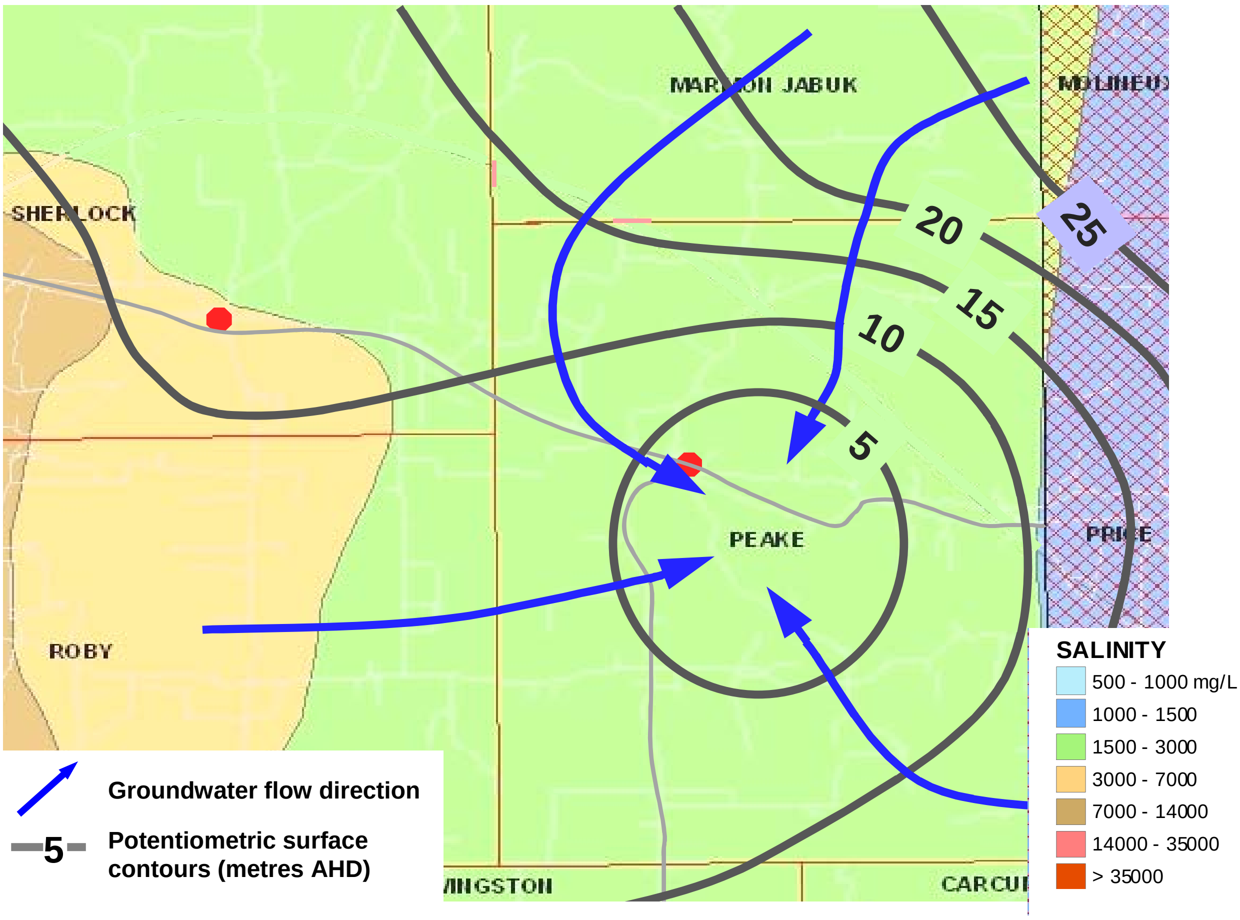

Figure 26. Groundwater flow direction during the irrigation season

Of most concern is the flow reversal from the west where the groundwater salinity is higher. The rate of groundwater movement from the west is dependent on the magnitude of the drawdown, which is determined by the extraction rate. The modelling exercise described earlier has calculated the rate of flow reversal for the various pumping scenarios. By examining the recorded salinities from stock and domestic wells, the resultant salinity distribution can be used to estimate the change in salinity at a given point for each scenario.

Because of the very high dependence on groundwater in the area, salinity levels should not rise above tolerance levels for stock. The ANZECC (2000) guidelines place a limit of 5000 mg/L for no adverse impact on sheep, with some reluctance to drink but no loss of production from 5000 10 000 mg/L.

Figure 27 displays the natural pre-irrigation rate of salinity increase in the westerly direction derived from salinity values taken from confined aquifer wells before 1970. Three distinct zones were identified, with the salinity gradient varying from 200–525 mg/L/km.

