Barossa Valley Prescribed Water Resources Area groundwater assessment

Department for Environment and Water

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Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Landscape Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

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1 Introduction

The Barossa Prescribed Water Resources Area (PWRA) covers an area of approximately 528 km^2, and is located approximately 60 km north-east of Adelaide. It encompasses the highland areas of the Mount Lofty Ranges and the Barossa Valley (Figure 1). This technical note presents an updated hydrogeological assessment of the groundwater level, salinity and extraction trends in the Barossa PWRA and sustainability issues to inform a review of the Water Allocation Plan, which controls groundwater management in the area. It contains recommendations for consideration in decision-making on management options for the area. While these recommendations are limited to considering whether current extraction can be maintained in the next 10 years, while retaining the character of the resource, they should be considered in the context of long-term resource protection.

This technical note is additional to, and complements, the annual technical notes prepared for the same region as part of DEW's routine water resource status reporting. More importantly, it provides an update to previous work on the capacity of the groundwater resource (Cranswick et al, 2015) based on more recent climate and extraction data. It also revises earlier proposed resource condition indicators (Cranswick et al, 2016) based on a more detailed examination of sustainability issues and the location of the licensed extractions.

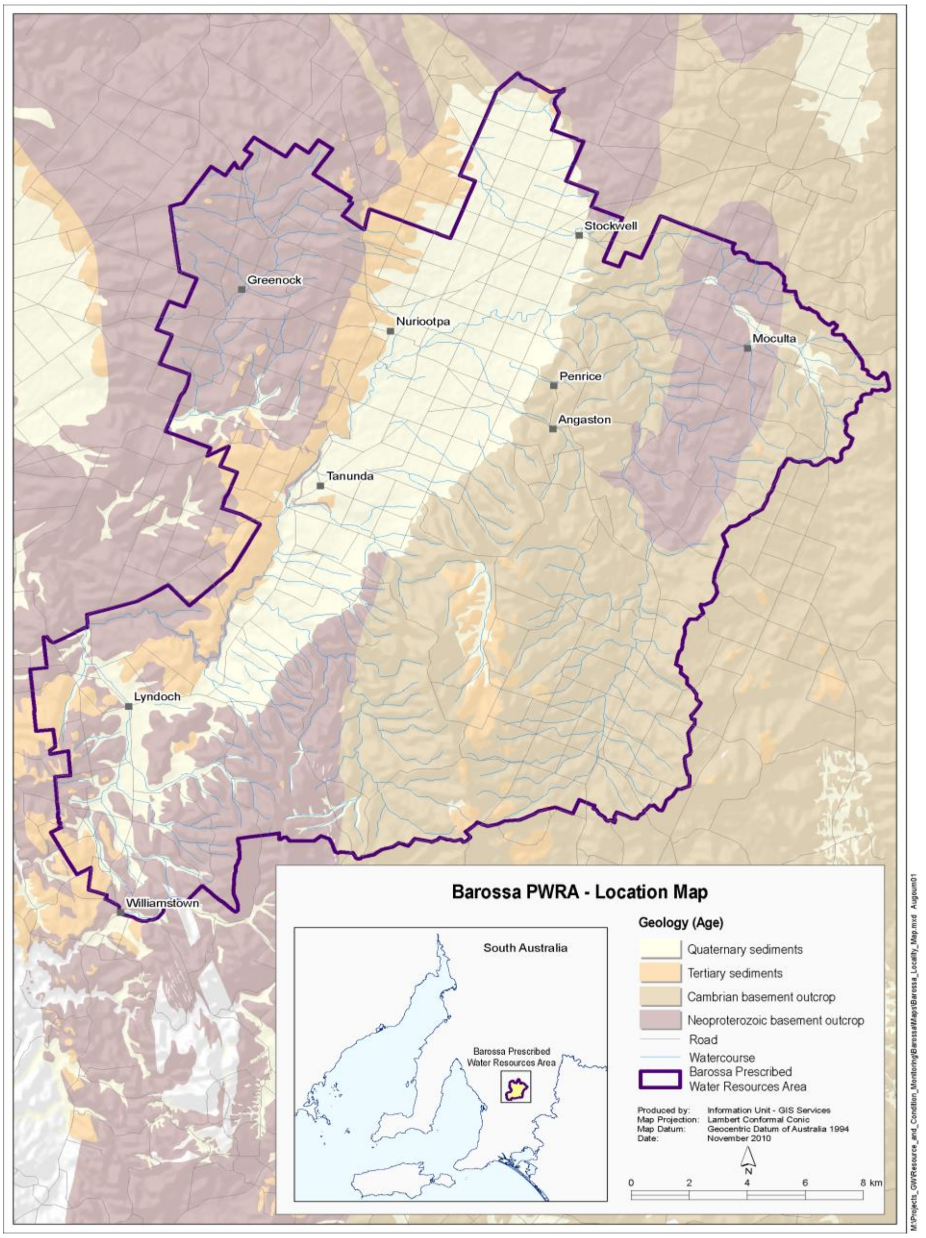


Figure 1. Location of the Barossa PWRA

2 Climate

The climate of the Barossa region is characterised by hot, dry summers and cool to mild, wet winters. Annual rainfall varies from more than 750 mm at the highest elevations in the Barossa Ranges, to about 300 mm north of Angaston. Rainfall is a very important part of the groundwater balance because it is a source of replenishment or recharge to aquifers by infiltration through the soil, or by percolation from streamflow in drainage lines. Rainfall data is presented for the Bureau of Meteorology station at Tanunda (station 23318) where the long term annual average rainfall is 545 mm (Figure 2). The cumulative deviation from mean annual rainfall (plotted in orange) identifies periods where rainfall trends are above or below average. An upward slope indicates a period where the rainfall is greater than the average, while a downward slope indicates a period where the rainfall is below the average. More detailed analysis of recent trends is presented later in this report.

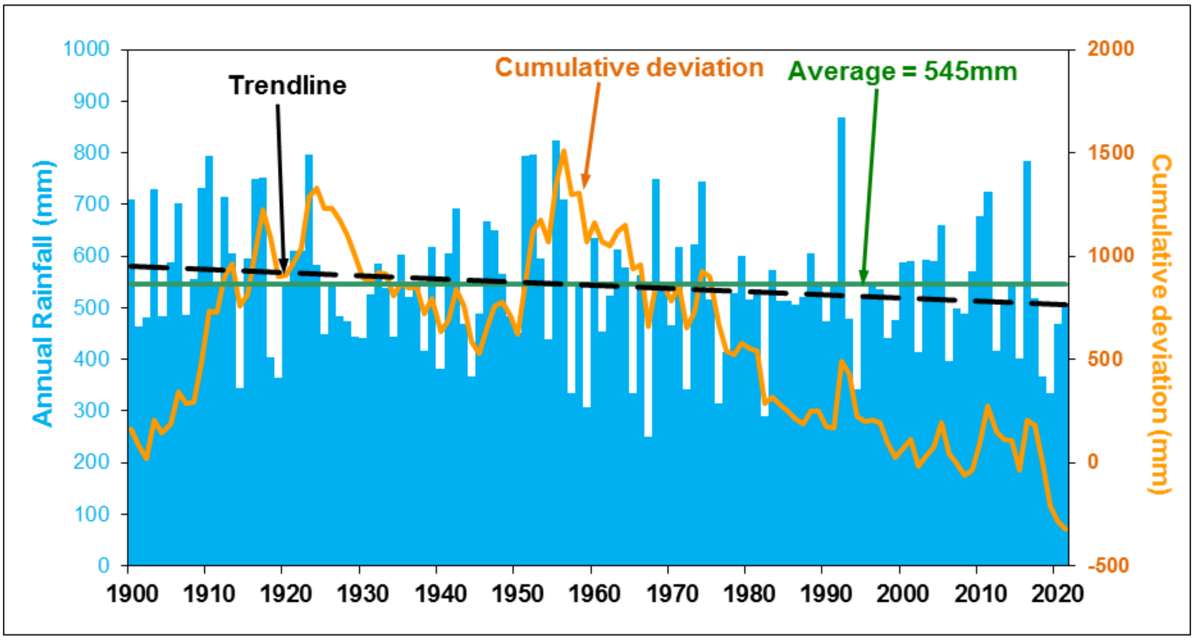


Figure 2. Rainfall data from BoM Tanunda rainfall station (23318)

Figure 2 shows that the long term rainfall trend is declining and that Tanunda has experienced an extended period of below average rainfall since 1956, with the exception of wet years in 1975, 1992, 2005, 2011 and 2016. In particular, rainfall has been very much below average since 2017.

Climate change projections carried out by the Goyder Institute (Charles and Fu, 2014) indicated that by 2050, the Adelaide and Mt Lofty Ranges NRM Region could experience a decrease in average annual rainfall by between 6.3% and 8.4% and an increase in average annual maximum temperature by between 1.3 and 1.8°C.

These projections indicate that over the long term, climate change will impact predominately unconfined aquifers through a reduction in recharge, with those aquifers with limited storage capacity being more vulnerable than those with large storage capacity. The higher temperatures may increase irrigation demand; however, extraction limits and metering can help mitigate this risk.

The projections do not predict that every year between now and 2050 will experience gradually decreasing rainfall. There will still be climate variability and some periods of above average rainfall that will recharge aquifers and reduce demand for irrigation. It is not possible to predict which years or sequences of years will be wet or dry which suggests an adaptive management approach is best suited for the groundwater resources of the Barossa PWRA.

3 Hydrostratigraphy

Within the Barossa PWRA, groundwater occurs in four major aquifers: Upper aquifer, Lower aquifer, Lyndoch Alluvial aquifer and the Fractured Rock aquifer (Figure 3). The Lyndoch Alluvial aquifer was previously considered part of the Upper aquifer but this investigation has found that it is not hydraulically connected to this aquifer which is contained within the main Barossa Valley.

Upper aquifer

Interbedded sands, gravels and clays of Quaternary and Tertiary age form an unconfined aquifer which is recharged from local rainfall and from infiltration of streamflow from the North Para River and tributaries where they cross the Barossa Valley Floor. Groundwater discharge back into the North Para River occurs downstream from Nuriootpa (Cranswick et al, 2015). Groundwater flow is generally toward the south-west with groundwater salinities ranging from 740 to over 11 000 mg/L.

Lower aquifer

The Lower aquifer consists of Tertiary carbonaceous clays, gravels, sands and silts that were deposited in the deepest part of the basin with grain size of the sediments tending to increase with depth. The aquifer is confined and is most likely recharged by lateral flow from the fractured rock aquifers to the east. Similar to the overlying Upper aquifer, groundwater flow is generally toward the south-west; however, groundwater salinities are lower, ranging from 600 to over 2500 mg/L (Cranswick et al, 2015).

Lyndoch Alluvial aquifer

The Lyndoch Valley contains a shallow alluvial aquifer comprising basal sands and gravels which reach a maximum thickness of about 40 m and are overlain by up to 20 m of clay, resulting in the aquifer being semi-confined. Groundwater flow is in a northerly direction.

Fractured Rock aquifers

Fractured Rock aquifers occur in basement rocks (sandstones, quartzites, shales and metamorphosed schists and marbles) which surround and underlie the sedimentary aquifers within the valley. Infiltration of rainfall provides recharge to the aquifer in these areas. The fractured rock aquifer is unconfined in areas where it outcrops, and confined where it is overlain with the Quaternary and Tertiary sediments of the Upper and Lower aquifers.

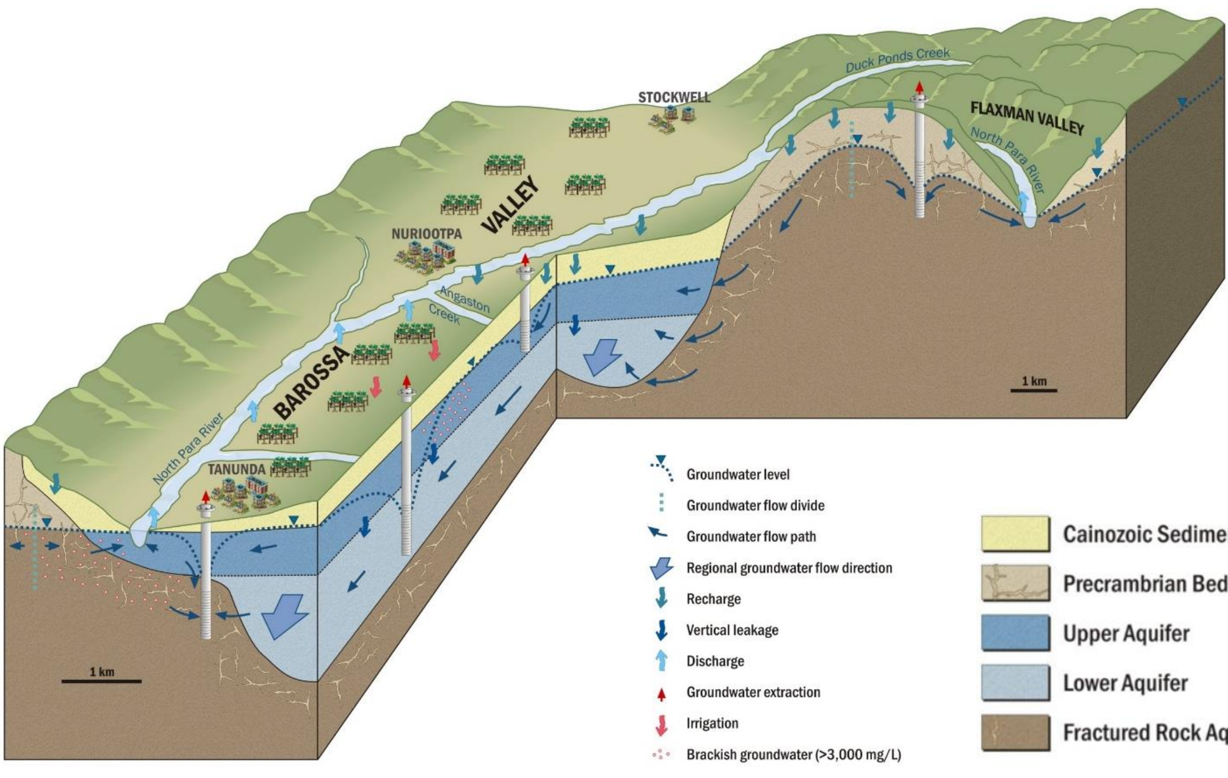


Figure 3. Conceptual model of the Barossa PWRA groundwater resources (after Cranswick et al., 2015)

4 Upper aquifer

Analysis of drillers' logs and the production of 3D aquifer surfaces has enabled all wells which are completed in the Upper aquifer to be determined resulting in a minor revision to the mapped extent of the aquifer. This has allowed much more information on the watertable elevation and salinity to be consolidated than has previously been available enabling a better delineation of aquifer extent which is presented in Figure 4. Also shown are the locations of the Upper aquifer licensed wells and observation wells. The hydrographs of selected representative observation wells are labelled and presented later in Figure 7.

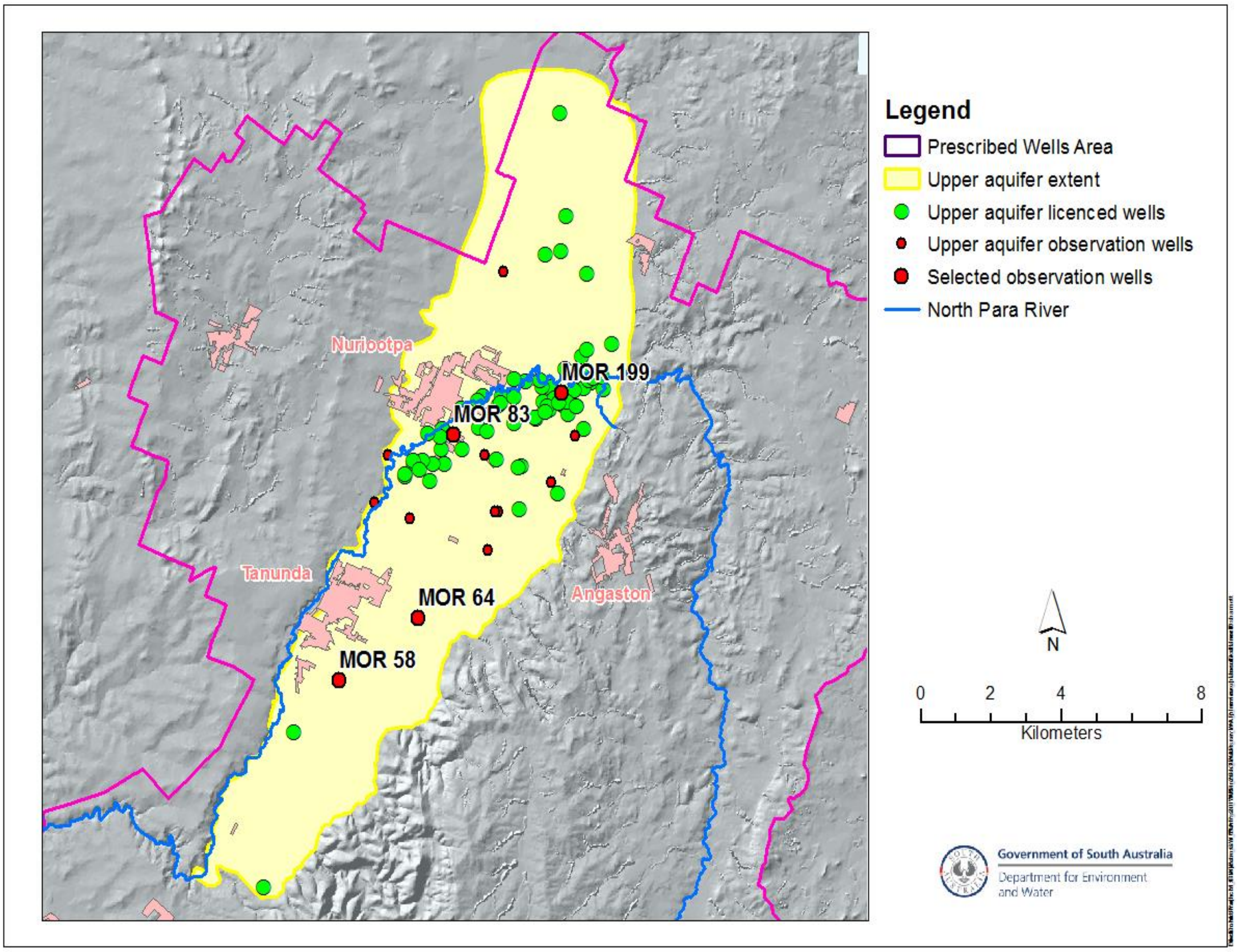


Figure 4. Extent of the Upper aquifer and location of licensed wells

4.1 Extraction and allocation

Figure 5 shows that metered extraction from the Upper aquifer since 2003-04 has been consistently below 500 ML/year, with annual variations caused by variations in rainfall where irrigation demand is reduced during wetter years, especially if significant rainfall occurs during the irrigation season. Conversely, demand increases during dry years when the irrigation season is lengthened. The metered extractions are currently well below the volume of allocation.

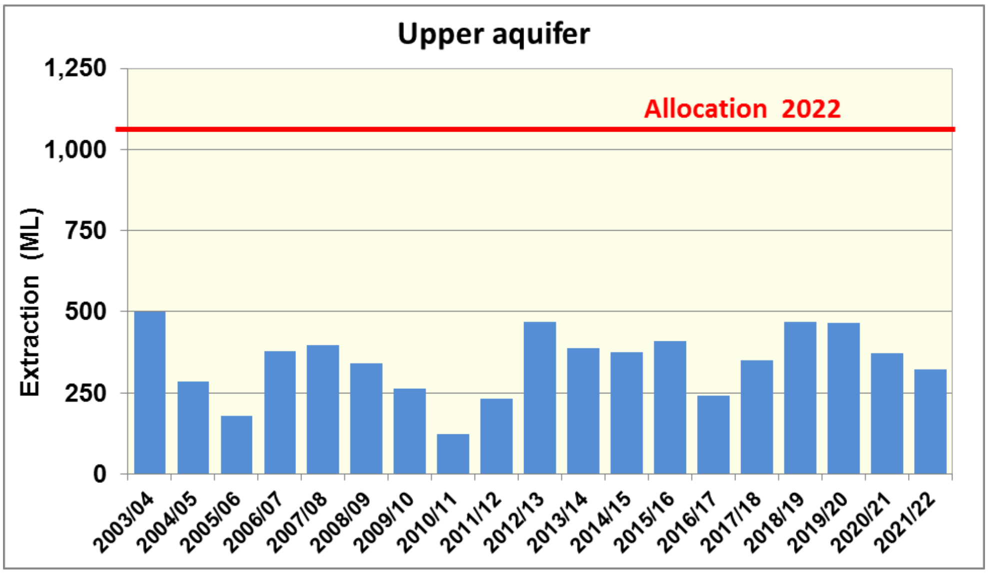


Figure 5. Metered extraction from the Upper aquifer

The metered extraction as a percentage of the individual licensed allocations for the 2020-21 water use year is presented in Figure 6 and shows a significant number of allocations which are not currently being used. This reduction in demand is probably a reflection of the variability of groundwater salinity and increasing use of better quality alternative water sources, such as the Barossa Infrastructure Limited scheme which imports River Murray water.