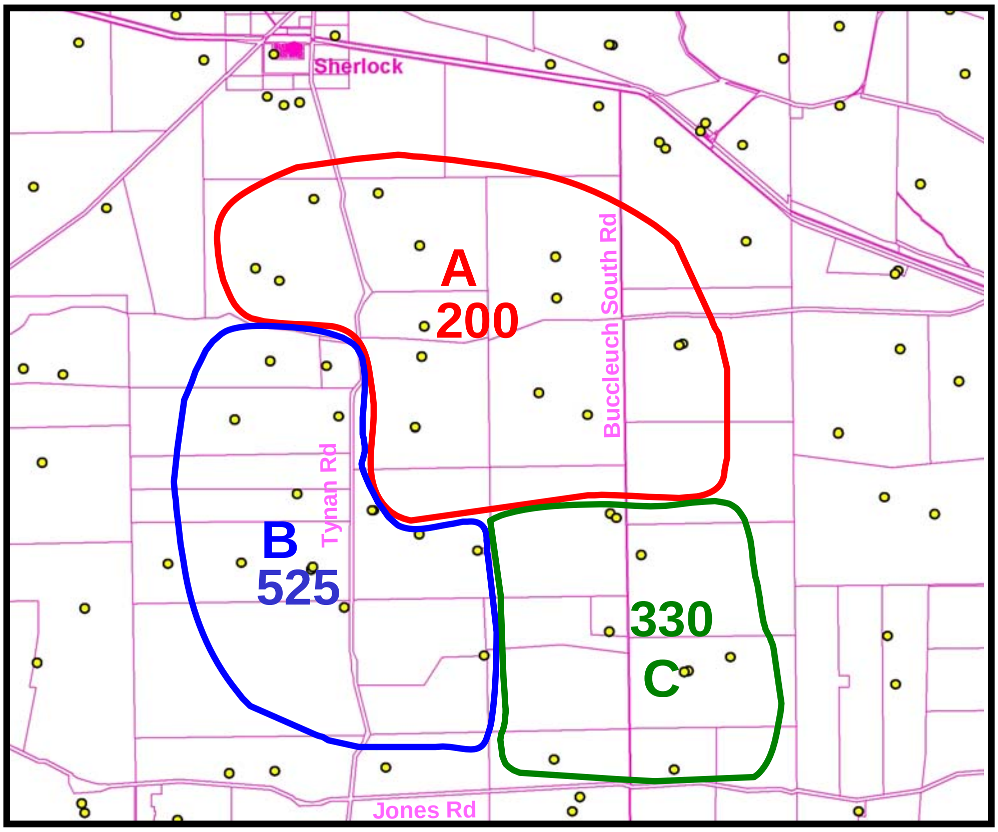

Figure 27. Pre-irrigation rate of salinity increase toward the west

For each modelled scenario, the distance of flow reversal in the vicinity of Buccleuch South Rd was calculated over a 20 year period. The predicted rate of salinity increase due to flow reversal can then be determined for each zone. Table 4 shows the predicted salinity rise over the next 20 years for each zone expressed in mg/L/y, and also as a percentage increase. Figure 28 also presents the range of salinity increases for various extraction rates in each zone delineated above.

A conservative approach has been used in making these calculations. The percentage increase in salinity was made using the lowest salinity recorded in the zones. The flow reversal rates were calculated by the model at several points along Buccleuch South Rd.

To the west of this road, the gradients inducing flow reversal would be lower and the resultant flow reversal rates would also be lower than the values used in Table 4.

As a reminder, the scenarios listed in Table 4 are as follows;

Scenario 1 = 2006/07 use of 1170 ML/y

Scenario 2 = full authorisation volumes of 2205 ML/y

Scenario 3 = intermediate rate of 1660 ML/y

Scenario 4 = requested volumes of 6500 ML/y (without controls on pumping)

Table 4. Modelled salinity increases

Scenario	Flow reversal (m/y)	Zone A			Zone B			Zone C		
		Salinity gradient (mg/L/m)	Salinity increase (mg/L/y)	% increase per y	Salinity gradient (mg/L/m)	Salinity increase (mg/L/y)	% increase per y	Salinity gradient (mg/L/m)	Salinity increase (mg/L/y)	% increase per y
1	5.65	0.2	1.1	0.04	0.525	3.0	0.08	0.33	1.9	0.1
2	13.04	0.2	2.6	0.1	0.525	6.8	0.2	0.33	4.3	0.2
3	5.65	0.2	1.1	0.04	0.525	3.0	0.08	0.33	1.9	0.1
4	82.50	0.2	16.5	0.7	0.525	43.3	1.1	0.33	27.2	1.4