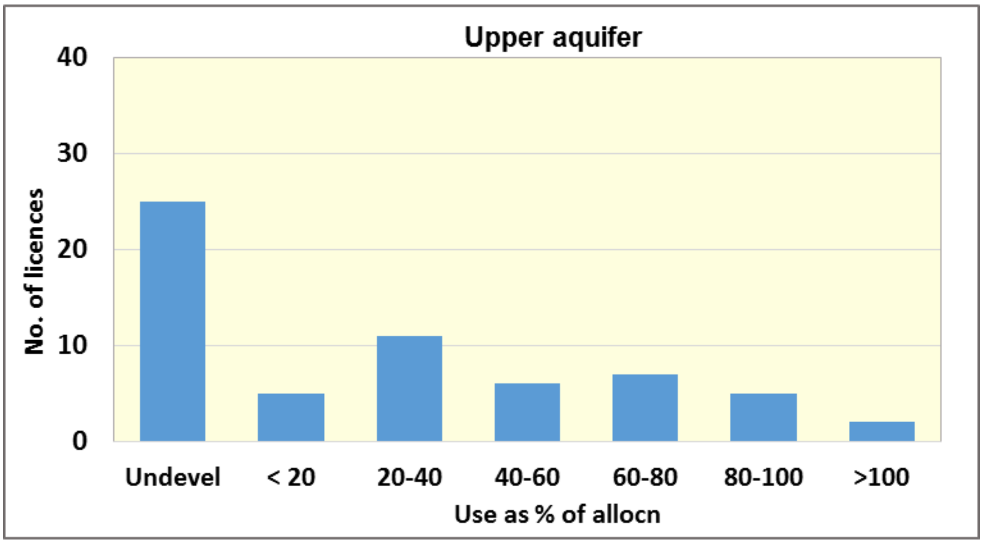


Figure 6. Use vs allocation for the Upper aquifer for 2020-21

4.2 Water level trends

Regular water level monitoring is undertaken in 11 Upper aquifer observation wells with a selection presented in Figure 7 (locations of these wells in Figure 4). The cumulative rainfall deviation for the Tanunda station is plotted in blue. The wells closest to extraction (MOR 83, MOR 199) show relatively stable trends with a muted relationship with rainfall apart from the last few years when well below average rainfall was experienced and groundwater levels have declined. Well MOR 58 shows a similar stable relationship but well MOR 64 and other observation wells located well away from extraction, show a close relationship with rainfall and display a long term declining trend.

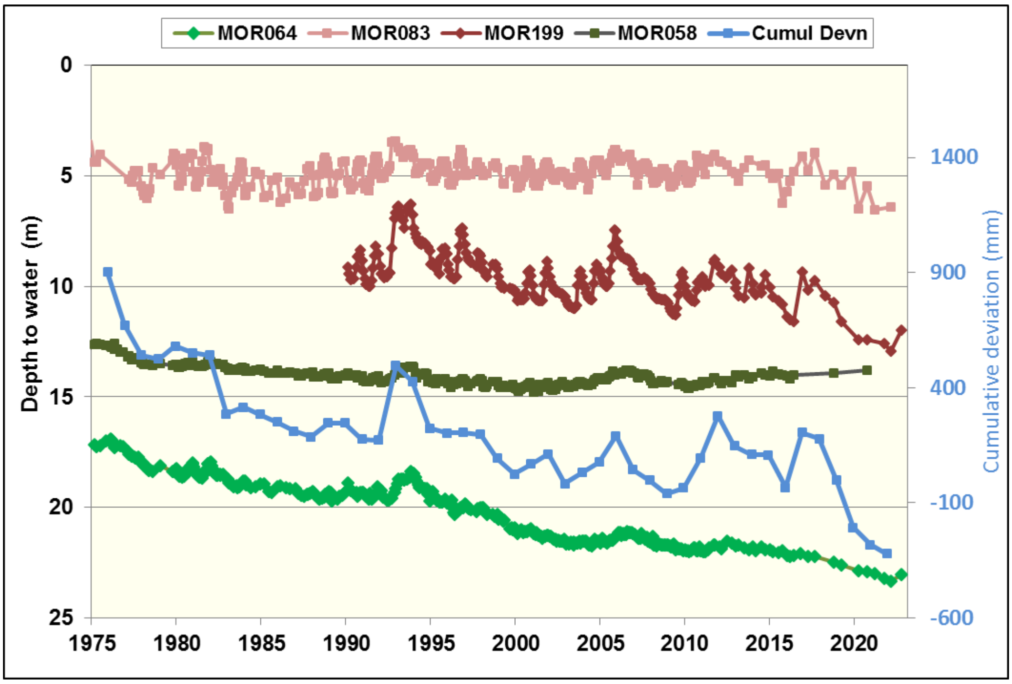


Figure 7. Selected water level hydrographs for the Upper aquifer

4.3 Salinity distribution

Figure 8 shows the salinity of the Upper aquifer derived from the latest salinity values from 338 wells recorded over the last 30 years from 338 wells, including the 2021 sampling program. Broad trends can be observed where lower salinities are associated with infiltration of streamflow from the North Para River and tributaries where they cross the Barossa Valley floor. It is likely that much of this lower salinity groundwater was recharged several thousand years ago when the climate was much wetter than now. Salinities are higher in lower rainfall areas to the northwest where recharge from rainfall is lower.

4.4 Salinity trends

Figure 9 shows long term trends from four representative irrigation wells (locations shown in Fig. 8) which are generally stable, with some showing a slightly declining trend and some a small percentage increase in the main valley area near Nuriootpa were most of the extraction occurs.

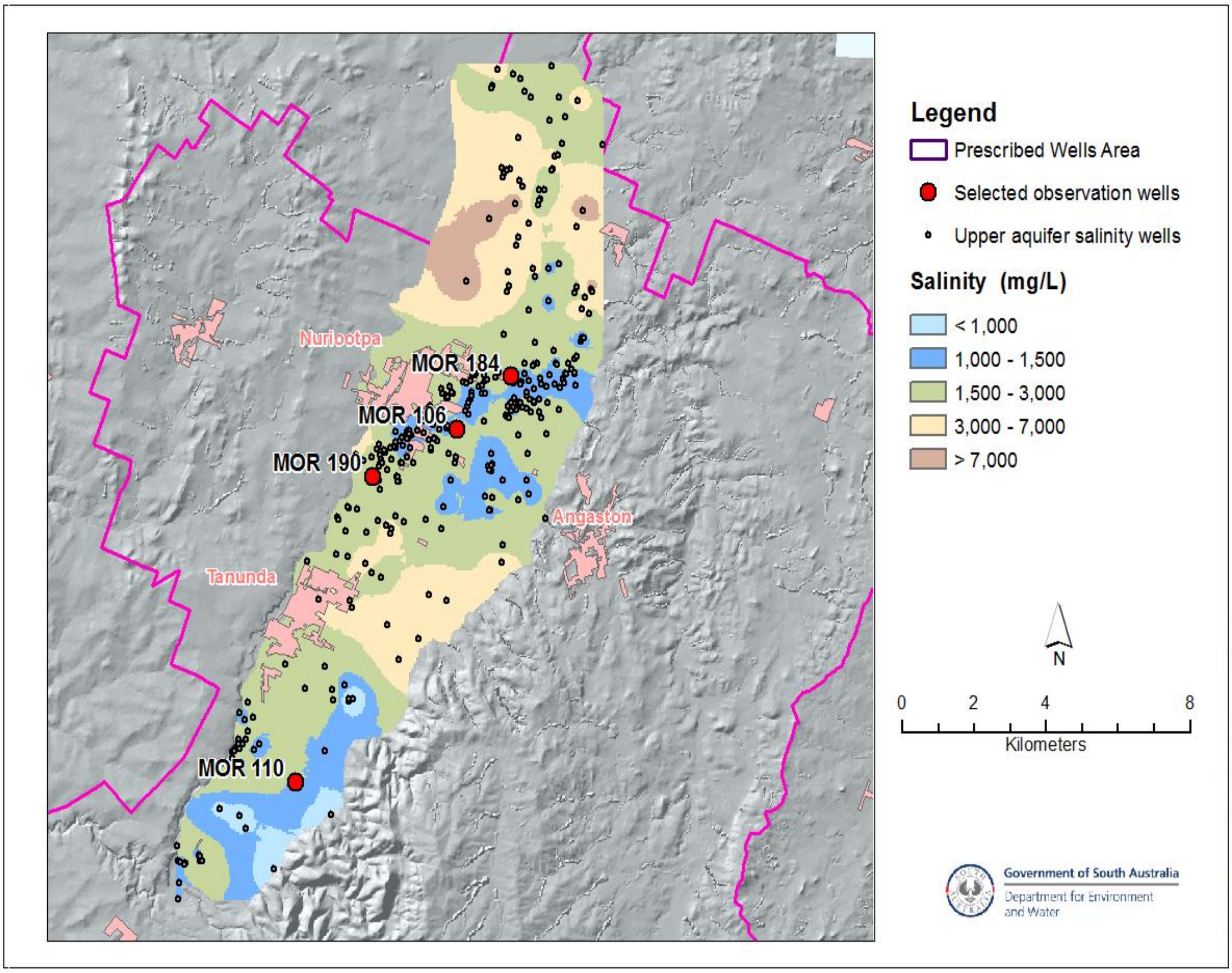


Figure 8. Salinity distribution the Upper aquifer in 2021

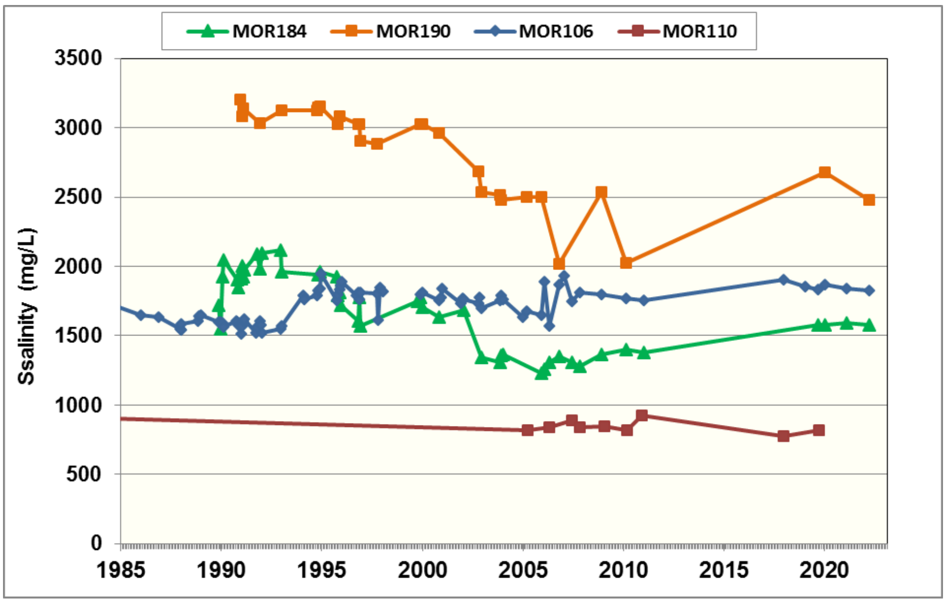


Figure 9. Long term salinity trends for the Upper aquifer

5 Lower aquifer

The Lower aquifer is confined and consists of Tertiary carbonaceous clays, gravels, sands and silts that were deposited in the deepest part of the basin. Figure 10 presents the extent of the Lower aquifer, together with the locations of the Lower aquifer licensed wells and observation wells. The hydrographs of selected representative observation wells are labelled and presented later in Figure 13.

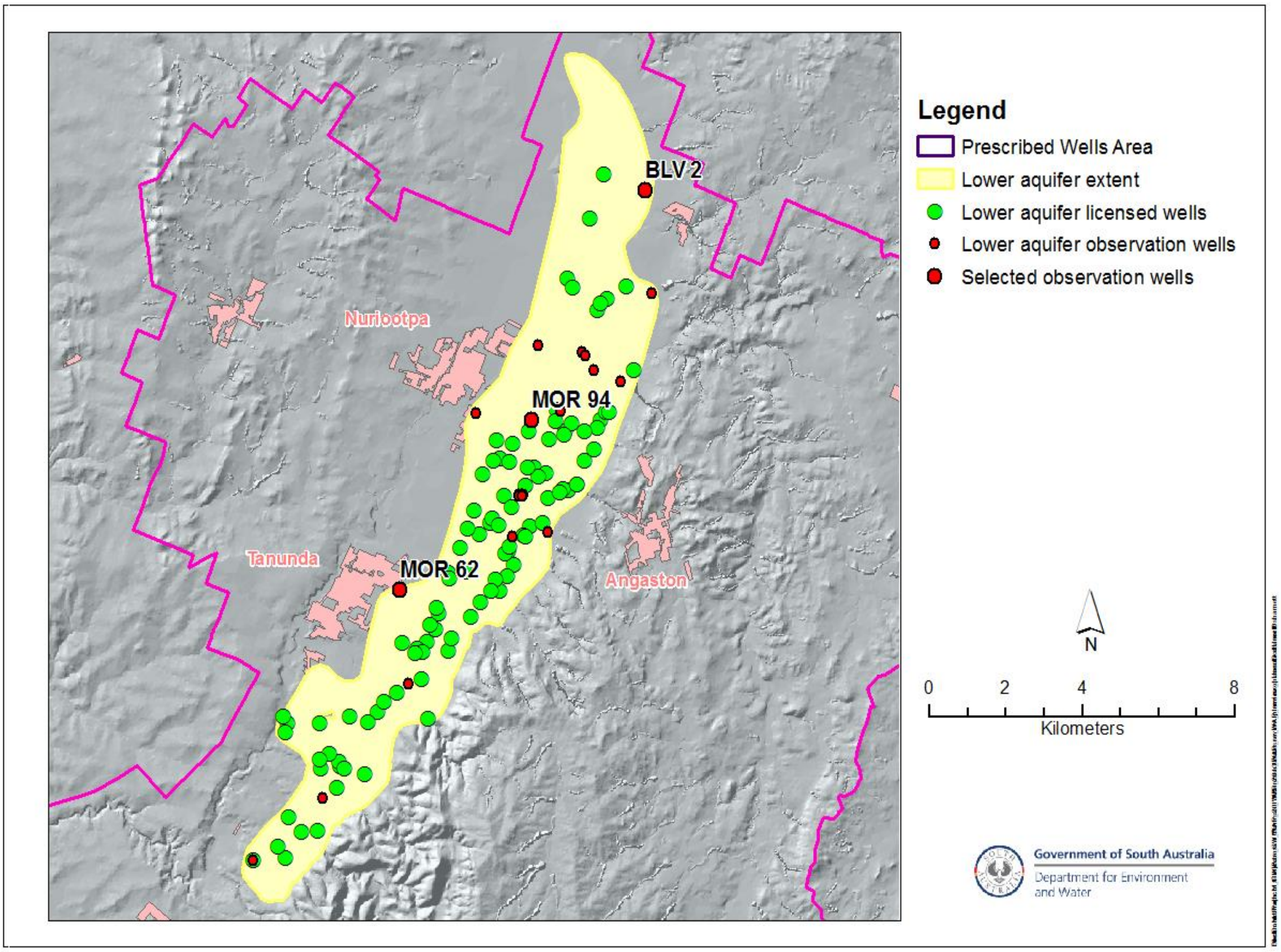


Figure 10. Extent of the Lower aquifer and location of licensed wells

5.1 Extraction and allocation

Figure 11 shows that metered extraction from the Lower aquifer since 2003-04 has been fairly consistent and mostly below 1,500 ML/year, with seasonal variations caused by variations in rainfall. Extraction has increased in recent years due to very much below average rainfall. Extractions are well below the volume of allocation.

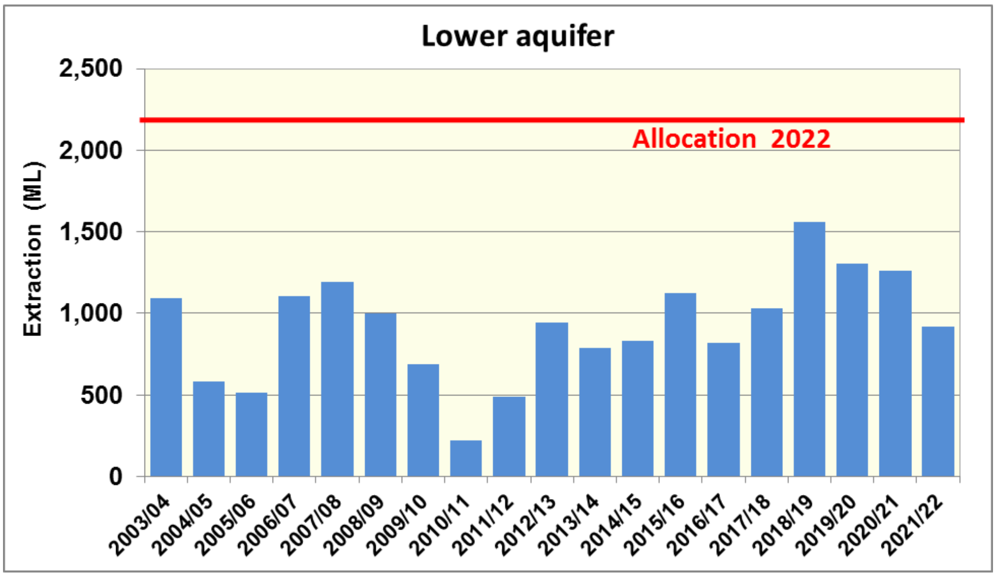


Figure 11. Metered extraction from the Lower aquifer

The metered extraction as a percentage of the individual licensed allocations for the 2020-21 water use year is presented in Figure 12 and shows a higher degree of development of the allocations than seen for other aquifers. This is probably the result of this aquifer having lower salinities and more reliable well yields.

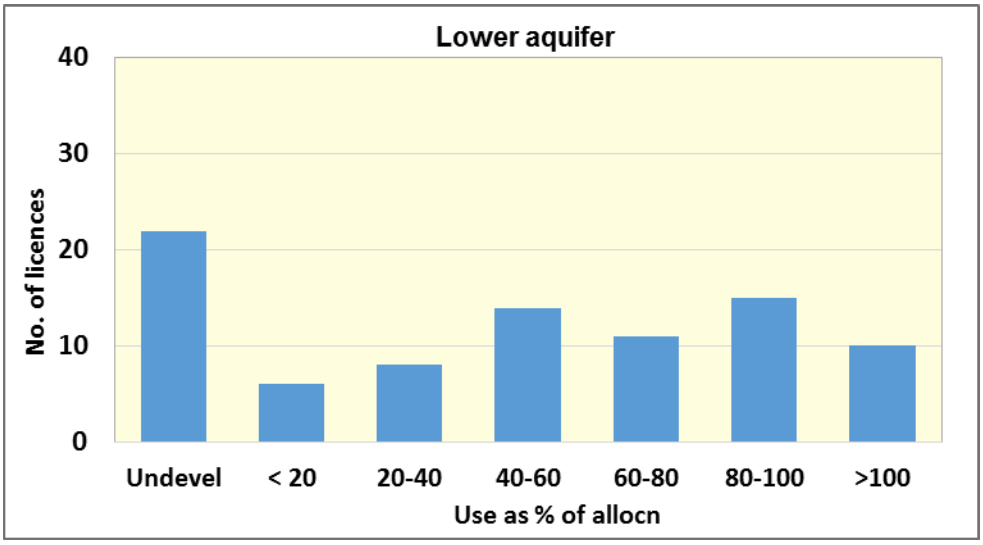


Figure 12. Use vs allocation for the Lower aquifer for 2020-21

5.2 Water level trends

Water level monitoring has been carried out since 1975. Figure 13 presents hydrographs for selected Lower aquifer wells. Pressure levels at the end of the winter recovery period in the centre of valley (MOR 94) have generally been stable except for minor variations due to climate–induced changes in extraction (e.g., pressure levels during the wet 1992-93 period were higher due to reduced pumping). Seasonal drawdowns have decreased since 1990 in response to reduced extraction. Pressure levels have declined by 2-3 m in recent years corresponding to very much below average rainfall which resulted in increased extraction from the resource. The seasonal drawdowns in wells BLV 2 and MOR 62 are quite small and reflect the lack of extraction in their vicinity. These wells are showing a long term gradual decline averaging 0.06 m/year.

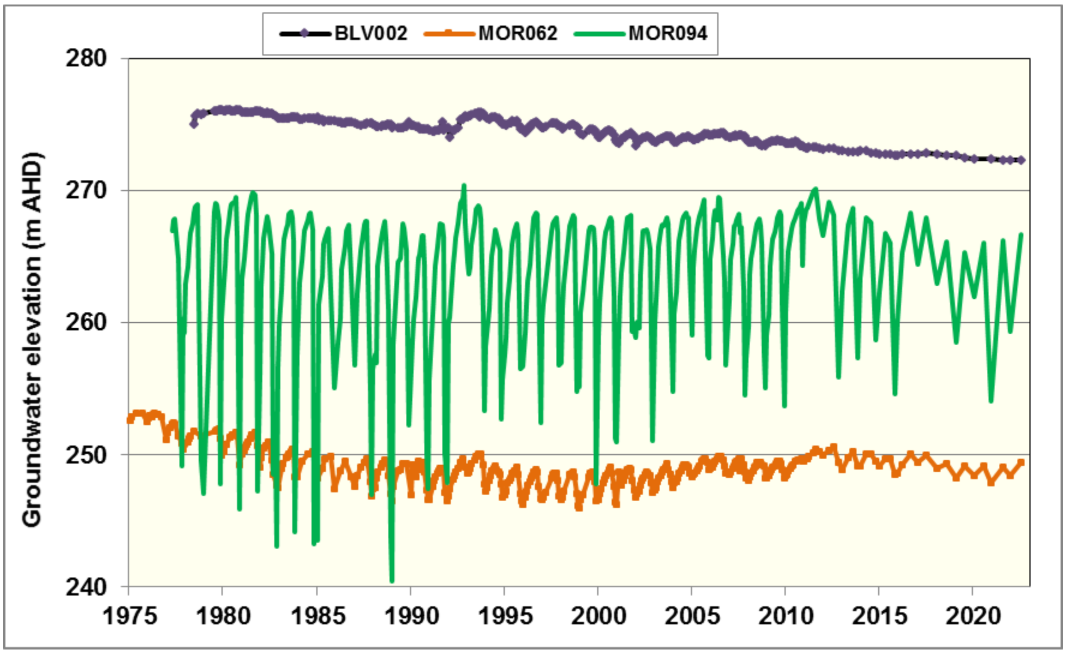


Figure 13. Selected water level hydrographs for the Lower aquifer

5.3 Salinity distribution

Figure 14 shows the extent of the Lower aquifer and the salinity distribution derived from the latest salinity values recorded over the last 30 years including the 2021 sampling program. Most of the irrigation wells have salinities below 1500 mg/L, with values generally decreasing toward the south where rainfall is higher and the salinity of the FRA (which recharges the Lower aquifer by lateral flow), is lower.

5.4 Salinity trends

Long term salinity trends are generally stable with Figure 15 showing from four representative irrigation wells (locations shown in Figure 14). Well MOR 140 is typical of some wells along the western margin of the Lower aquifer between Nuriootpa and Tanunda that are showing gradual rising salinity trends since 2005, most likely because of upward leakage from the underlying confined FRA which is induced by drawdown due to pumping.

Rising trends could also be associated with the occasional older leaky well with poor construction that allows connection with the overlying Upper aquifer or underlying FRA which contain higher salinity water.

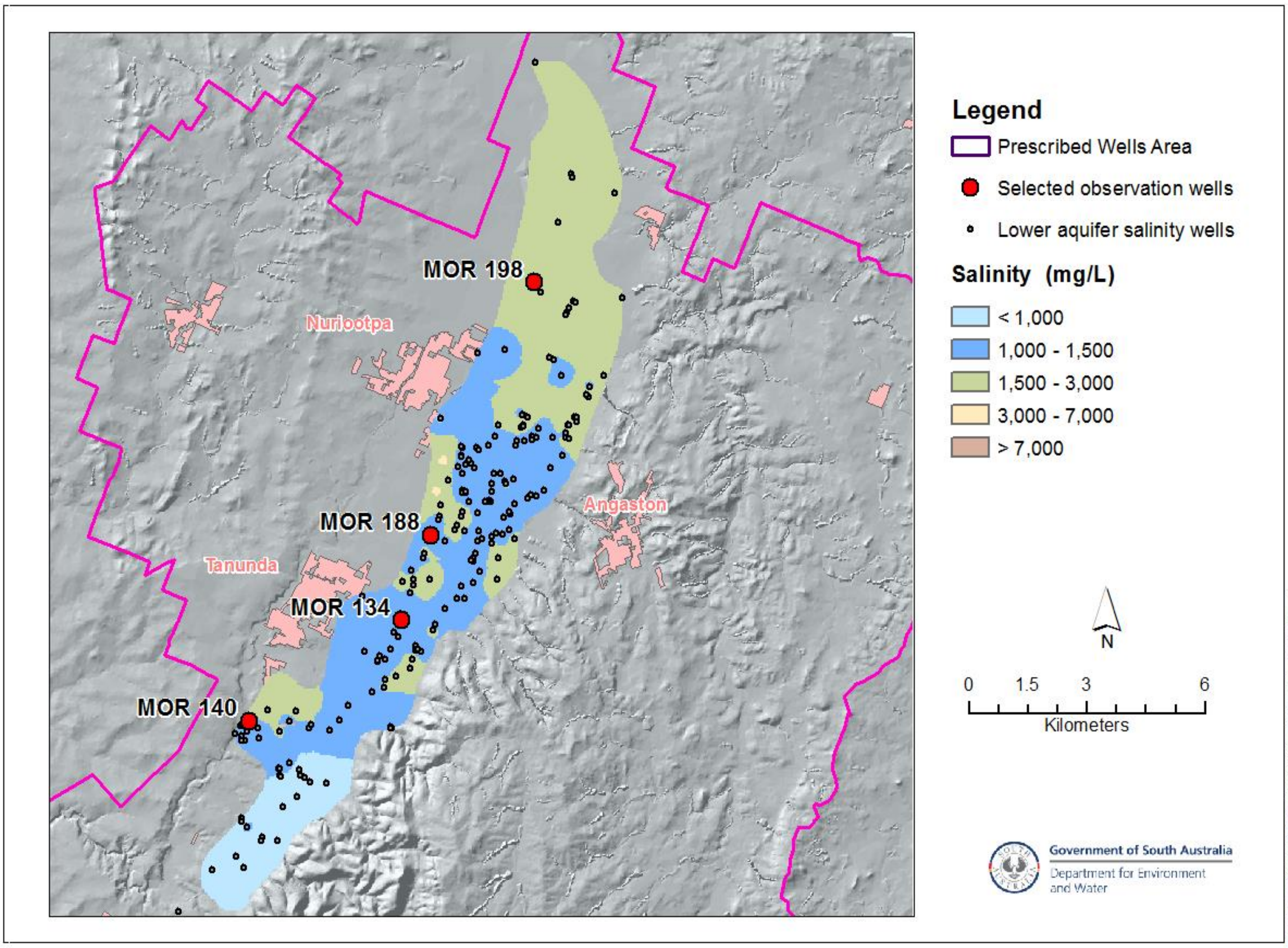


Figure 14. Salinity distribution for the Lower aquifer in 2021

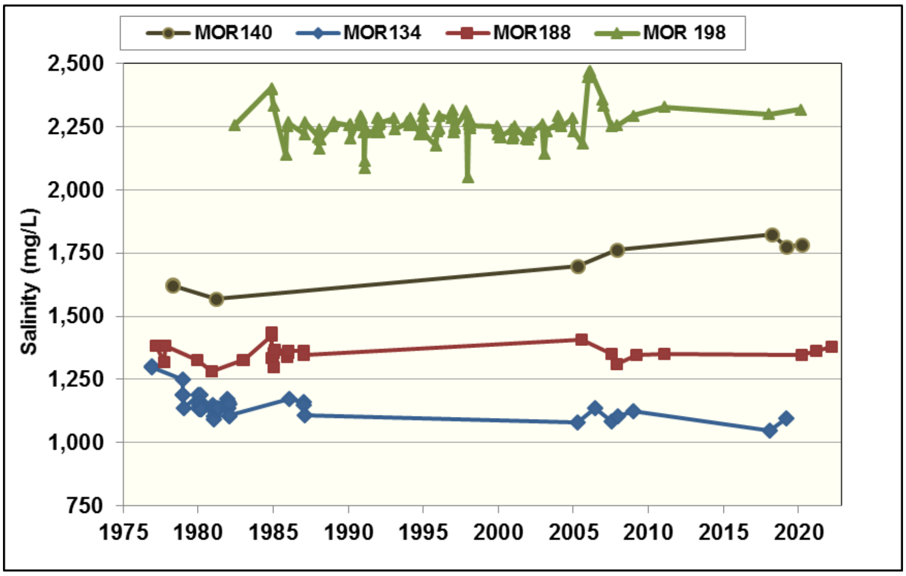


Figure 15. Long term salinity trends for the Lower aquifer

6 Lyndoch Valley

The Lyndoch Valley contains a shallow alluvial aquifer which overlies the FRA which is confined. This alluvial aquifer was previously considered to be part of the Upper aquifer; however closer examination of geological logs as part of this review, has shown that there is no lateral hydraulic connection between this aquifer and the Upper aquifer which is restricted in extent to the main valley. The Lyndoch Alluvial (LA) aquifer consists of basal sands and gravels which reach a maximum thickness of about 40 m and are overlain by up to 20 m of clay, resulting in the aquifer being semi-confined. Groundwater flow is in a northerly direction. A schematic east-west cross section is presented in Figure 16.

Because of the younger geological age and more energetic environment of deposition compared to the main valley, there has not been the opportunity for the formation of a thick weathered clayey zone on top of the FRA. Because of the thin or absent weathered zone (Figure 16), there is potentially a greater connectivity between the FRA and the alluvial aquifer in some locations, which is also suggested by Cranswick et al (2015).

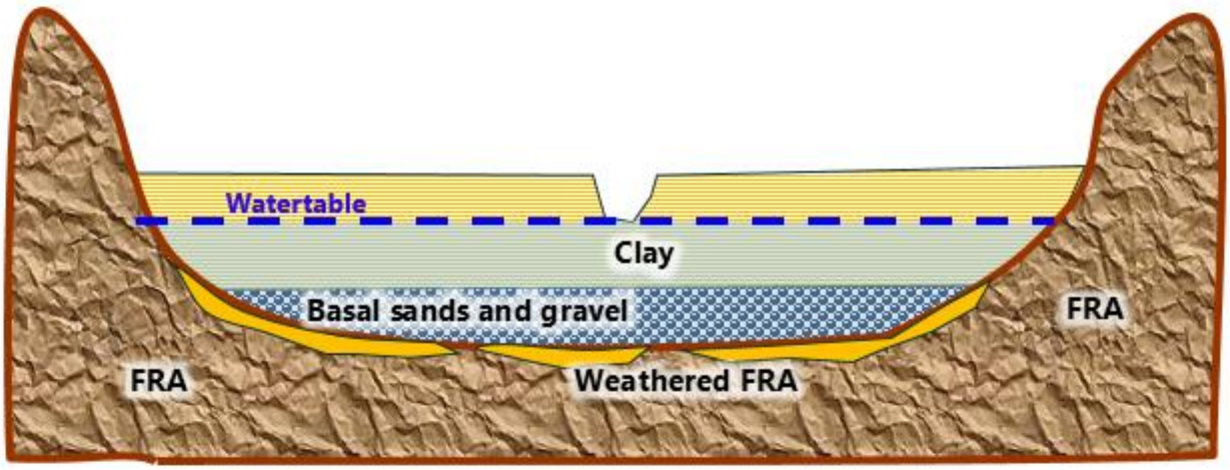


Figure 16. Schematic east-west cross section of the Lyndoch Alluvial aquifer

Figure 17a presents the extent of the alluvium and the basal gravel LA aquifer as well as the licensed wells (in green) and the observation wells (in red) whose hydrographs are presented in Figure 20. The confined FRA licensed wells are shown in Figure 17b; however; there are currently no observation wells monitoring water levels in this aquifer.

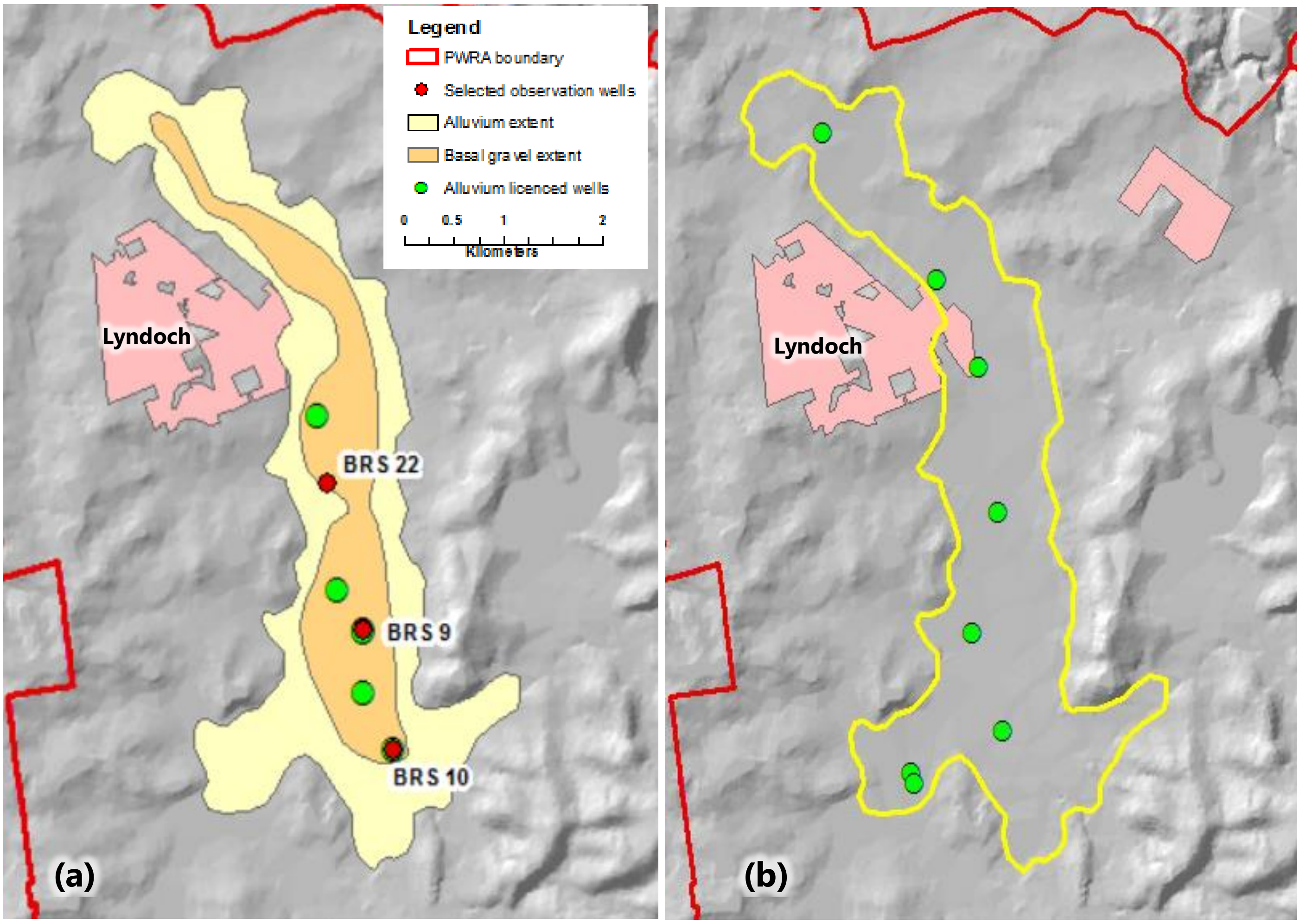


Figure 17. (a) Extent of the Lyndoch Alluvial aquifer and location of licensed wells (b) Confined FRA licensed wells

6.1 Extraction and allocation

There are only two active licences using the LA aquifer with one accounting for about 70 % of the total extraction with the full allocation generally used. Figure 18 shows that metered extraction from the LA aquifer since 2013-14 which generally follows usage trends from other aquifers. Extraction has increased in recent years in response to below average rainfall but is below the 2021 allocation volume of 63 ML.

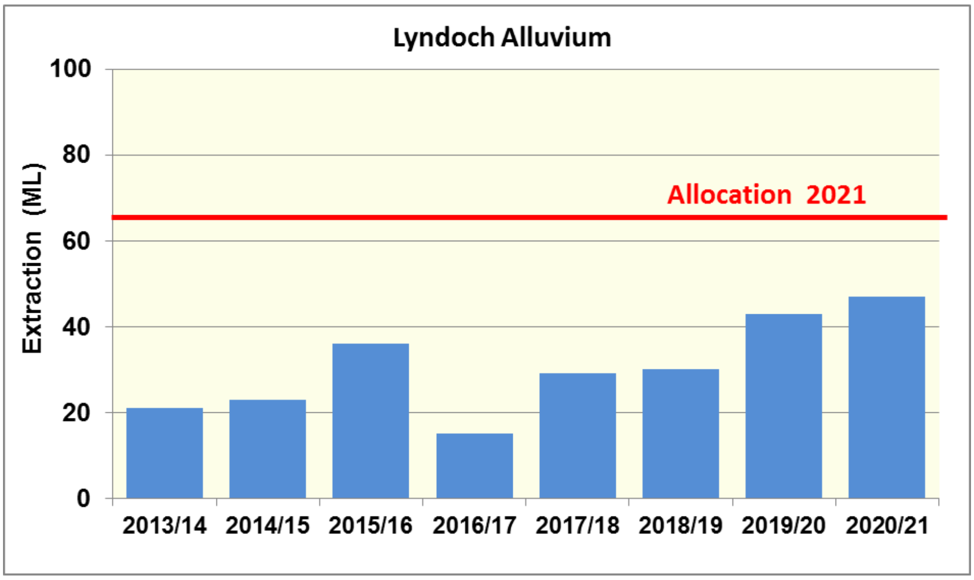


Figure 18. Metered extraction from the LA aquifer

Extraction from the Lyndoch confined FRA is presented in Figure 19. There are six active licences, with one accounting for over 50% of total use. Extractions are higher than from the alluvial aquifer due to the higher yields from irrigation wells that can be drilled to a greater depth. Extractions follow a similar pattern to other aquifers (except for the last two years), and are well below the level of allocation.

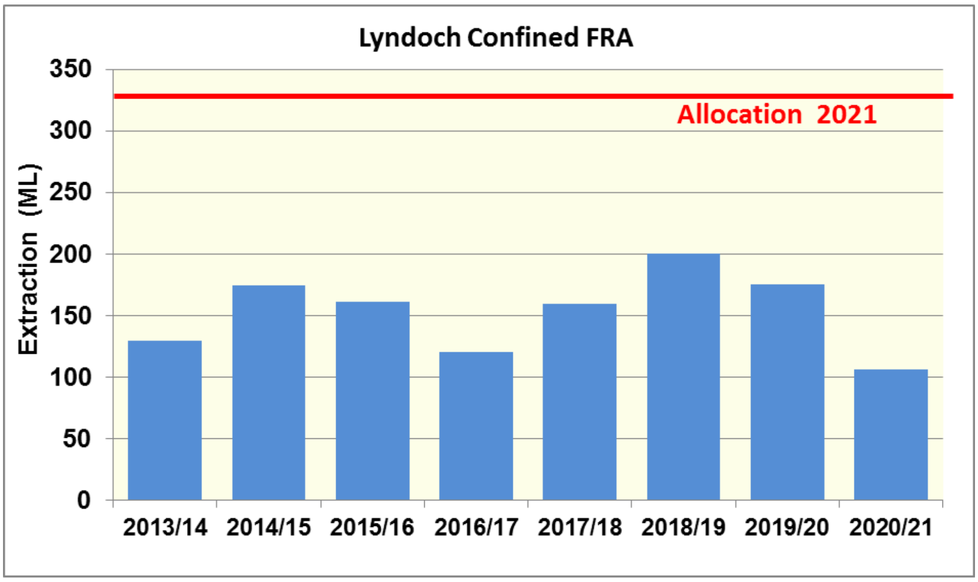


Figure 19. Metered extraction from the Lyndoch Confined FRA

6.2 Water level trends

Water level monitoring has been carried out since the late 1980s. Long term trends from 1992 to 2020 show a gradual pressure level decline varying from 0.3 to 0.5 m/year as shown in Figure 20, with the magnitude of decline decreasing to the north as the aquifer increases in thickness. The lack of recharge from streamflow in the south has resulted in the lowering of the flow gradient within the aquifer from south to north. This is brought about by lateral flow within the aquifer which lowers the water level in the south to a greater extent than to the north. There appears to be an overall relationship with rainfall patterns. These declines represent a decrease in pressure with the basal gravel aquifer and not a decrease in saturated thickness of the aquifer which is still being fully saturated.

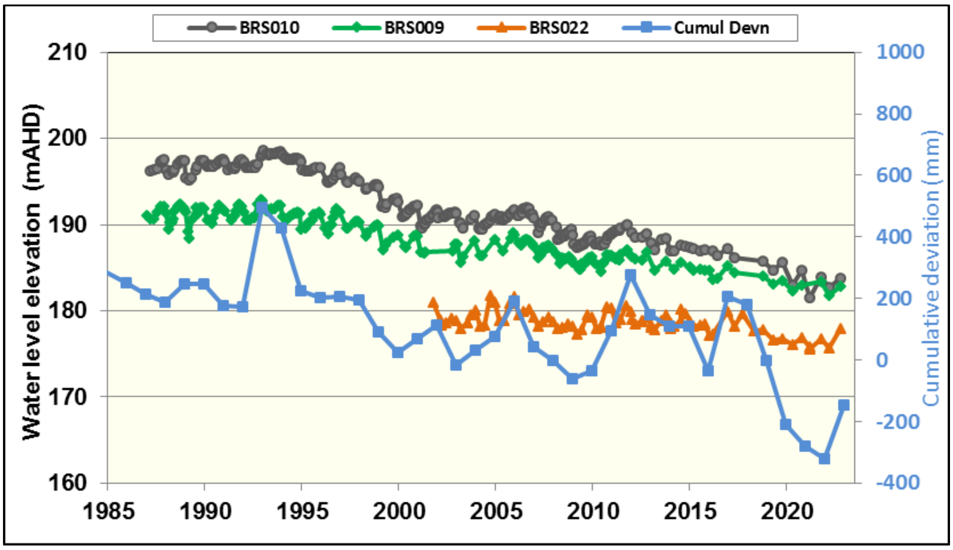


Figure 20. Selected hydrographs for the LA aquifer

6.3 Salinity distribution

Figure 21 shows salinity distribution for the LA aquifer and FRA including the confined portion underlying the LA aquifer, following the 2021 sampling program. The location of observation wells featured in Figures 22 and 23 are also shown. The LA aquifer (Figure 21a) shows large areas of below 1000 mg/L in south where recharge from Lyndoch Creek occurs. It is likely that much of this lower salinity groundwater was recharged historically during a wetter climate. There are some areas of higher salinity up to 1500 mg/L which correspond to similar salinities in the underlying confined FRA (Figure 21b) and suggests some upward leakage may have occurred. The lower confined FRA salinities appear to have originated due to lateral flow from the higher ground to the east which experiences high rainfall.