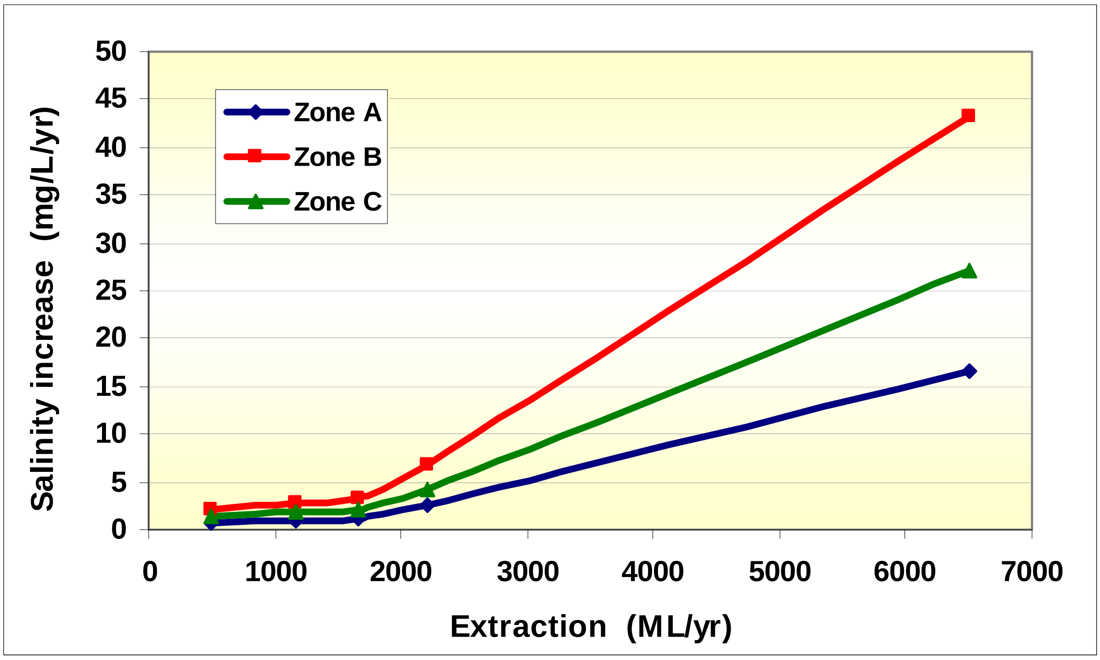

Figure 28. Rates of salinity increase for various extraction scenarios

Zone B has the highest rate of salinity increase because it is closer to the higher salinity groundwater to the west and conversely, Zone A has the lowest rate of rise because it is furthest from the higher salinity groundwater.

To enable these salinity increases to be understood from a water use perspective, Figure 29 displays the time taken for the stock water use limit of 5000 mg/L to be exceeded in each zone for various extraction rates, assuming the highest salinity value recorded in the zone as the benchmark.

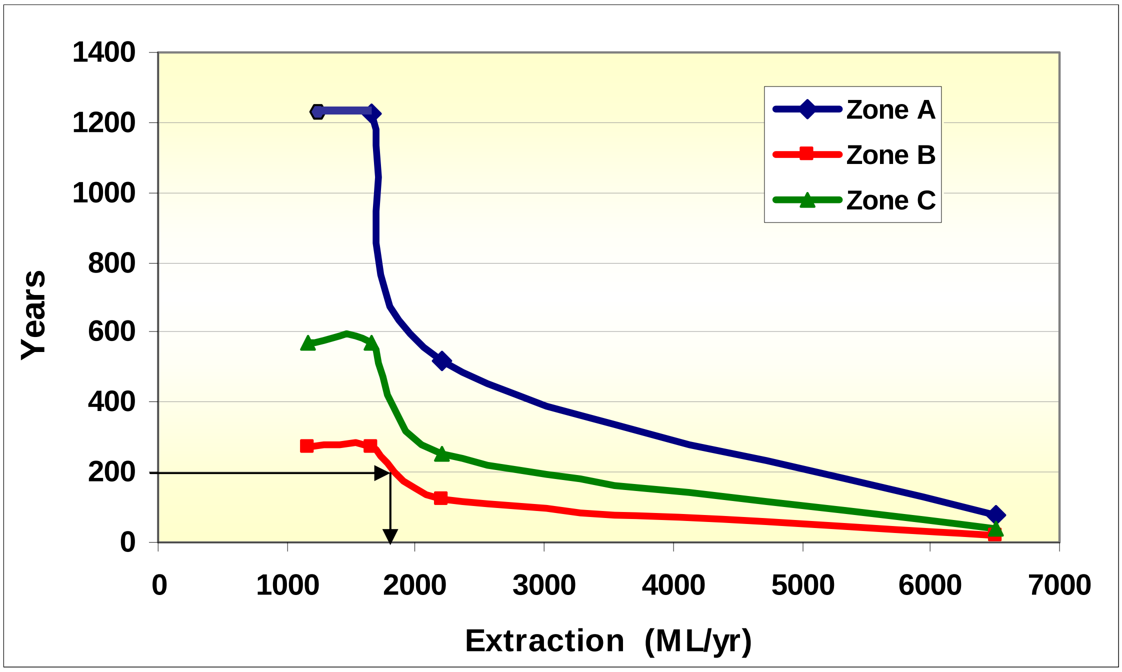

Figure 29. Time until stock salinity limit exceeded

Figure 29 shows that extractions over 5000 ML/y will result in the stock limit being exceeded in all zones within 200 years (and for Zones B and C, within 100 years). However, the stock limit will not be exceeded within 200 years if extractions remain below 1800 ML/y, as indicated by the arrows in Figure 29.

6.1.4 SUMMARY

A limit of 5000 ML/y is recommended to avoid the risk of collapse of the confining layer within several kilometres of the centre of concentration of pumping.

Any determination of what constitutes an acceptable rate of rise in salinity resulting from irrigation-induced drawdowns is beyond the scope of this report. Although the Environment Protection (Water Quality) Policy 2003 places a 10% change in salinity as an upper limit for protection of freshwater ecosystems, it does not specify timeframes or limits for other uses.