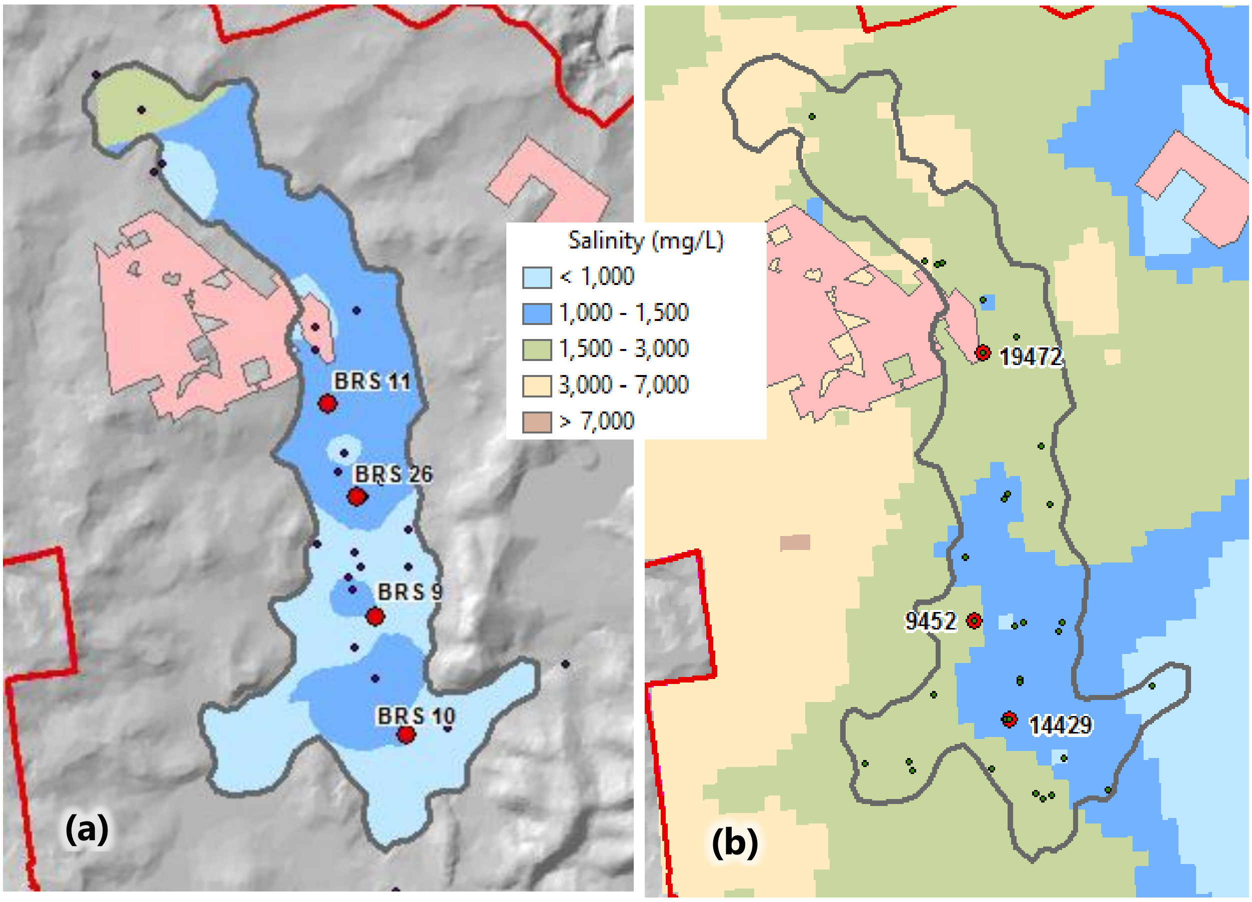


Figure 21. Salinity distribution for (a) the LA aquifer (b) the FRA in 2021

6.4 Salinity trends

Long term trends are presented in Figure 22 for representative LA aquifer irrigation wells (locations shown in Figure 21a), which indicate that trends are relatively stable, with some exceptions. Well BRS 9 appears to indicate the intermittent injection of lower salinity surface water into the well. Well BRS 26 was deepened in 2000 from 9.1 m in 2000 to a depth of to 26 m which is close to the underlying confined FRA, and subsequent rise in salinity is strong evidence of upward leakage, most likely induced by local pumping.

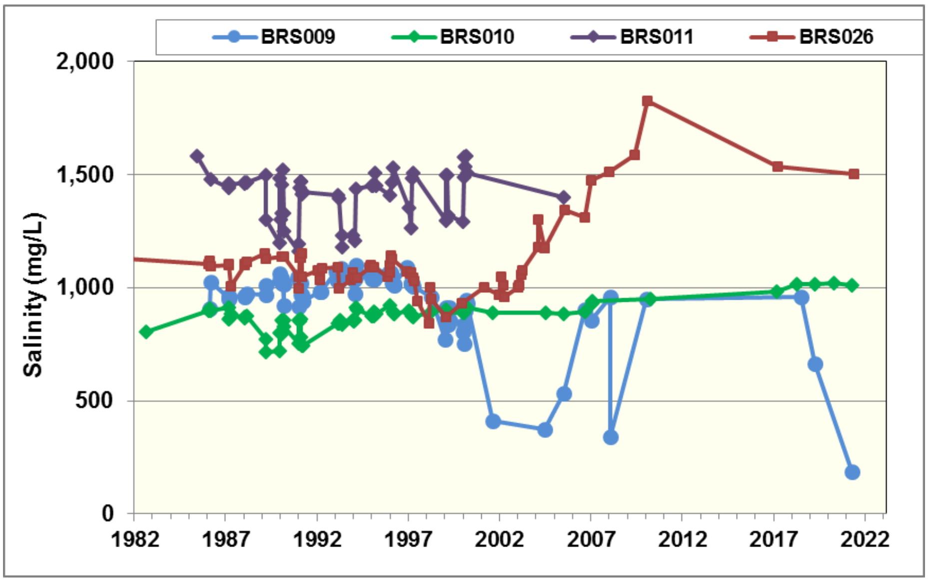


Figure 22. Long term salinity trends for the LA aquifer

Salinity trends for the confined FRA are displayed in Figure 23. Although monitoring is not consistent over the long term, some trends are stable, but well 6628-9452 displays some freshening during the 2000s which may indicate downward leakage from the overlying low salinity LA aquifer or direct recharge of surface water.

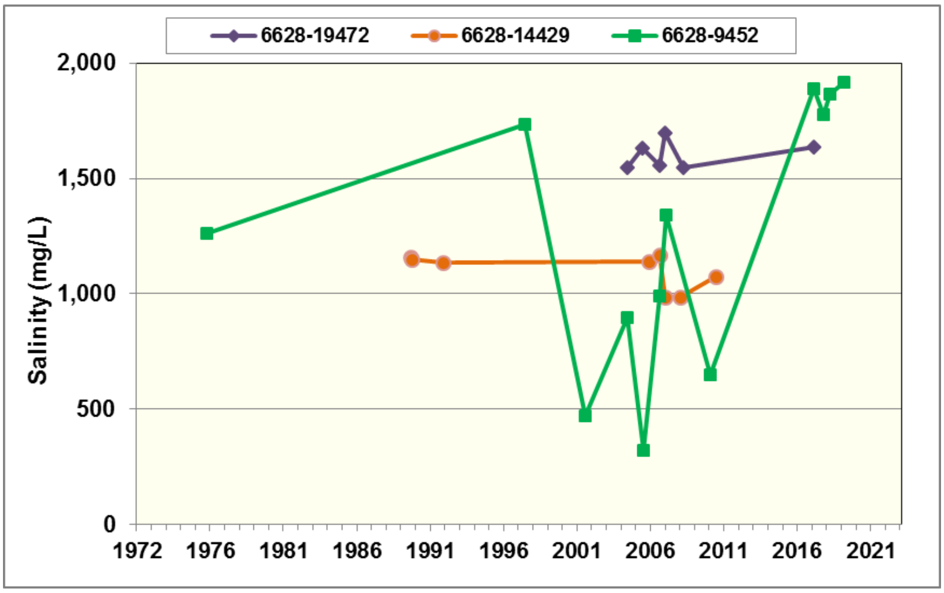


Figure 23. Long term salinity trends for the confined FRA aquifer

7 Fractured Rock aquifer

The fractured rock aquifer (FRA) occurs throughout the whole PWRA, either as an unconfined aquifer where it outcrops at the ground surface surrounding the Barossa valley, or as a confined aquifer underlying the Tertiary and Quaternary sediments within the valley.

Figure 24 presents the boundaries of the confined FRA in the central part of the basin where the aquifer occurs at depths of over 75 m and is confined by the overlying Tertiary sediments. Elsewhere, the FRA is unconfined, covering the areas of higher topography surrounding the PWRA where the aquifer outcrops or is covered by thin unsaturated Tertiary sediments. It is also confined in the Lyndoch Valley by alluvial sediments. Also shown are the locations of the FRA licensed wells and observation wells. The hydrographs of selected representative observation wells are labelled and presented later in Figures 27 and 28.

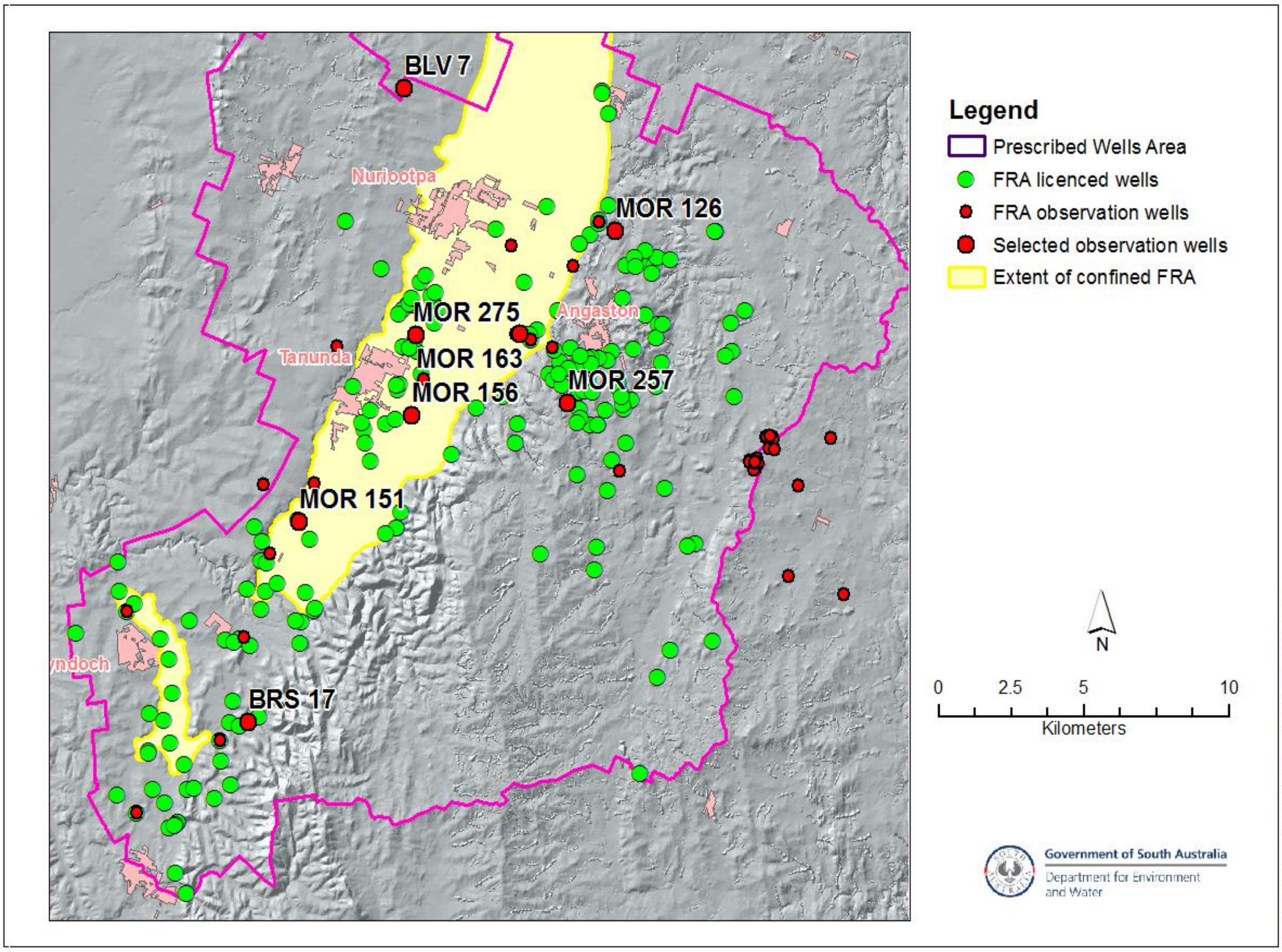


Figure 24. Extent of the Fractured Rock aquifer and location of licensed wells

7.1 Extraction and allocation

Figure 25 shows that metered extraction from the FRA aquifer since 2003-04 has been fairly consistent and always below 2,500 ML/year, with seasonal variations caused by changes in rainfall. Extraction has increased in recent years due to very much below average rainfall. Metered extractions are well below the volume of allocation.

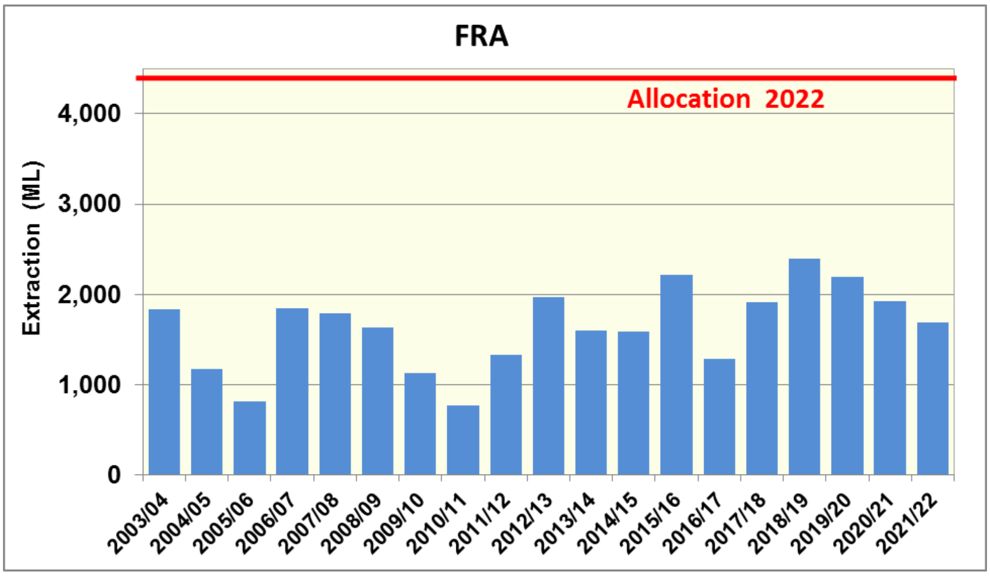


Figure 25. Metered extraction from the FRA aquifer

The metered extraction as a percentage of the individual licensed allocations for the 2020-21 water use year is presented in Figure 26 and shows a lower degree of development of the allocations than the other aquifers discussed previously. This underuse of allocations is probably due to variable well yields and generally higher salinities than other aquifers and the availability of alternative sources.

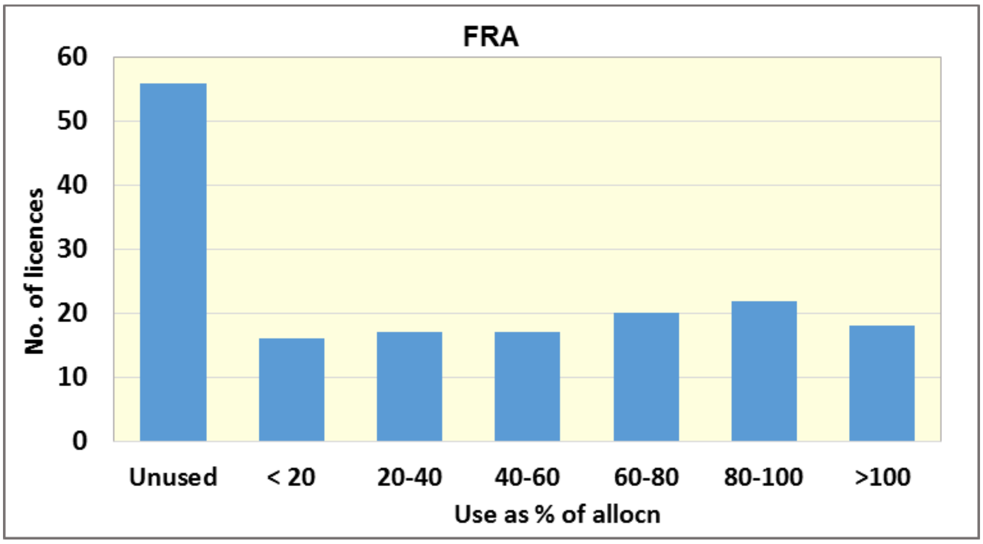


Figure 26. Use vs allocation for the FRA aquifer

7.2 Water level trends

Unconfined FRA

Water level monitoring has been carried out since the mid-1970s. Because this is an unconfined aquifer, the water levels in Figure 27 show a relationship with rainfall patterns where water level declines are mainly driven by periods of below average rainfall (prior to 1992-93, during the millennium drought and recent years). Long term trends vary from relatively stable to a gradual declines of up to 20 m.

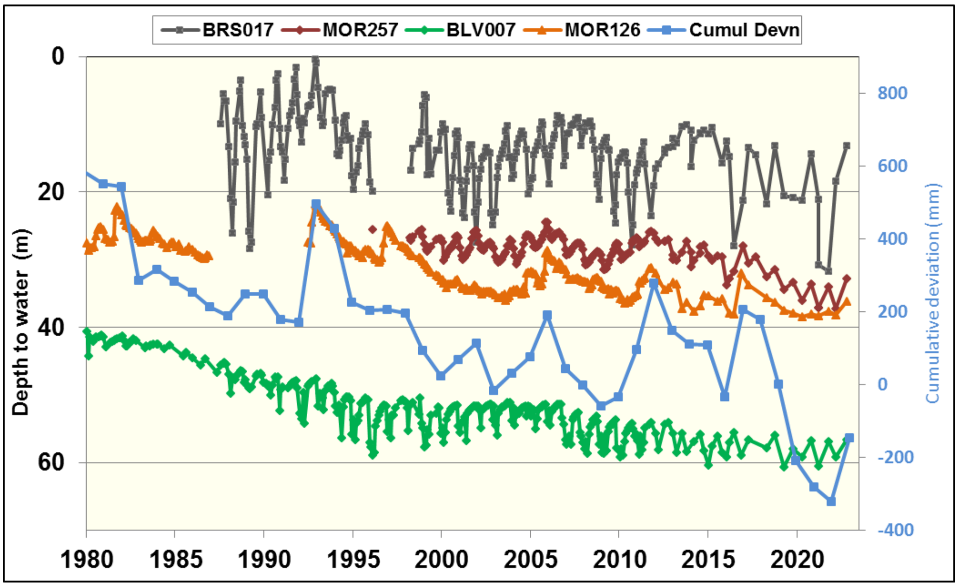


Figure 27. Selected hydrographs for the unconfined FRA aquifer

Confined FRA

The confined aquifer pressure level trends (Figure 28) are similar to those of the confined Lower aquifer. The trends are generally stable with seasonal drawdowns reflecting the magnitude of annual extractions which appear to have decreased after 2010. There is a lack of influence from rainfall trends except for MOR 275 which is located close to eastern highland where the FRA outcrops and experiences high rainfall.

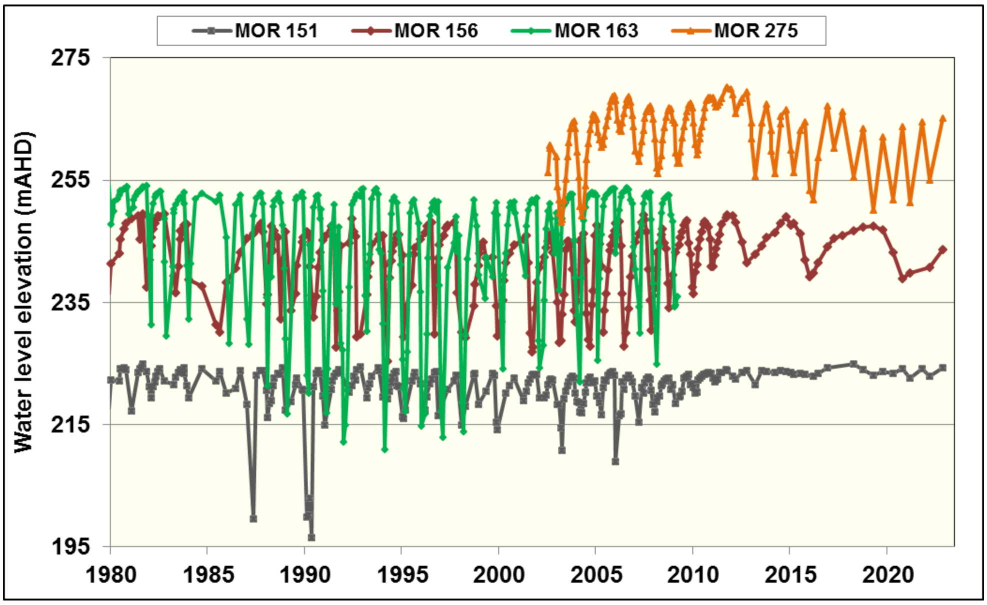


Figure 28. Selected hydrographs for the confined FRA aquifer

7.3 Salinity distribution

As shown in Figure 29, salinities in the FRA are quite variable with the lowest salinities (below 1000 mg/L) found to the east and southeast where the rainfall is highest and consequently where recharge would also be high. The low salinity groundwater in the FRA has moved laterally to the west beneath the Tertiary sediments. The higher salinities of over 3,000 mg/L occur to the west where rainfall is lower.