The predicted salinity increases for a range of extractions is presented for discussion.

6.2 UNCONFINED AQUIFER

6.2.1 COASTAL PLAIN

Although there is no current use due to high salinities, a generous volume of 2000 ML/y should be made available for allocation for potential future extractions for purposes such as desalination or aquaculture. In addition, provision for the protection of groundwater dependent ecosystems could be made, even though such use would be small due to the high salinities.

6.2.2 MALLEE HIGHLANDS

As the unconfined Murray Group Limestone aquifer in the PRS PWA is the same aquifer developed in the adjoining Mallee PWA, a consistent approach in determining the Permissible Annual Volume (PAV) is warranted. The area of this MA is 217 km^2 and using the same method as used in the Mallee PWA which takes into account recharge, throughflow and use of storage, a PAV of 1215 ML/y is recommended as the maximum volume that could be allocated. Because of the large depth to the watertable (mostly greater than 30 m), is recommended that no provision be made for groundwater dependent ecosystems.

APPENDICES

A. GROUNDWATER MODEL

The flow of groundwater through the pore spaces in an aquifer obeys certain rules of physics and consequently, can be calculated using mathematical equations. These equations require knowledge of the characteristics of the aquifer, such as the thickness and permeability, together with the gradient of the watertable which is the driving force for groundwater flow from high elevations to low elevations.

A groundwater model attempts to reproduce the observed groundwater levels by making hundreds of these mathematical calculations in three dimensions. In this exercise, the MODFLOW three dimensional groundwater flow model was used. It is widely used throughout the world, and was developed by the United States Geological Survey (McDonald and Harbagh, 1988).

EXTENT

The Peake model extends from Wynarka in the north (N 6110 000) to Coonalpyn in the south (N 6049 000), and from Cooke Plains in the west (E 370 000) to Parrakie in the east (E 430 000) as shown by the blue rectangle in Figure A1. The wide extent of the model grid outside the Peake area is to ensure that the model boundaries do not influence the drawdown impacts from extractions. The model has a grid size of 250 m, which is more detailed than the model for the adjacent Mallee PWA.

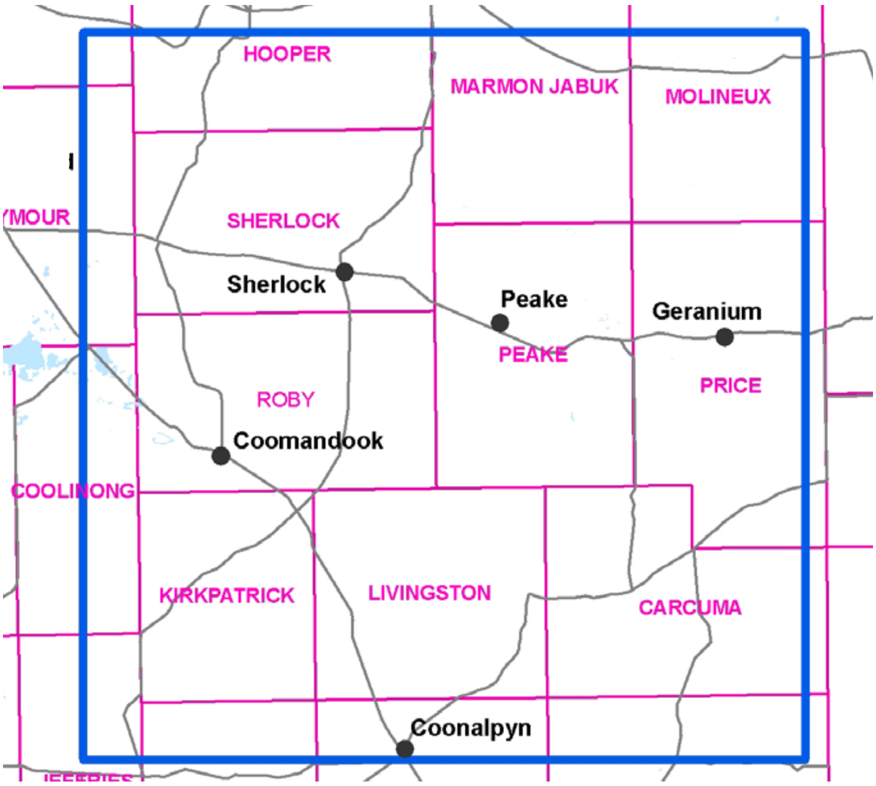

Figure A1. Model extent

STRATIGRAPHY

The model has five layers:

- Layer 1 — Unconfined limestone aquifer: extends over whole of model area.
- Layer 2 — Ettrick Formation/carbonaceous clay confining layer: extends over whole model area, controls leakage between unconfined and confined aquifers.
- Layer 3 — Buccleuch Group confined coral aquifer: extends over whole model area, but thins considerably east of Peake. Most extractions are from this layer.
- Layer 4 — Semi - confining layer: extends over whole model area, controls leakage between coral and sand confined aquifers.
- Layer 5 — Renmark Group confined sand aquifer: extends over whole model area, averages 150 m in thickness. There is minor pumping from this layer.
- Layer 6 — Confining layer: extends over whole model area, low permeability clays overlying basement.

The elevation and thickness of the layers were taken from geological logs from the numerous water and mineral wells in the area. A simplified cross section showing the model layers is shown in Figure A2.

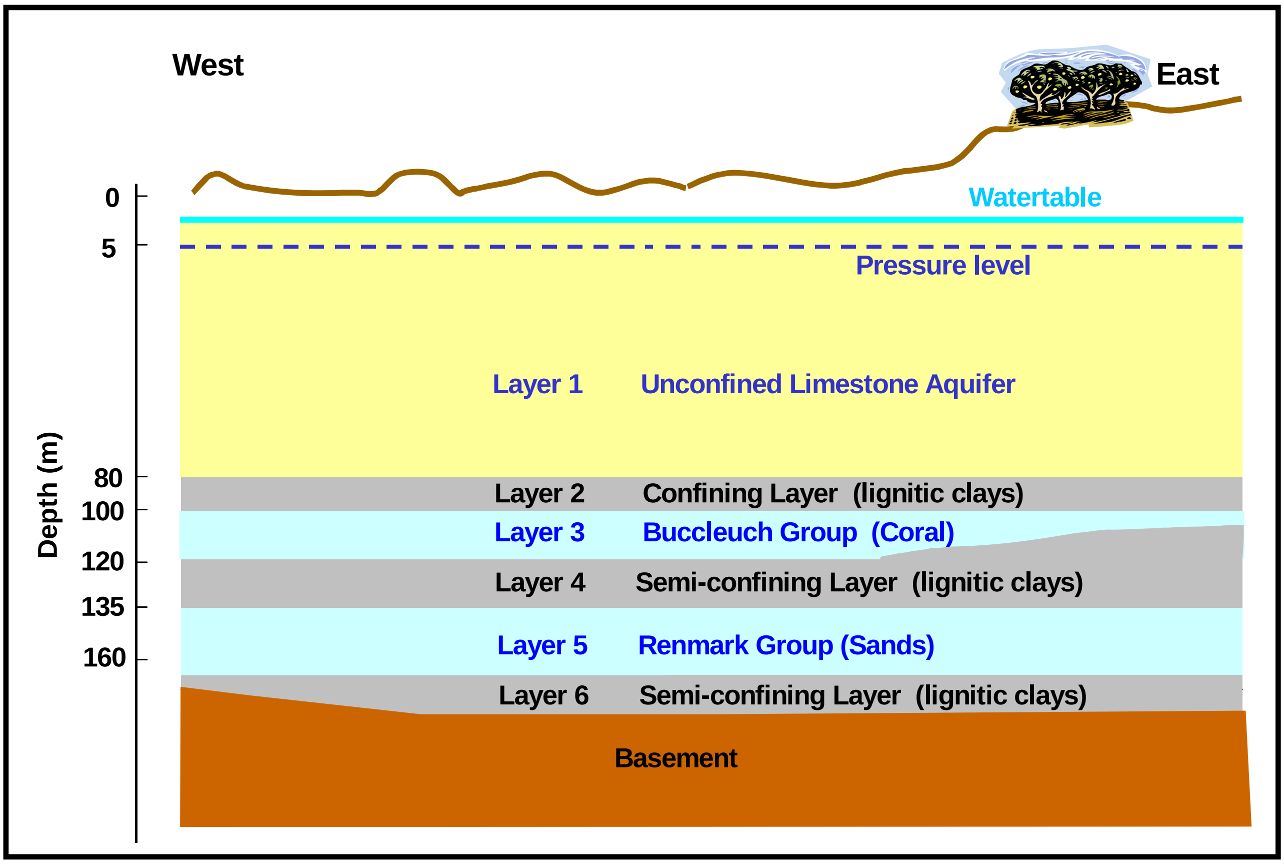

Figure A2. Simplified model cross section

BOUNDARY CONDITIONS

The model area, which is limited in size compared to the lateral extent of the aquifers in the PWS PWA, is not a closed hydrogeologic system. To represent this limitation, model boundary conditions were used to account for the conceptualised flow to and from areas beyond the extent of the model area.

Layer 1 (Unconfined limestone aquifer):

- The eastern and northeastern edges of the model area have general-head boundaries to allow flow into the model. Similarly, the western edge has a general head boundaries to allow flow out of the model.
- The southern boundary is a assumed to be no flow boundary as the groundwater movement is essentially parallel to it.

Layers 2, 4 and 6 (Confining layers):

- These confining layers are surrounded by no flow boundaries as flow within these layers is essentially vertical.

Layers 3 and 5 (Confined aquifers):

- The eastern and northeastern edges of the model area have general-head boundaries to allow flow into the model. Similarly, the western edge has a general head boundaries to allow flow out of the model.
- The southern boundary is a assumed to be no flow boundary as the groundwater movement is essentially parallel to it.

STARTING HEADS

Starting heads were taken from recent (but pre-pumping) observation well data for both the unconfined and confined aquifers. In the confined aquifer outside the areas affected by pumping, water levels are mostly constant.

RECHARGE

A recharge rate of 0.1 mm/y was applied to the unconfined limestone aquifer based on CSIRO estimates (Allison and Hughes, 1983). Water levels in the unconfined aquifer are largely unaffected by extractions or recharge, except in very wet years.