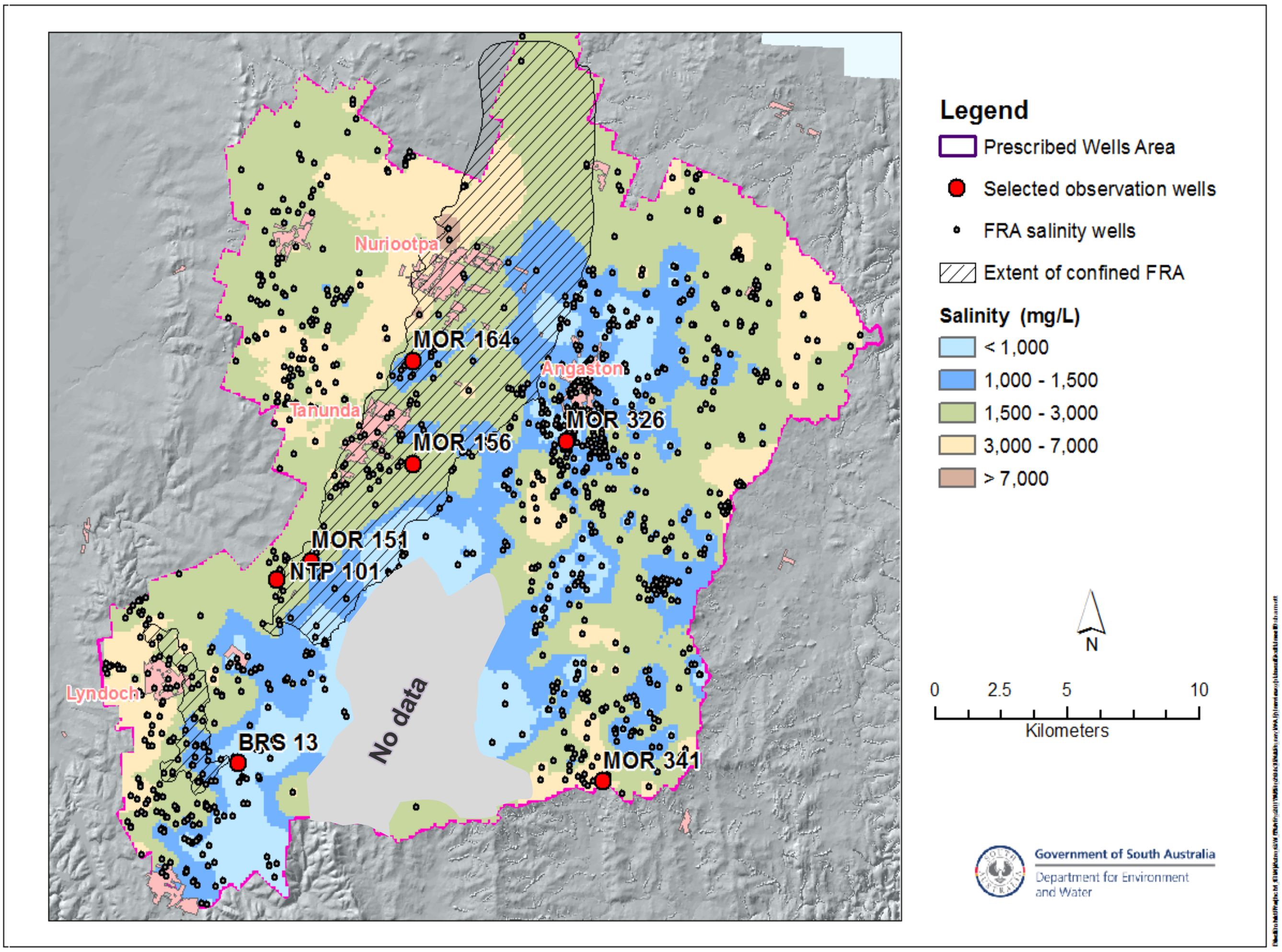


Figure 29. Salinity distribution for the FRA aquifer in 2021

7.4 Salinity trends

Figure 30 shows long term trends from four representative irrigation wells in the unconfined FRA (locations shown in Figure 29) which indicate that trends are stable in areas of low salinity where recharge is high; however, in higher salinity areas where recharge is less reliable, some rising trends are evident. This most likely reflects local conditions and the fact that salinity often increases with depth in fractured rock aquifers with increased extraction in drier years may draw on this deeper more saline resource.

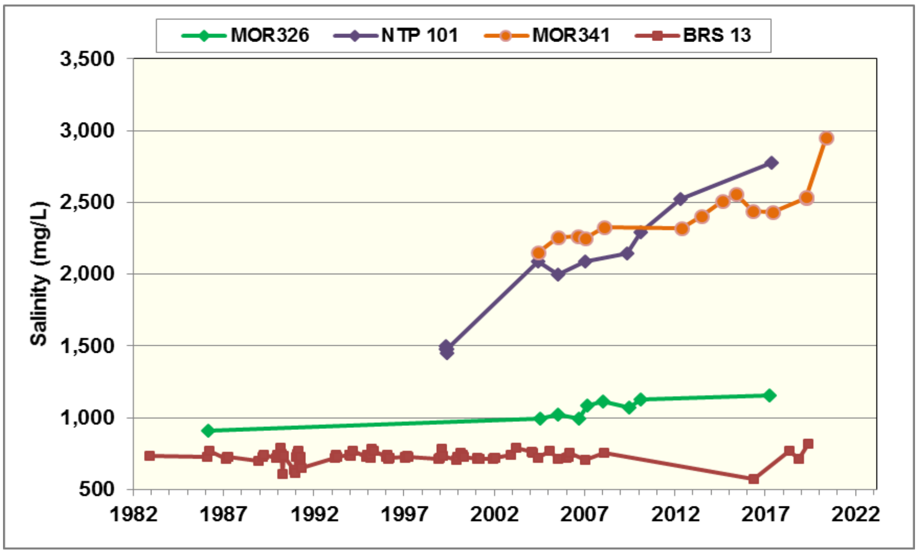


Figure 30. Long term salinity trends for the unconfined FRA aquifer

The long term salinity trends which are presented in Figure 31 for representative irrigation wells in the confined FRA (locations shown in Figure 29) are relatively stable overall with some rising and falling trends for some periods.

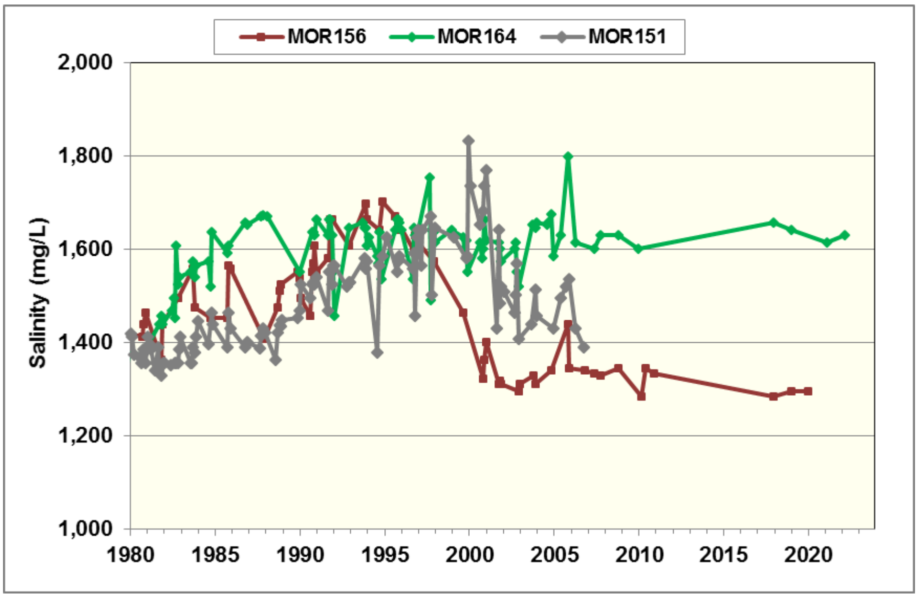


Figure 31. Long term salinity trends for the confined FRA aquifer

8 Influences on water level trends

An assessment of the main drivers of groundwater level trends can contribute to a discussion of appropriate management responses to declining water levels and climate change. For the aquifers in the Barossa PWRA, the possible influences on groundwater levels are the inputs to the groundwater system (rainfall, infiltration of streamflow, lateral inflow) and the outputs (extraction and natural discharge). The water level trend reflects the state of balance between these two components: if the inputs are greater than the outputs, water levels will rise and vice versa. As far as the outputs are concerned, it should be noted that extraction generally occurs intermittently during the summer months, whereas natural discharge (lateral outflow, evapotranspiration) is a continuous process that occurs all year round.

Groundwater monitoring began in 1975 and so the influences of the various drivers on water levels can only really be analysed since that time.

Rainfall

Rainfall provides recharge to unconfined aquifers. Recharge cannot be measured directly and estimates of the volume of recharge have very large uncertainties. As was discussed earlier in this report, there has been generally below average rainfall since 1955 except for wet periods in 1975, 1992, 2005, 2011 and 2016. Figure 32 presents the rainfall cumulative deviation for Tanunda since 1975 which emphasises the below average trend. Since 1975, the accumulated deficit is 1200 mm below average.

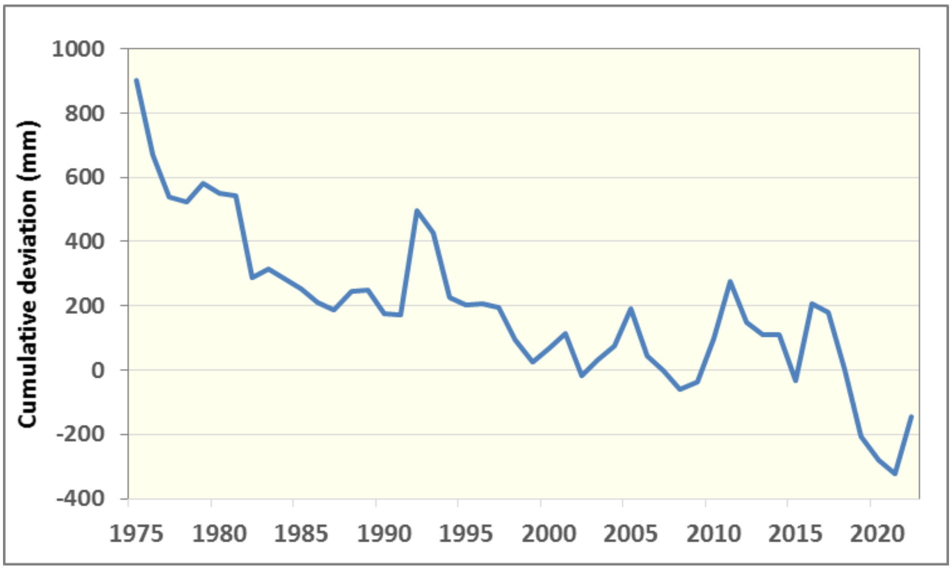


Figure 32. Rainfall cumulative deviation for Tanunda since 1975

Streamflow

Although streamflow is ultimately driven by rainfall, there are other factors (such as the timing and intensity of rainfall) that can result in streamflow trends being slightly different from rainfall trends. Figure 33 shows the North Para River flow volumes recorded at Yaldara. A marked reduction in flows appears to have occurred after both the 1992 and 2016 wet years.

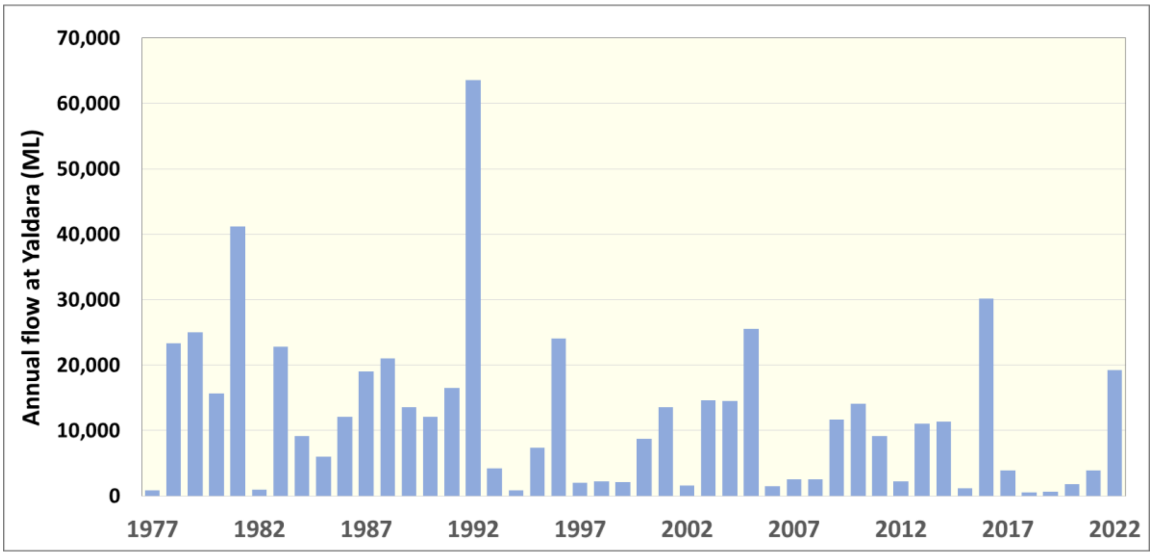


Figure 33. North Para streamflow at Yaldara

Extraction

Metered extraction has only been available since 2003-04 as shown in Figure 34. Although the trend is broadly stable, there are annual variations based on climatic variations. Irrigation demand is reduced during wetter years, especially if significant rainfall occurs during the irrigation season. Significant reductions of up to 60 % have occurred in some years. Conversely, demand increases during dry years when the irrigation season is lengthened, as demonstrated by higher extractions during 2018-19.

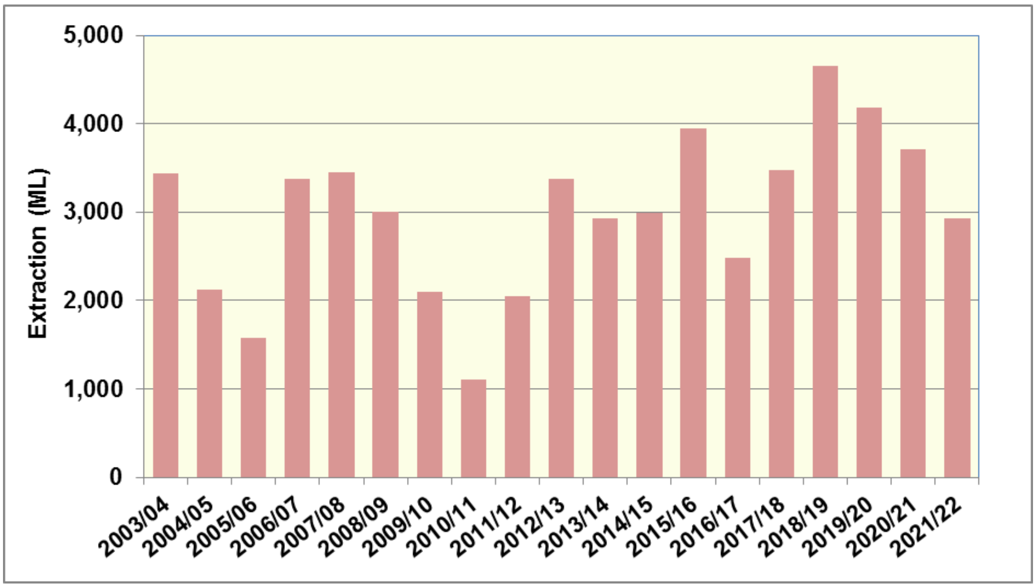


Figure 34. Metered extraction for all aquifers in the Barossa PWRA

The influence that extraction has on water level trends is dependent on several factors, including the type of aquifer (unconfined or confined), the permeability of the aquifer, the timing of irrigation and how closely the irrigation wells are located.

Because the groundwater in the Barossa PWRA is applied to vineyards by drip irrigation, the volume and intensity of extraction is much less than other prescribed areas where more extensive irrigation is carried out e.g., in the Mallee PWA where irrigation of vegetables is carried out by centre-pivot irrigation. Table 1 below compares the volume and intensity of extraction from the Barossa PWRA aquifers with irrigated areas in other prescribed areas with different crops and methods of irrigation.

The intensity of extraction is derived by dividing the extraction volume by the area over which it is taken.

Table 1. Comparison of extraction volumes and intensity

Area	Extraction (ML/yr)	Intensity (ML/yr/km^2)	Irrigation type
Barossa (Upper)	234	10.6	Drip on vineyards
Barossa (Lower)	1260	9.9	Drip on vineyards
Barossa (FRA)	480	12.9	Drip on vineyards
Mallee	15,076	25.3	Centre-pivot on vegetables
NAP	11,800	23.3	Sprinkler on vegetables
Tintinara	14,693	36.4	Flood, pivot on pasture
Padthaway	39,508	55.6	Flood, pivot, drip

The lower volume and intensity of extraction in the Barossa PWRA would result in less significant impacts on water level trends than might be expected in other prescribed areas.

This assessment accounts for the influence of the total extraction from each aquifer. Generally, management interventions result in a reduction in extraction that is considerably less than 100 %.

8.1 Upper aquifer

The hydrographs of observation wells closest to the main area of extraction along the North Para River are presented in Figure 35 together with the streamflow and extraction. The water levels do not show a close relationship with extraction, although a broad indirect correlation is apparent whereby in wet years, a rise in the watertable results from an increase in recharge. These wet years also cause a reduction in irrigation demand and extraction, but this does not automatically result in a regional watertable rise in an unconfined aquifer (otherwise there would be widespread rising watertables in areas where no extraction occurs). During the periods 2013-15 and 2019-21 highlighted in the graph, there is a decline in water level at the same time as a reduction in extraction. Overall, there appears to be a gradual long term trend of declining extraction.

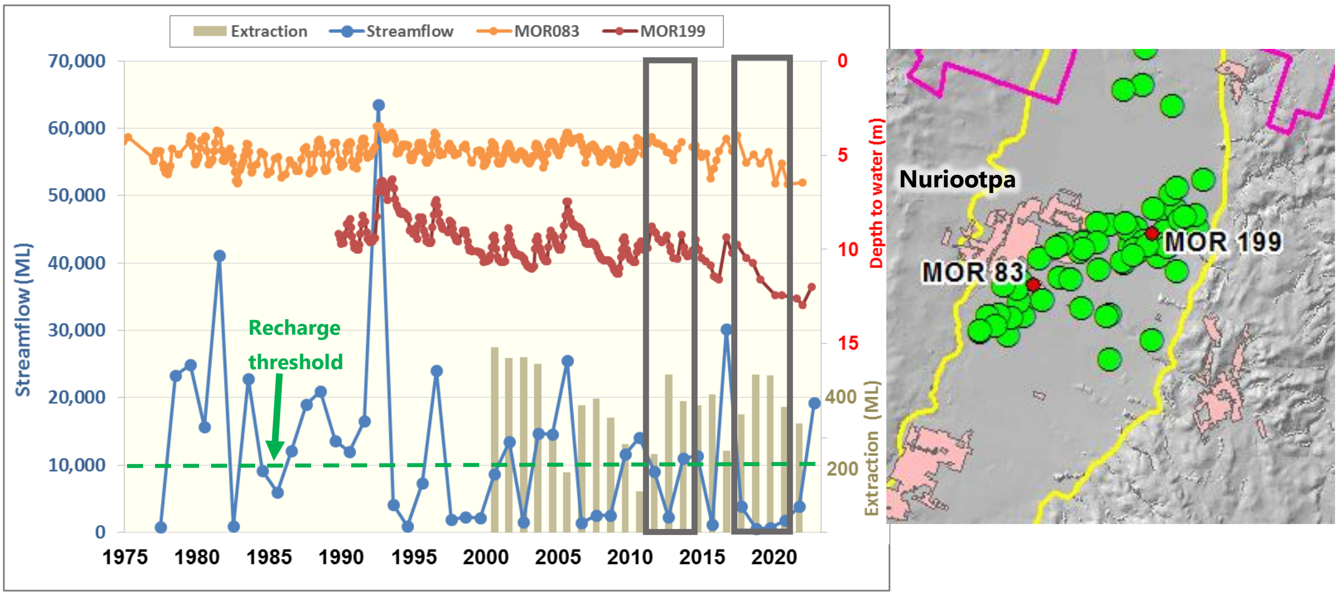


Figure 35. Comparison of Upper aquifer water level trends with streamflow and extraction

Figure 35 also shows the reasonably close relationship between streamflow and watertable levels indicating the importance of recharge through the stream bed. This volume of recharge is estimated to average about 560 ML/yr (Cranswick et al, 2015) which is a similar order of magnitude to the annual extractions from the Upper aquifer. Figure 35 highlights that watertable levels are maintained when the streamflow exceeds around 10,000 ML, but decline when flows are below this threshold as a result of natural discharge and extraction to a lesser extent. these declines, especially since 2016.

8.2 Lower aquifer

As this is a confined aquifer not directly recharged by rainfall, extraction is a major driver of pressure level changes, particularly the magnitude of the seasonal drawdowns during the irrigation season. However, climate can influence the level of recovery in pressure levels as shown in Figure 36. If a wet spring occurs, extraction will commence later than normal, allowing levels to recover to a higher than normal level. Conversely, a dry spring will encourage an early start to the irrigation season resulting in a lower than normal recovery level.

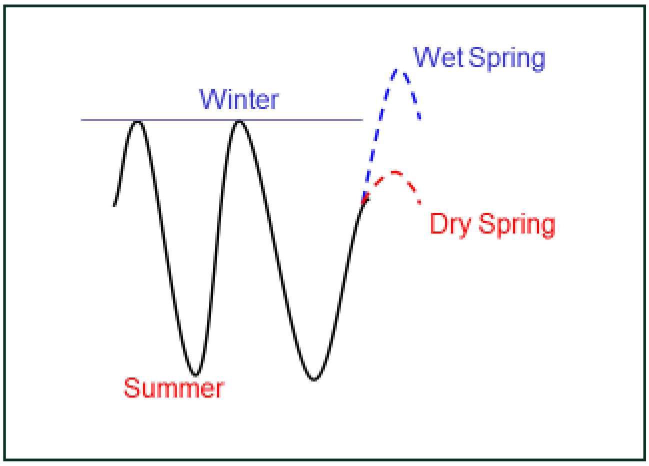


Figure 36. Influence of climate on recovered pressure levels

Another possible contributor to pressure level trends is hydrostatic loading. This process has been observed in other sedimentary basins (Barnett, 1995, 2008) and occurs when for example, a declining watertable results in less water being stored in the unconfined aquifer, and consequently less weight pressing down on the confining layer. This reduced weight decreases the hydrostatic pressure on the underlying confined aquifer and causes pressure levels to decline. This process may have contributed, in small part, to the recent decline in pressure levels which mirror trends in the overlying unconfined aquifer.

8.3 Fractured rock aquifer

Figure 37 shows the water level trends from various unconfined FRA observation wells, the rainfall trend and metered extraction. Three wells are located some distance away from any licensed extraction (MOR 240 – 2 km, MOR 282 – 0.8 km, MOR 265 – 0.5 km) and could be considered to be minimally affected by pumping. They show a close relationship with rainfall, especially in recent years since 2017. Well MOR 257 (plotted in red) is located adjacent to an area of concentrated pumping immediately south of Angaston and displays very similar trends with the other wells and also a very close relationship with rainfall. It does not show a close relationship with extraction, although as with the unconfined Upper aquifer, a broad indirect correlation is apparent whereby in wet years, a rise in the watertable results from an increase in recharge even though a reduction in irrigation extraction also occurs. During the periods 2007-09 and 2019-21 highlighted on the graph, there is a decline in water level at the same time as a reduction in extraction. Figure 37 shows that proximity to extraction shows no significant impact on groundwater level trends and that natural discharge processes predominate.

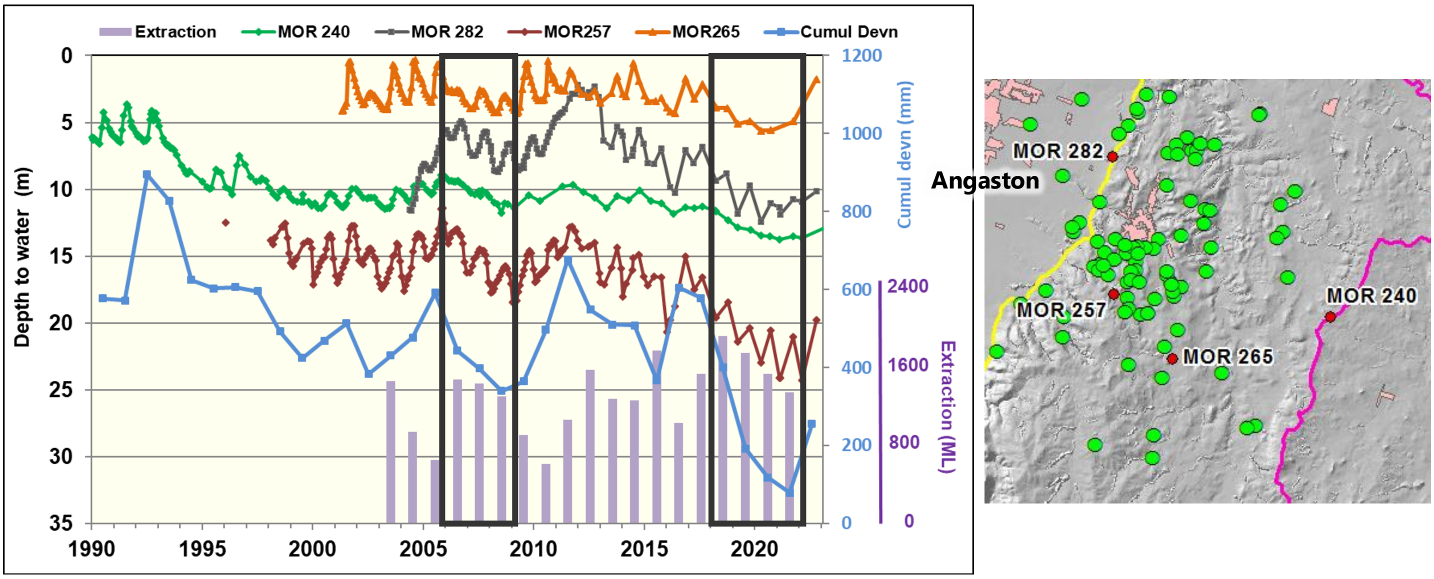


Figure 37. Comparison of FRA water level trends with rainfall

8.4 Lyndoch Alluvial aquifer

Although pumping would normally be the dominant influence in a semi-confined aquifer, the low volumes of extractions and the broad relationship to rainfall may suggest an influence from streamflow recharge. Unfortunately there is no stream gauge on the Lyndoch Creek, but the water level declines have a similar trend to streamflow in the North Para River (Figure 33). Lateral flow within the aquifer from south to north is probably a major influence.

8.5 Summary

Upper aquifer

In the area of concentrated pumping, groundwater levels are controlled by recharge from streamflow in the North Para River, which in turn is strongly dependent on rainfall. Away from the influence of losing streams, rainfall is the dominant driver through diffuse recharge. There is no evidence that the current low volumes of extraction (300-400 ML/yr) have had a significant influence on water level trends, with recharge and natural discharge being prominent. Modelling predictions (Li and Cranswick, 2016) show that significant increases in extraction toward full allocation would increase the rate and magnitude of water level decline, and probably increase the recharge threshold from streamflow required to maintain water levels.

Lower aquifer

Extraction is a major driver of pressure level changes for this confined aquifer, particularly the magnitude of the seasonal drawdowns during the irrigation season. However, climate can influence the level of winter recovery in pressure levels by varying the start of the irrigation season, and in the medium to longer term, may influence recharge by lateral throughflow from the unconfined FRA.

Lyndoch Alluvial aquifer

Streamflow and lateral flow within the aquifer are the main drivers of water levels trends with the small volume of extraction being a minor contributor. However, given the declines in groundwater pressure of 10 -15 m since the late 1980s (Figure 20), there is a risk that use of full allocation could result in the groundwater pressure level declining below the confining clay (Figure 16) which would result in this aquifer becoming unconfined in the timeframe of the next Water Allocation Plan .

Fractured Rock aquifer

Monitoring data strongly suggests that rainfall is the predominant driver of water level trends in the unconfined portion of the aquifer. There is no evidence that current extraction levels (1500-2000 ML/yr) have a significant influence, with recharge and natural discharge being prominent. Significant increases in extraction are unlikely to change this situation due to the complex and compartmentalised nature of the FRA. The confined portion of the aquifer has similar drivers as the confined Lower aquifer.

9 Sustainability issues

9.1 Upper aquifer

9.1.1 Connection with surface water and/or GDEs

As the Upper aquifer is unconfined, it receives recharge from rainfall as well as infiltration from streamflow from the North Para River and tributaries where they cross the Barossa Valley floor. Downstream of Nuriootpa, this aquifer discharges to the North Para River and is likely to support GDEs (permanent pools) in some locations. A closer examination of the location of licensed wells and their likely interaction with GDEs is presented in Appendix A and shows that the risks to GDEs from licensed extraction is low at current pumping levels. This risk will not significantly increase if extractions were to increase because of the generally low yields and the distance of the licensed wells from the GDEs.

9.1.2 Water level declines

As has been discussed in the previous section, water level declines of about 2-3 m in the area of heaviest extraction along the North Para River have only occurred over the last few years in response to low streamflow. The saturated thickness of the Upper aquifer in this area is currently about 35 m, with a conservative estimate of 3000 ML stored in the aquifer. These recent declines represent a decrease in storage of less than 10 %. Elsewhere in areas of little extraction, water level declines of up to 5 m over the last 45 years have mirrored rainfall trends. In both cases, the declines are predominantly driven by climate and natural discharge, but not significantly by extraction. Management intervention to prevent these trends from worsening should involve reducing the potential for significant increases in extraction above current levels.

9.1.1 Climate change

Because the water level trends show a relationship with rainfall as well as streamflow, the Upper aquifer could be considered sensitive to climate change. A warmer and drier climate could increase demand for irrigation. Even though the Upper aquifer is robust with a large storage capacity, it could be vulnerable to climate change if the increase in demand led to significant increases in extraction without any management control.

9.2 Lower aquifer

9.2.1 Depressurisation of the confined aquifer

In other prescribed areas in South Australia, maintaining pressurisation within the confined aquifers (i.e., not allowing the confined aquifer to become unconfined), has been a management objective. This process of depressurisation reduces the hydrostatic pressure supporting the confining layer on top of the confined aquifer 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.

Presently in the centre of the valley where extractions are concentrated, the recovered winter pressure level at current extraction rates varies from 10 to 30 m above the top of the confining layer with the Lower aquifer remaining fully saturated. However, if extractions increase toward full allocation, depressurisation will be an issue to be closely monitored and may warrant measures to restrict extraction ~~i.e., allocation restrictions~~.

9.2.2 Salinity increases

Some wells along the western margin of the Lower aquifer between Nuriootpa and Tanunda have shown gradual rising trends since 2005, most likely because of upward leakage from the underlying confined FRA which lies at relatively shallow depths. Generally, the affected wells are completed just above the FRA. Trends appear to be stabilising in some wells but further monitoring is needed to confirm this.

9.2.3 Climate change

As the pressure level trends show little relationship with rainfall, the Lower aquifer could not be considered sensitive to climate change. However, as with the Upper aquifer, a warmer and drier climate could increase demand for irrigation. Because the Lower aquifer is robust with a large storage capacity, it would not be considered vulnerable to climate change over the next 20-30 years.

9.3 Lyndoch Alluvial aquifer

9.3.1 Water level declines

There has been a gradual decline in water levels of 10–15 m over the last 30 years. This represents a decline in pressure in the semi-confined basal gravel aquifer which is still fully saturated. The estimated storage within the basal aquifer is a conservative 1000 ML (excluding the elastic storage resulting from pressurisation of the aquifer). If annual extractions remain at about 50 ML/yr, the risk of physical depletion of the aquifer over the next 20-30 years is very low, however there is a risk of this confined aquifer becoming unconfined.

9.3.2 Salinity increases

Isolated increases in some irrigation wells have been observed as a reflection of individual well construction and localised upward leakage from the underlying confined FRA. Extraction at lower pumping rates over a longer period or improved well construction or rehabilitation may mitigate this issue.

9.3.3 Climate change

Because the water level trends show a broad relationship with streamflow, the LA aquifer could be considered sensitive to climate change. The declines are predominantly driven by climate and natural discharge (lateral flow), but not significantly by the small volumes of extraction.

9.4 Fractured Rock aquifer (unconfined)

9.4.1 Connection with surface water and/or GDEs

The FRA discharges directly into the North Para River and its tributaries in the upland area of the Flaxman Valley and on the western margin of the Barossa Valley floor and downstream to the Yaldara Weir (Cranswick et al, 2015).

These watercourses are ephemeral which means they do not flow in summer, which is when irrigation extractions occur. If there is no flow, there is no baseflow that would be affected by extraction, even if significant extraction occurred close to the watercourses. However, there are permanent pools that are assumed to be maintained by connectivity with the FRA. A closer examination of the location of licensed wells and their likely interaction with these pools is presented in Appendices A and B. So while the risks from licensed extraction can be considered low because of the limited number of operational irrigation wells within 250 m of the pools, further investigation which is beyond the scope of this report, is needed to confirm this.

9.4.2 Climate change

Because the water level trends in the unconfined FRA show a strong relationship with rainfall, it could be considered sensitive to climate change. A long term gradual decline in water levels that would result from a drying climate could lead to the dewatering of joints and fractures and a reduction in well yields. A reduction in recharge could result in reduced freshening of the aquifer and gradual increases in salinity. The unconfined FRA could therefore be classified as vulnerable to climate change in the long term. Given the localised impacts of extraction, management actions are highly unlikely to mitigate this risk on a regional scale, but may only have a small impact on water level responses in individual irrigation wells.

9.4.3 Salinity increases

Rising salinity trends have been observed in some irrigation wells in response to extraction from those individual wells which reflects local geology and groundwater conditions. Extraction at lower pumping rates over a longer period, or lower rates through multiple wells appropriately spaced may mitigate this issue.

9.5 Fractured Rock aquifer (confined)

Depressurisation is not an issue for the confined FRA because the confining layer is the weathered clayey portion of the top of the consolidated fractured rock which provides structural support against collapse. The long-term monitoring trends show no significant current sustainability issues for the confined FRA in terms of declining water levels or increasing salinity. As the pressure level trends show little relationship with rainfall, the confined FRA would not be considered as highly sensitive to climate change.

10 Summary and recommendations

This assessment of the groundwater level, salinity and extraction trends in the Barossa Prescribed Water Resources Area (PWRA) and potential sustainability issues was carried out to inform a review of the Water Allocation Plan. An analysis of the drivers of water level changes was also undertaken.

Overall, extraction trends in all aquifers have been relatively stable over the last 10 – 15 years, apart from annual variations caused by changes in rainfall. However, the last three years (to 2021) of significantly below average rainfall has resulted in decreased recharge and increased extractions which, along with natural discharge, have contributed to declines in water levels in all aquifers. Salinity levels are generally stable, except for small areas of the Lower aquifer where rises have occurred due to the probable upward leakage of more saline groundwater from underlying layers. These areas require further monitoring to confirm trends and the likely source of the salinity.

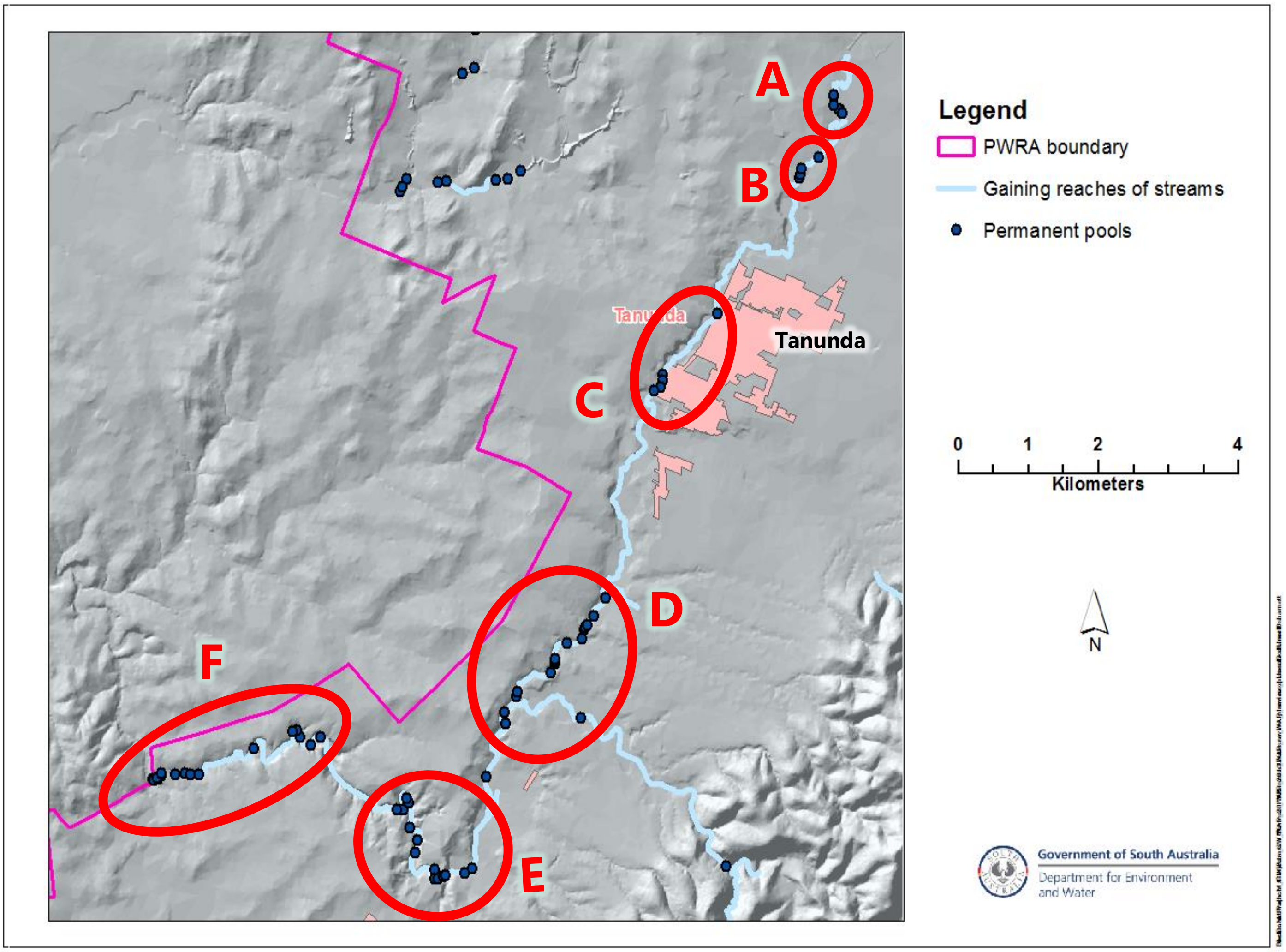
While it is recommended that current allocation levels can remain unchanged, there are sustainability risks from a significant increase in extraction, such as declines in storage and confined aquifer depressurisation. It is recommended that resource extraction limits be established and an adaptive "trigger-level" approach be adopted which can limit the volume of water that can be extracted (allocation) within a consumptive pool during periods when the resource is at higher risk. Buffer zones around existing licensed wells and permanent pools are also recommended to protect them from impacts due to the drilling of new extraction wells.

In the future, should sustainability issues arise or as part of a future review of the Water Allocation Plan, further investigations should occur and may be cause for the generation of new management zones or consumptive pools to manage issues in an appropriate, effective and targeted manner.