STEADY-STATE MODEL CALIBRATION

The steady-state model was calibrated by varying the following input model parameters (hydraulic conductivity and GHB conductance), within a specified range of reasonable values to obtain as close a match as possible between observed and simulated groundwater levels. Figure A3 shows the steady-state calibration for both the unconfined aquifer (Layer 1) and the confined Buccleuch Group coral aquifer (Layer 3) from where most extraction occurs. The observed water level elevation contours are shown in blue, with the modelled results shown in red.

There is quite reasonable agreement in both cases.

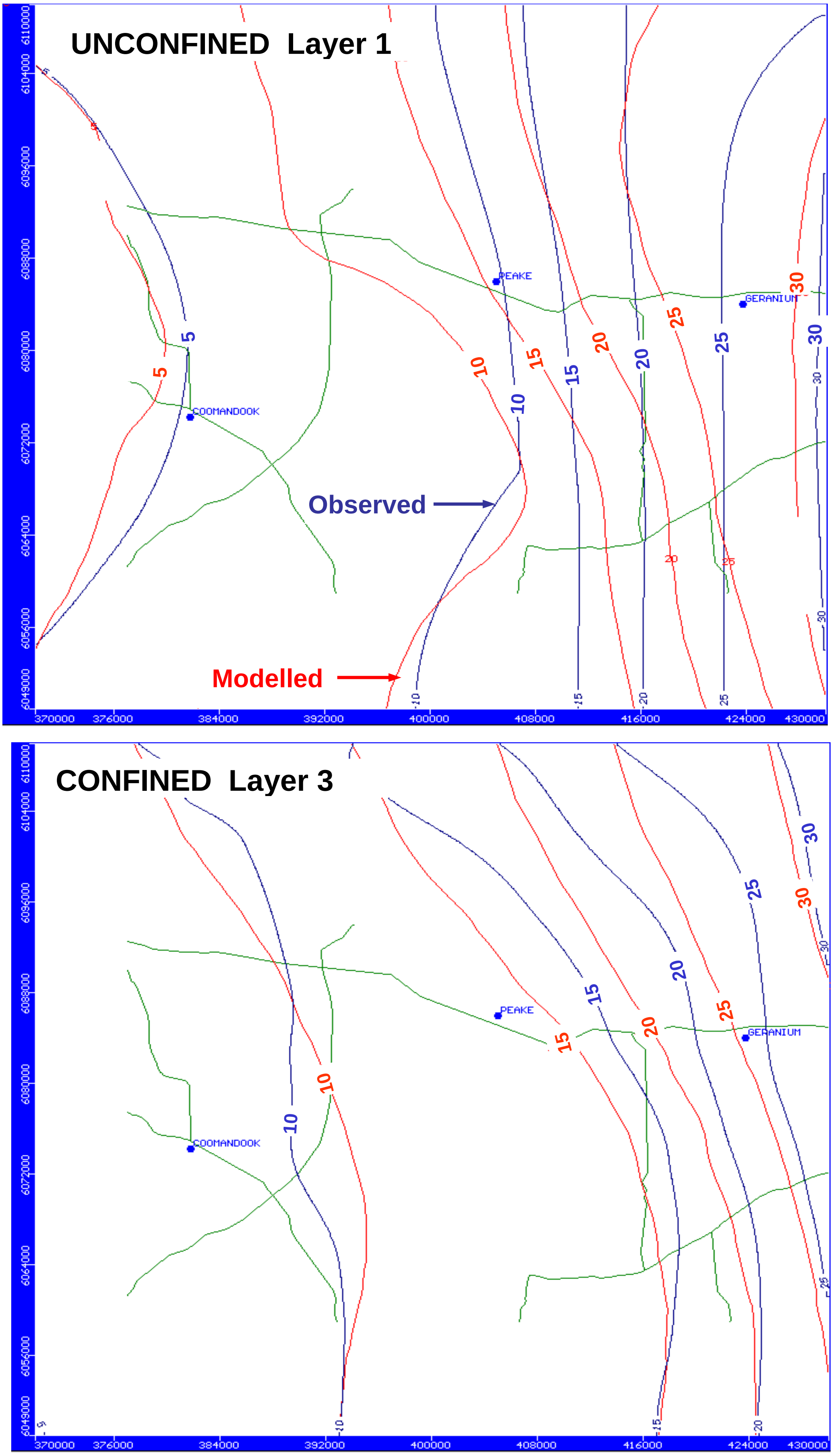

Figure A3. Steady state calibration for unconfined and confined aquifers

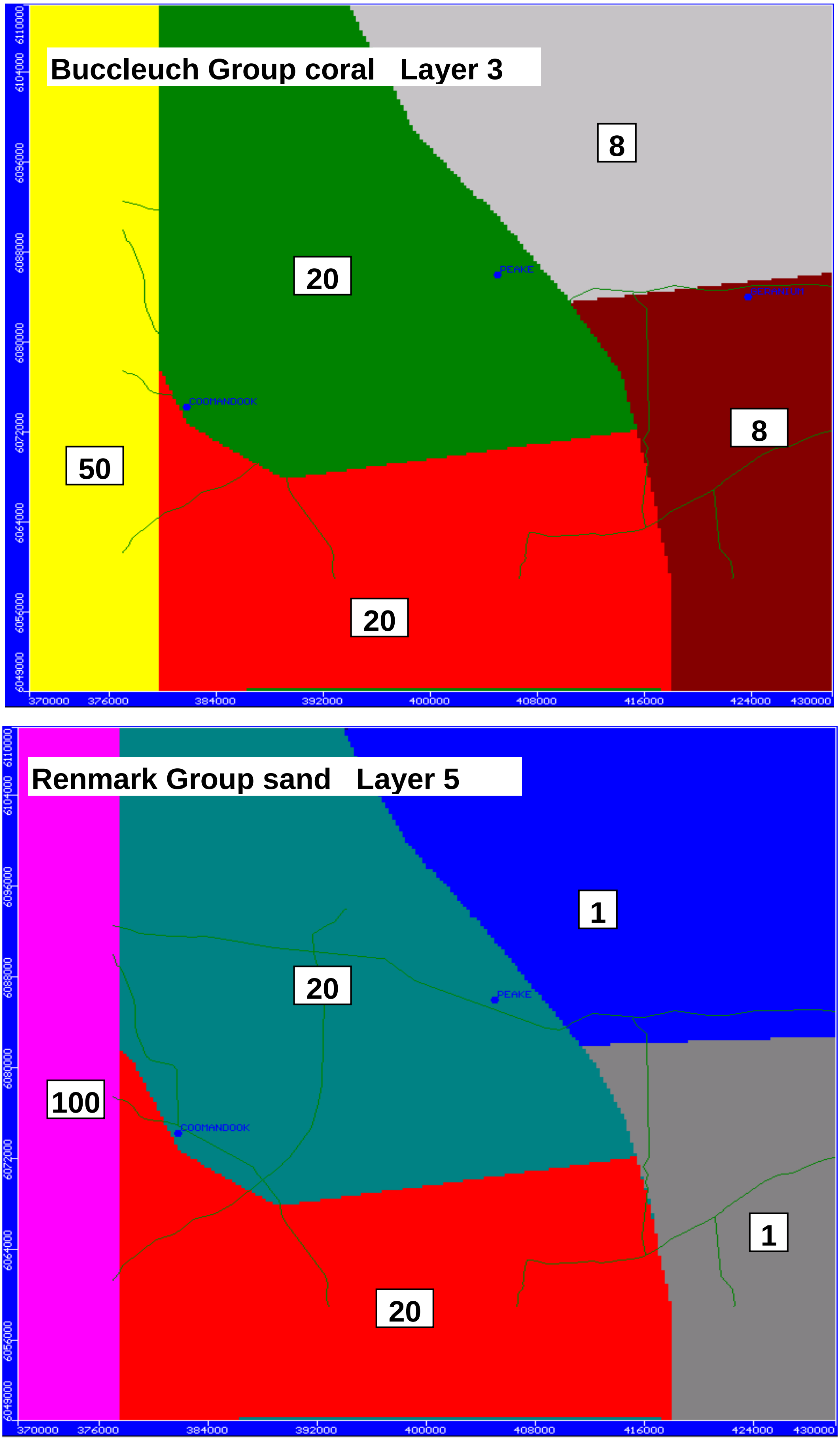

Figure A4. Hydraulic conductivity zones (m/d) for the confined aquifers

Figure A4 presents the horizontal hydraulic conductivity zones in the Buccleuch and Renmark Group confined aquifers (the only aquifers from which extractions occur). The very high values on the western margin are required to allow groundwater to flow out of the model where the aquifers thin against rising basement. These zones are well outside the influence of pumping.

PUMPING DATA

Extraction data has been assigned to all irrigation bores in the PRS PWA which has been based on meter data where possible. Estimates from landholders were used when meter data was not available.

TRANSIENT MODEL CALIBRATION

Results from the transient calibration are shown in Figure A5. Hydrographs are presented for observation wells in the confined aquifer at varying distances from the centre of concentrated pumping. The location of the observation wells can be seen in Figure 10. A very good agreement is apparent between the observed pressure levels and the levels predicted by the model. This good agreement gives a high level of confidence in the accuracy of the prediction results for the various extraction scenarios. Where the match is not exact, the model has over-predicted the drawdown which allows a conservative approach.

This calibration was achieved by using a single value of 0.00002/m for the specific storage of the ‘coral’ confined aquifer (Layer 3) throughout the model domain, and single value of 0.2 for the unconfined aquifer specific yield.