11 Appendix A

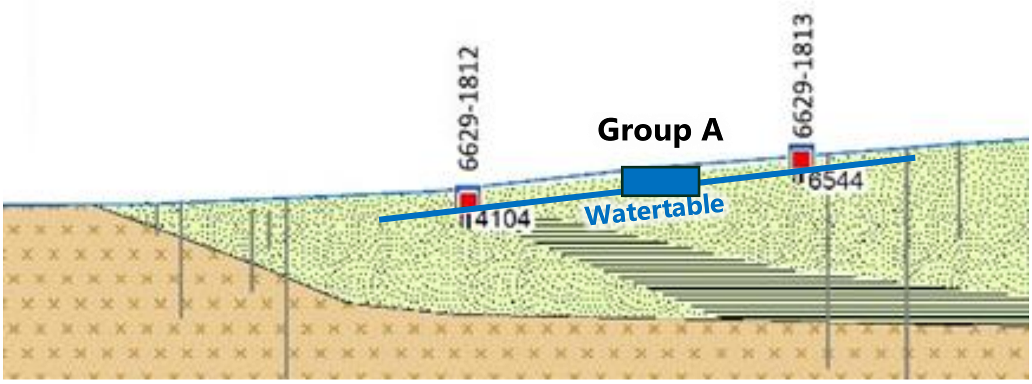
LOWLAND PERMANENT POOLS

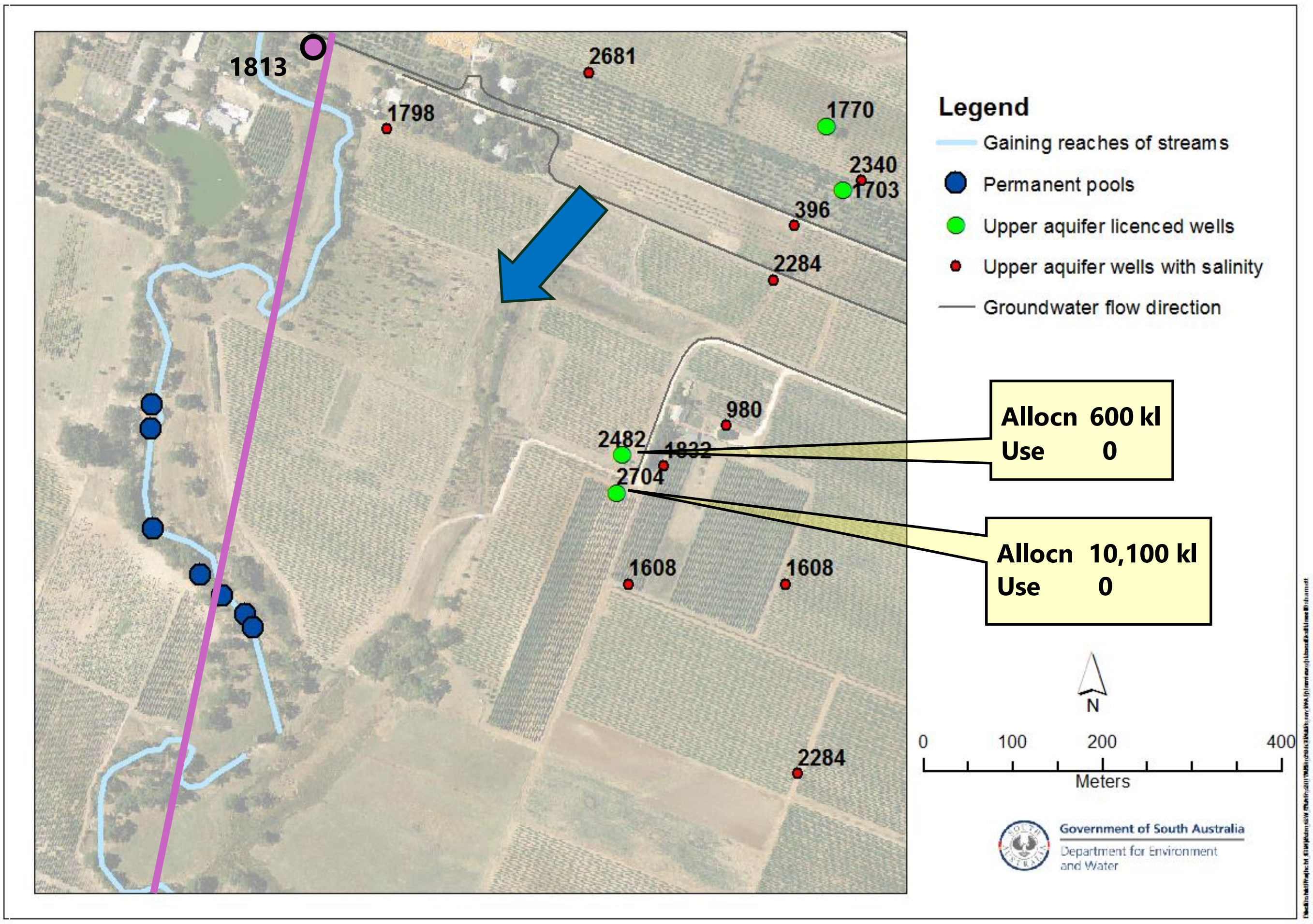
The map below shows the location of permanent pools on the valley floor and downstream reaches of the North Para River which have been grouped for convenience. Each group will be discussed in more detail, with the location of licensed and non-licensed wells shown. The status of the non-licensed wells is unknown. For each licensed well, the 2021 use and allocation is presented.



GROUP A

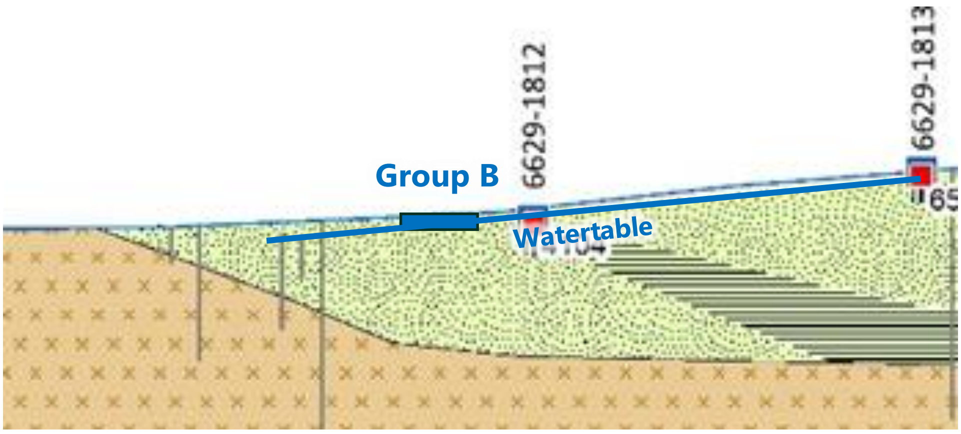
The north–south cross section along the river (displayed in purple) shows the pools are contained within the Upper aquifer which is about 25 m thick. Figure 3 shows salinities in the range 1500 to 2500 mg/L with groundwater flow to the southwest. There is no current extraction from the nearest licensed Upper aquifer wells which are 450m to the northeast.

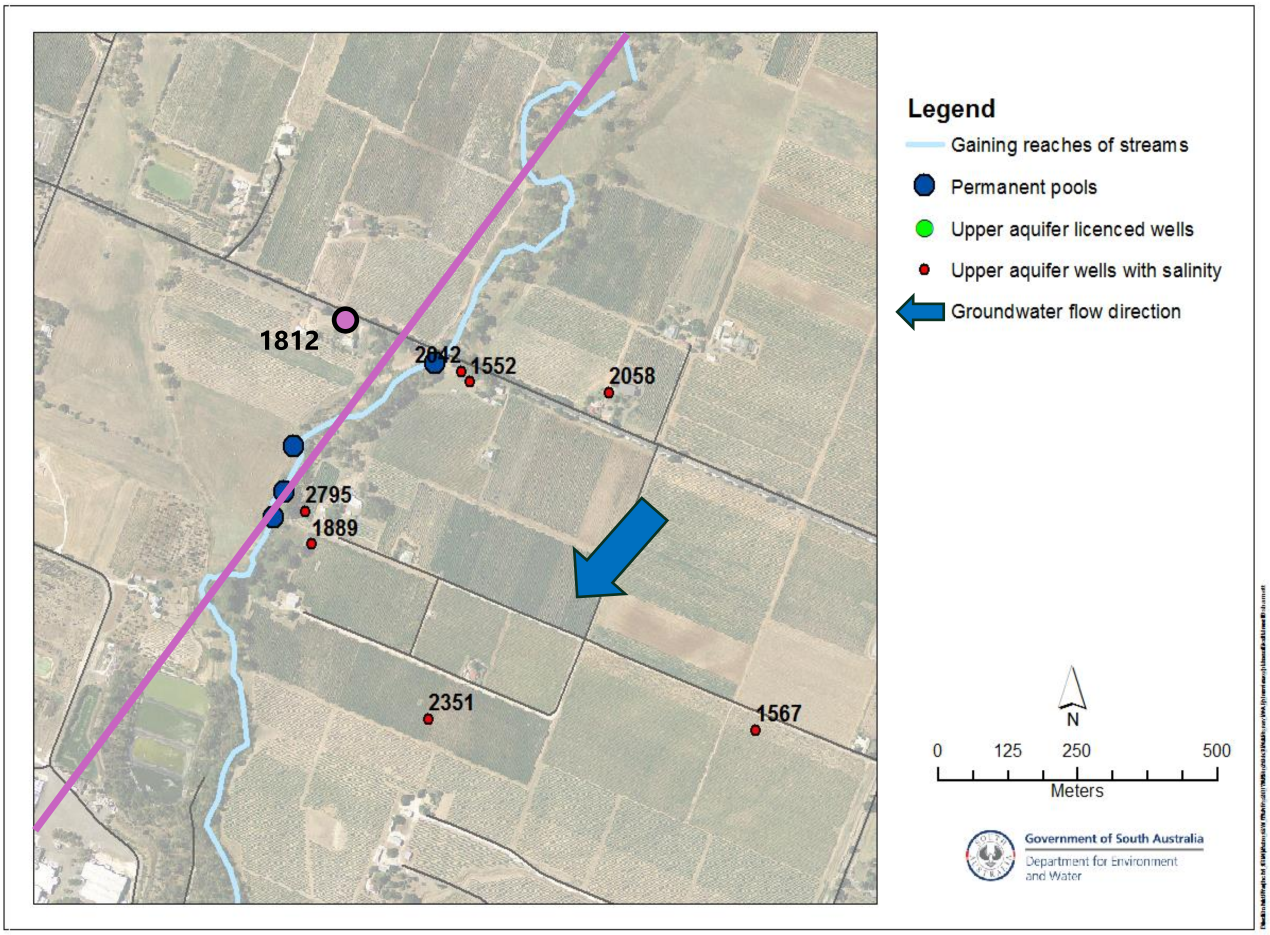




GROUP B

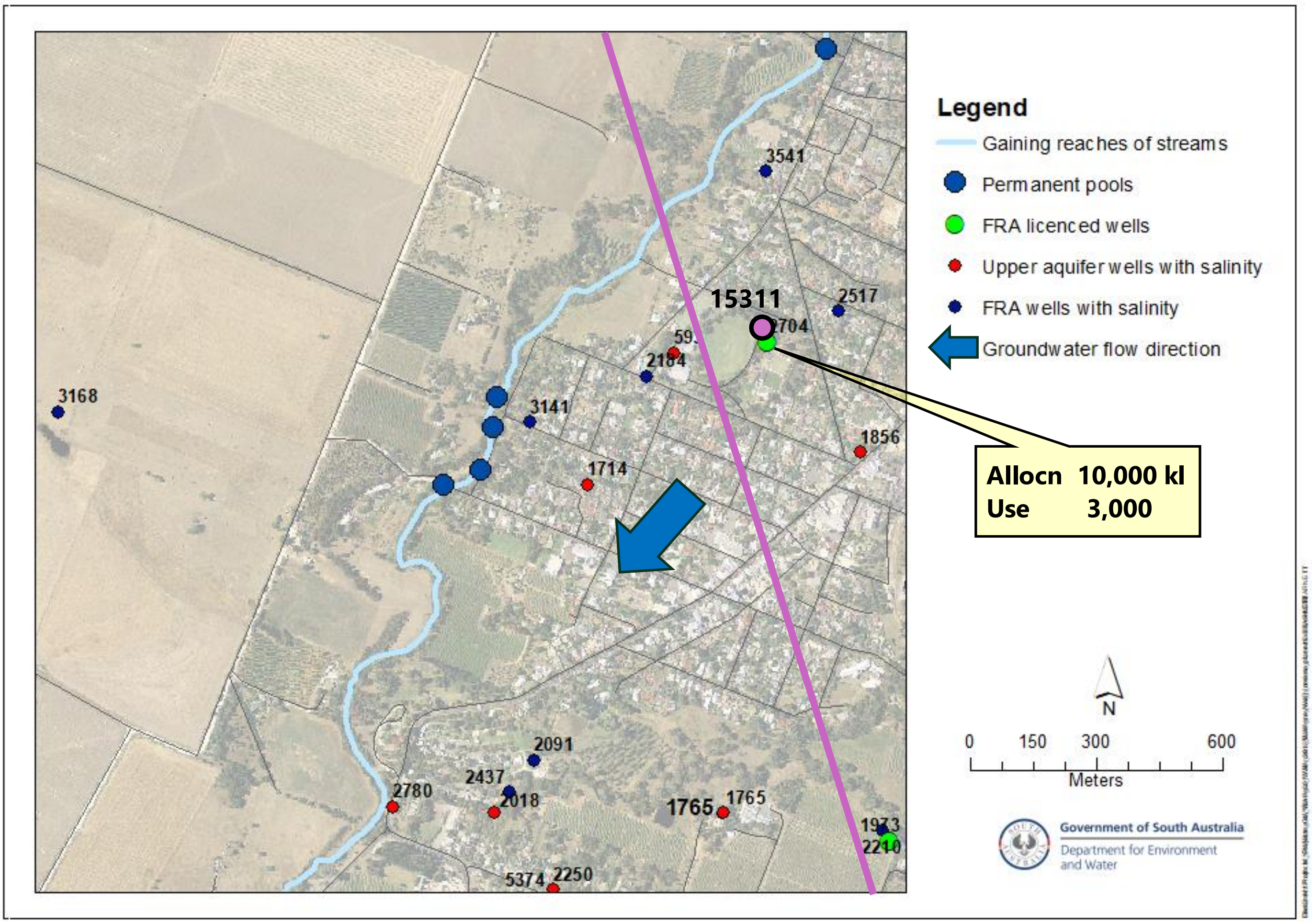
The north–south section along the river displayed in purple shows the pools are contained within the Upper aquifer which is about 10 m thick but thinning against rising basement to the west. The nearest licensed Upper aquifer wells are 1 km to the northeast, which is too far away to have any impact on the pools. Salinities in the range 2000 to 3000 mg/L with groundwater flow to the southwest.





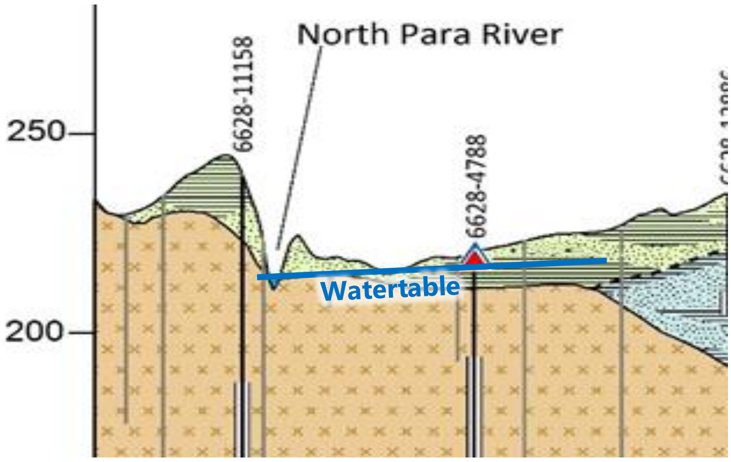
GROUP C

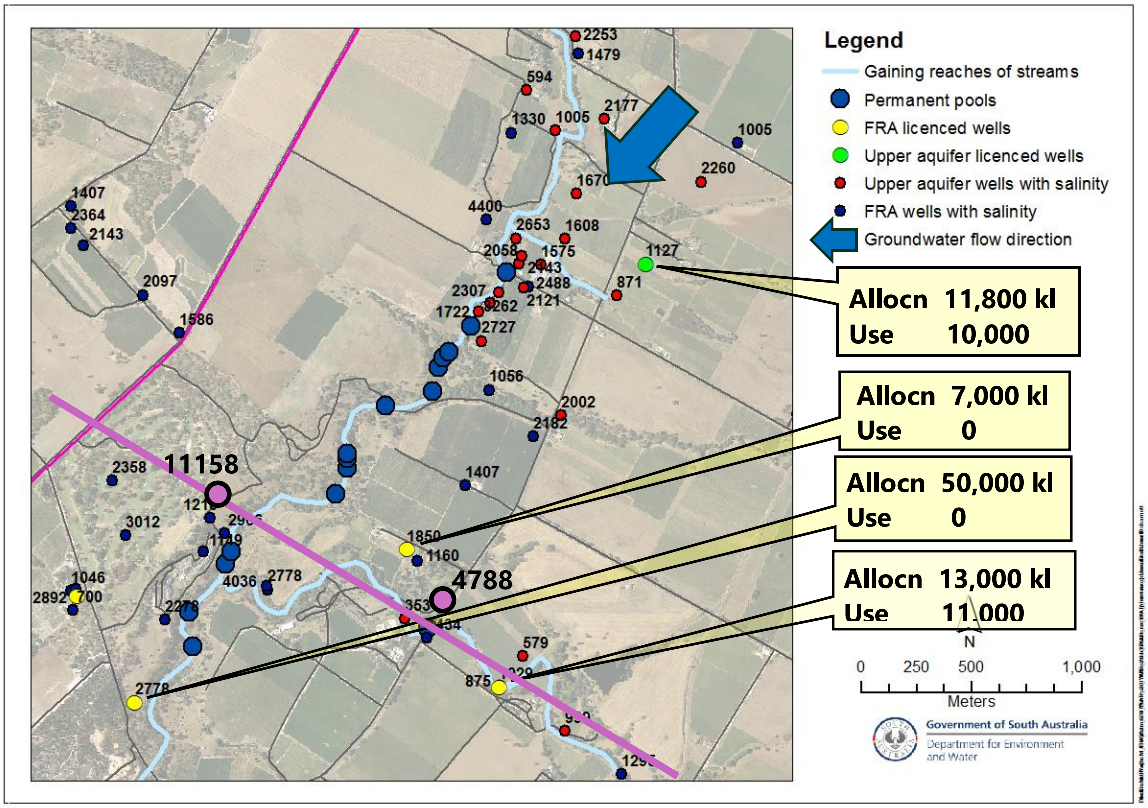
The southeast-northwest west section displayed in purple shows the permanent pools are contained within shallow alluvium adjacent to the fractured rock aquifer. The map shows the nearest licensed wells are 700 m away to the northeast in the FRA. The non-licensed FRA and alluvium/Upper aquifer wells are unlikely to be active because they are located in built up areas. Salinities in the FRA are around 2000 to 3000 mg/L and the alluvium/Upper aquifer salinities range from 5000 to 6000 mg/L. Groundwater movement appears to be toward the southwest. It is highly unlikely that there are significant impacts on the pools as a result of extraction.



GROUP D

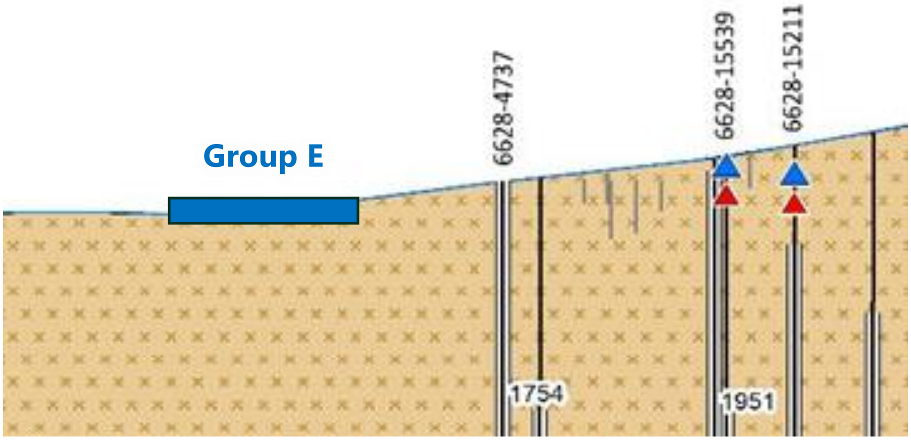
The east-west section displayed in purple shows the permanent pools are mostly contained within the fractured rock aquifer with some possible connection with the thin alluvium/Upper aquifer in the northern part. The location map shows the nearest Upper aquifer licensed well is 650 m away from the northern-most pool, while the nearest FRA licensed wells are about 450 m from various pools. Salinities in the FRA are around 1000 to 3000 mg/L and the alluvium/Upper aquifer salinities range from 1500 to 2500 mg/L. Groundwater movement appears to be toward the southwest. Due to the complex nature of fractured rock aquifers, it is likely that there are no significant impacts on the pools as a result of extraction. However it may be possible to test existing wells to estimate the likely zone of influence of FRA licensed extraction.