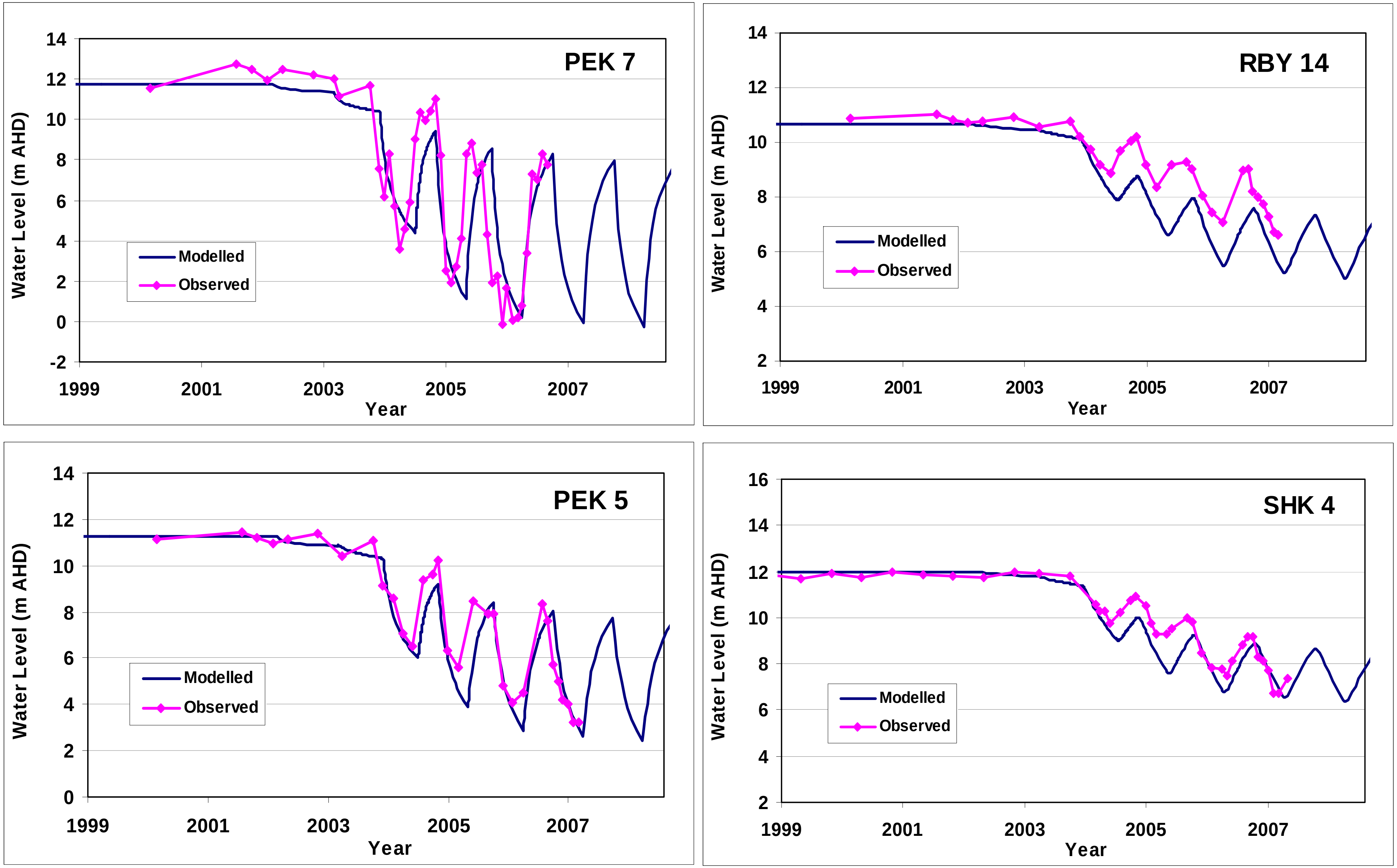

Figure A5. Transient calibration results

GLOSSARY

Act (the) — In this document, refers to the *Natural Resources Management Act* (SA) *2004*.

Adaptive management — A management approach, often used in natural resource management, where there is little information and/or a lot of complexity, and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through.

Aquifer, confined — Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

Aquifer test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resource available for development from the well.

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them.

Bore — *See well.*

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge. Continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality.

Dryland salinity — The process whereby salts stored below the surface of the ground are brought close to the surface by the rising watertable. The accumulation of salt degrades the upper soil profile, with impacts on agriculture, infrastructure and the environment.

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia).

EC — Electrical conductivity**.** 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C. Commonly used to indicate the salinity of water.

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment.

Environmental water requirements — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk.

GL — Gigalitre. One thousand million litres (1 000 000 000).

Groundwater — *See underground water.*

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers. *(See hydrology.)*

Irrigation — Watering land by any means for the purpose of growing plants.

Irrigation season — The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May.

ML — Megalitre**.** One million litres (1 000 000).

Model — A conceptual or mathematical means of understanding elements of the real world which allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change.

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured. (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things.

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.). *(See recharge area, artificial recharge.)*

Permeability — A measure of the ease with which water flows through an aquifer or aquitard. The unit is m^2/d.

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer; the unit is metres (m).

Precautionary principle — Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

PWA — Prescribed Wells Area.

RCT — Resource Condition Targets.

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. *(See artificial recharge, natural recharge.)*

SA Geodata — A collection of linked databases storing geological and hydrogeological data, which the public can access at the front counters of PIRSA and its regional offices. Custodianship of data related to minerals–petroleum and groundwater is vested in PIRSA and DWLBC, respectively. DWLBC should be contacted for database extracts related to groundwater.

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act).

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

Water allocation — (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 128 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water-dependent ecosystems — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground. The in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems.

Well — (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

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