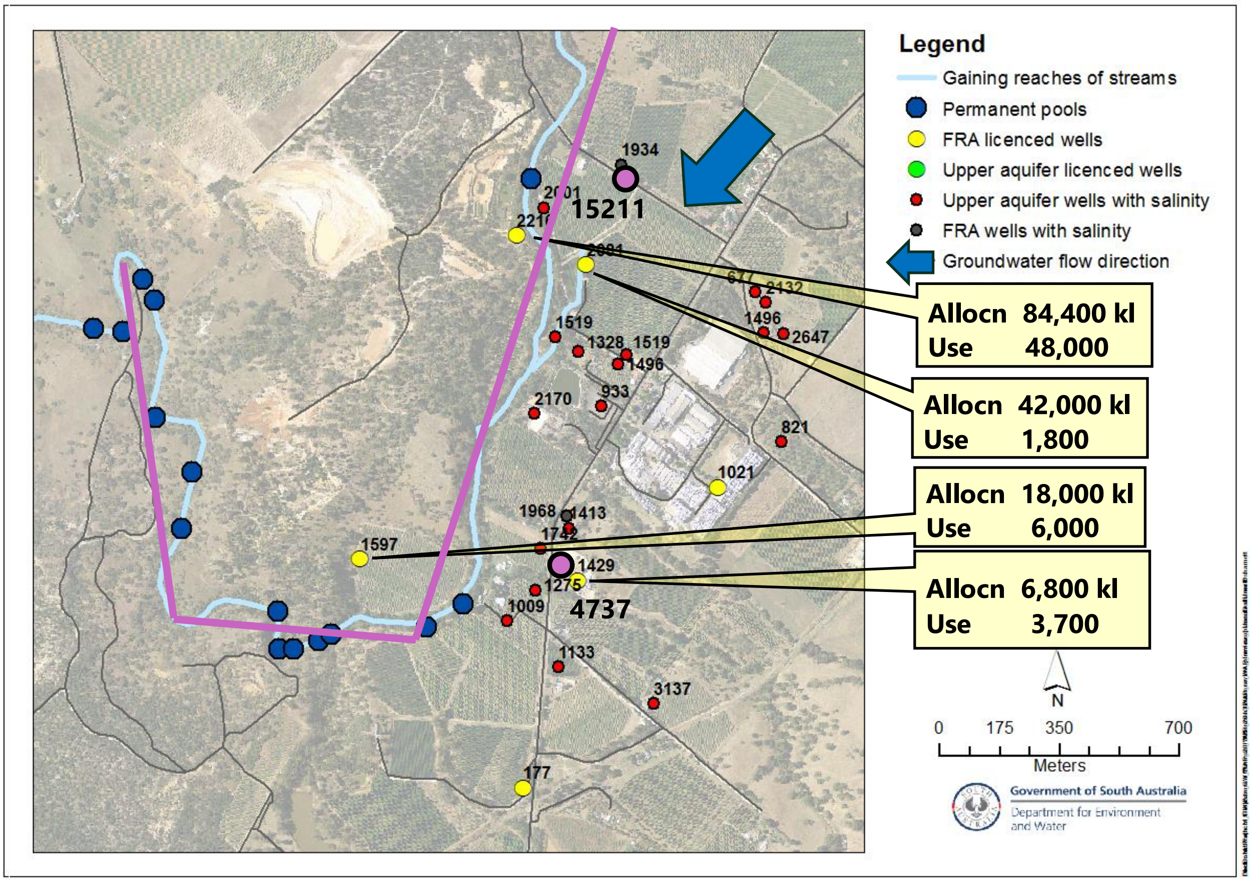




GROUP E

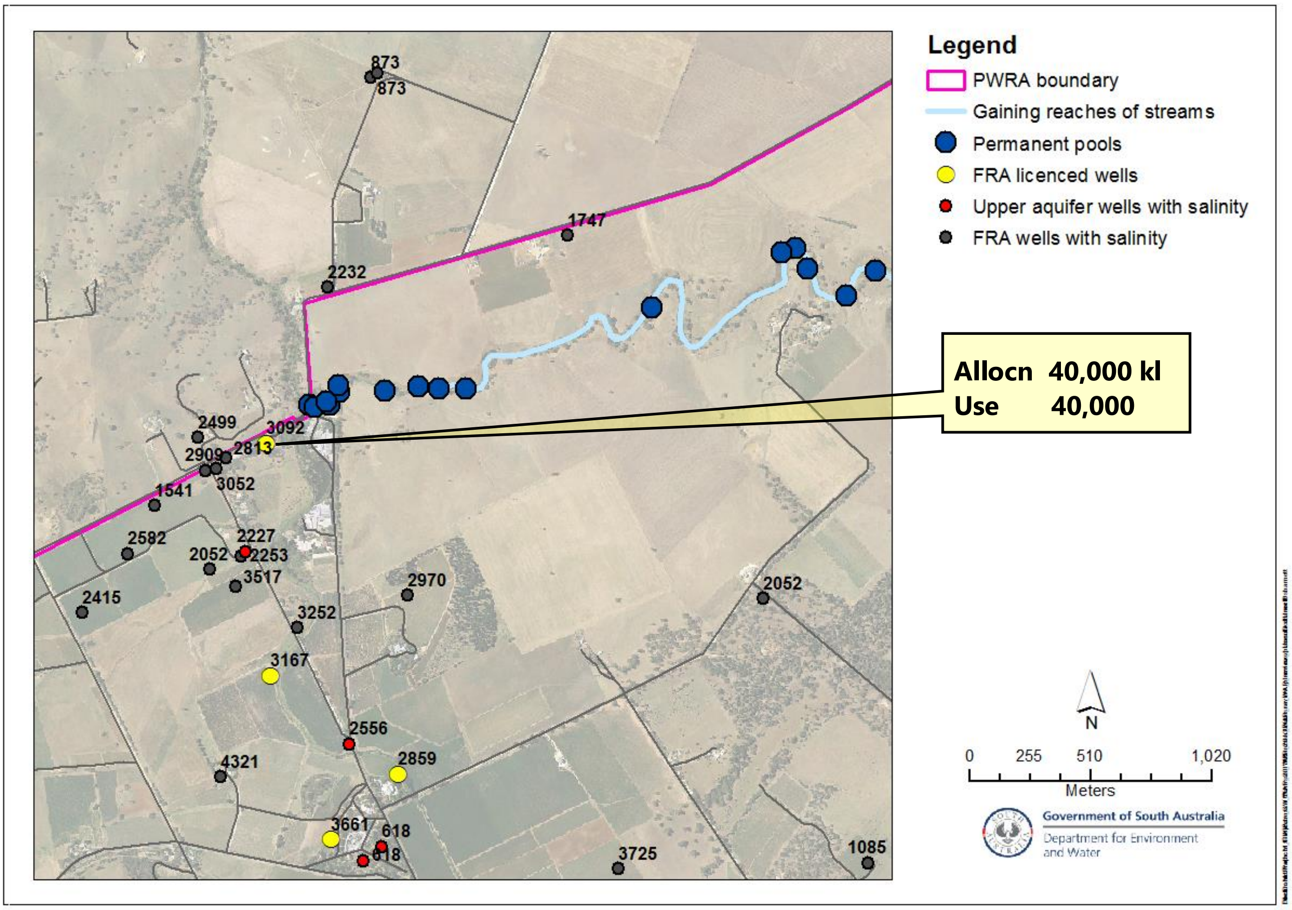
This cross-section along the river (in purple) shows the permanent pools are contained almost entirely within the fractured rock aquifer with some possible minor connection with the thin alluvium/Upper aquifer in the eastern part. The map shows the nearest FRA licensed wells are about 350 m from various pools in the east. Salinities in the FRA are around 1500 mg/L and the alluvium/Upper aquifer salinities range from 1000 to 1500 mg/L. Groundwater movement appears to be toward the southwest. Due to the complex nature of fractured rock aquifers, it is likely that there are no significant impacts on the pools as a result of extraction.





GROUP F

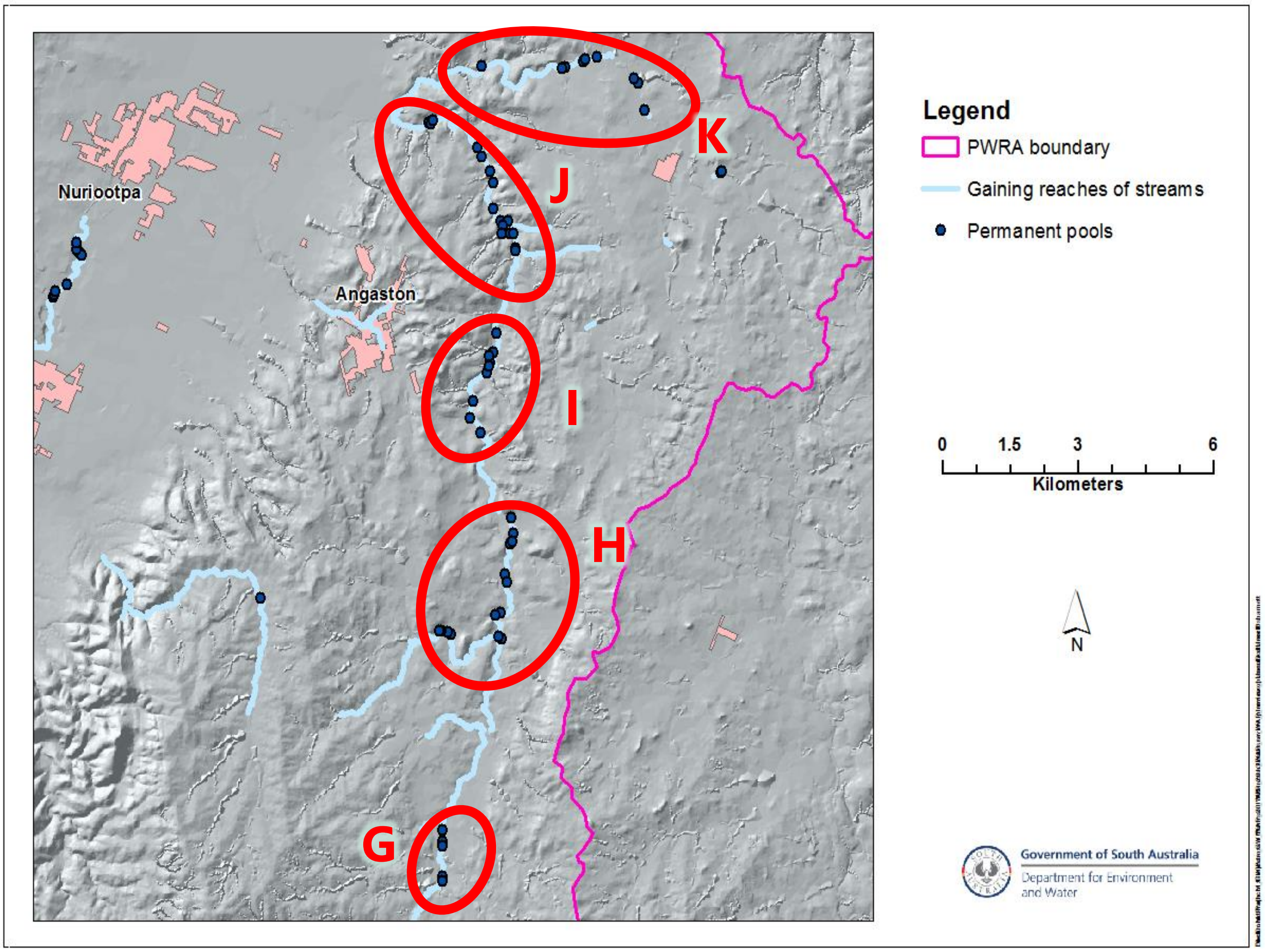
As with Group E, the permanent pools are contained entirely within the fractured rock aquifer whose salinities range from 2000 to 3000 mg/L. The nearest licensed FRA well is about 250 m from the pools at the Yaldara Weir. The status of the non-licensed FRA wells is unknown. It may be possible to test the extent of the zone of influence of this licensed well using other existing wells.



14 Appendix B

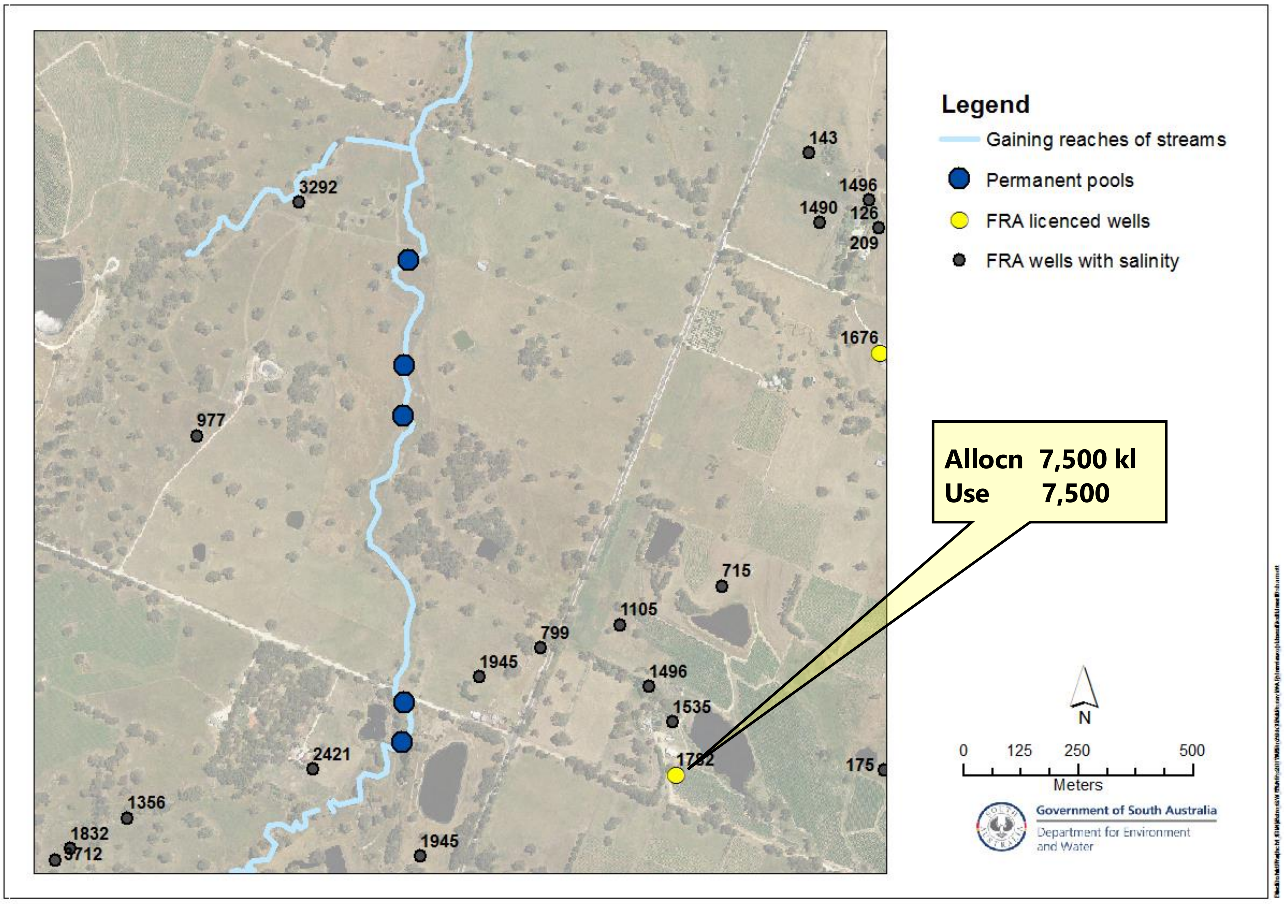
HIGHLAND PERMANENT POOLS

The map below shows the location of permanent pools in the highlands which have been grouped for convenience. All of these pools are connected to the FRA. Each group will be discussed in more detail, with the location of licensed and non-licensed wells shown. The status of the non-licensed wells is unknown. For each licensed well, the 2021 use and allocation is presented.



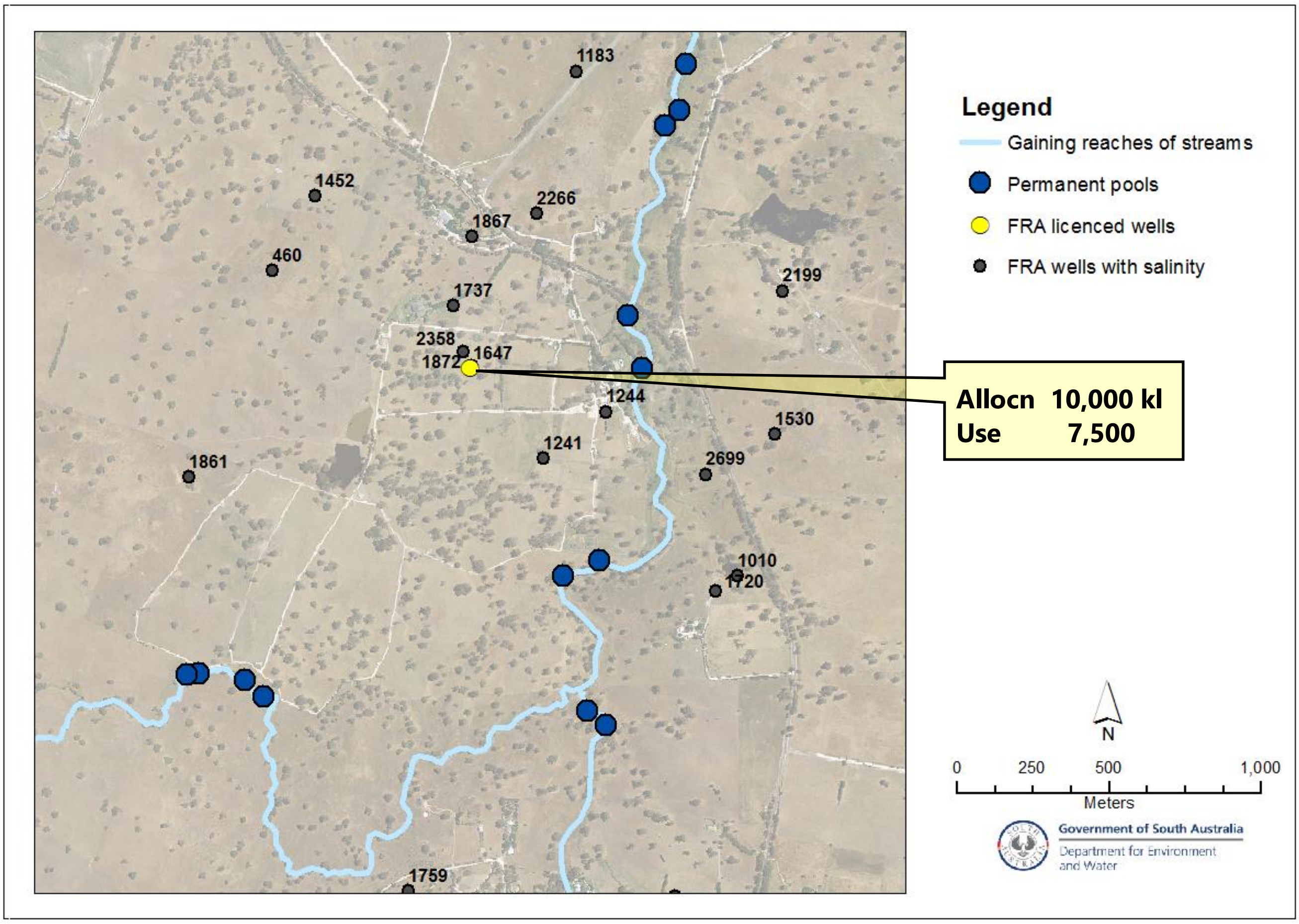
GROUP G

The nearest licensed FRA well is about 600 m from the pools. FRA salinities range from 1500 to 2500 mg/L. It is unlikely that licensed extraction would affect these pools from this distance.



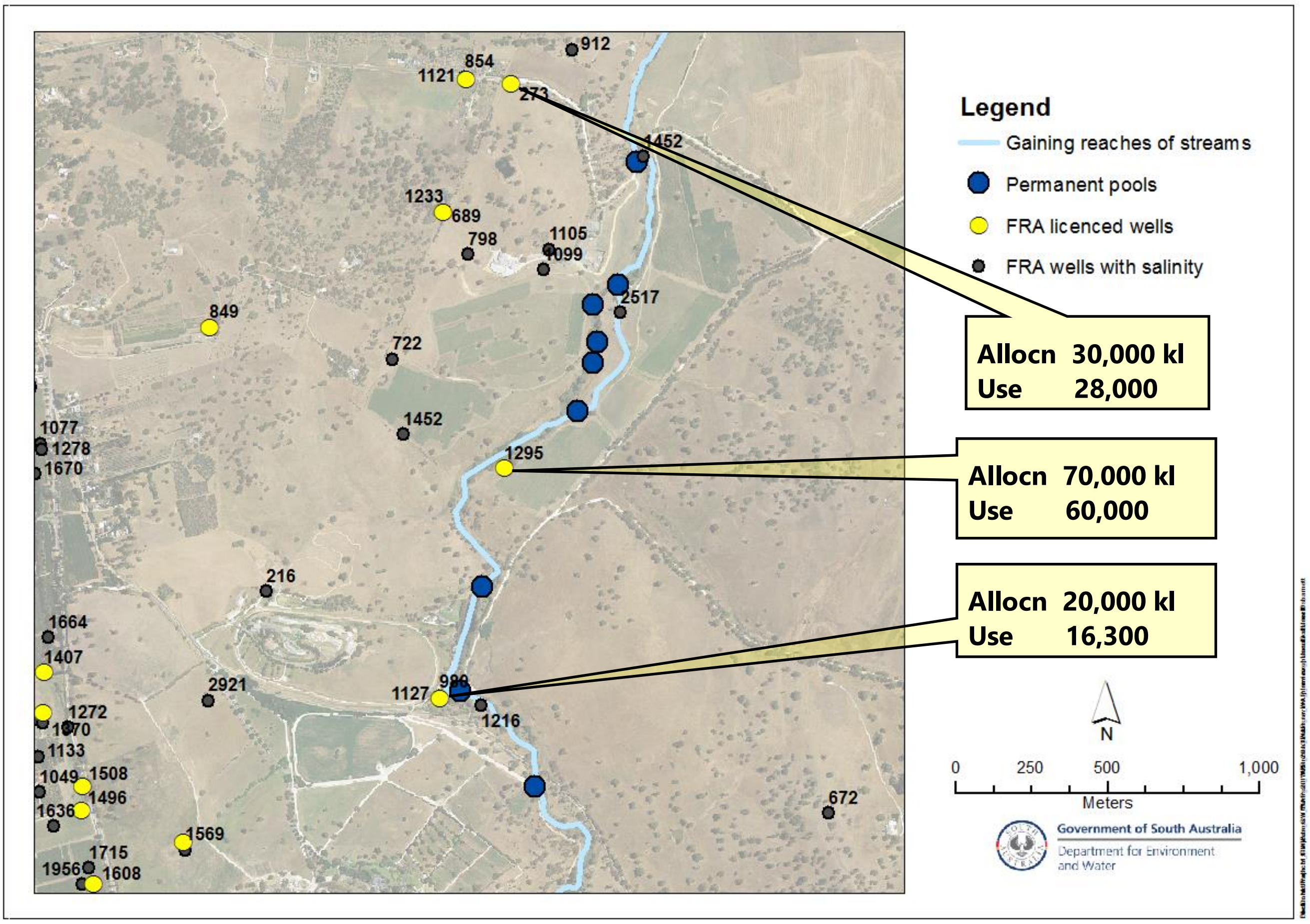
GROUP H

The nearest licensed FRA well is about 550 m from the pools. FRA salinities range from 1500 to 2500 mg/L. It is unlikely that licensed extraction would affect these pools from this distance.



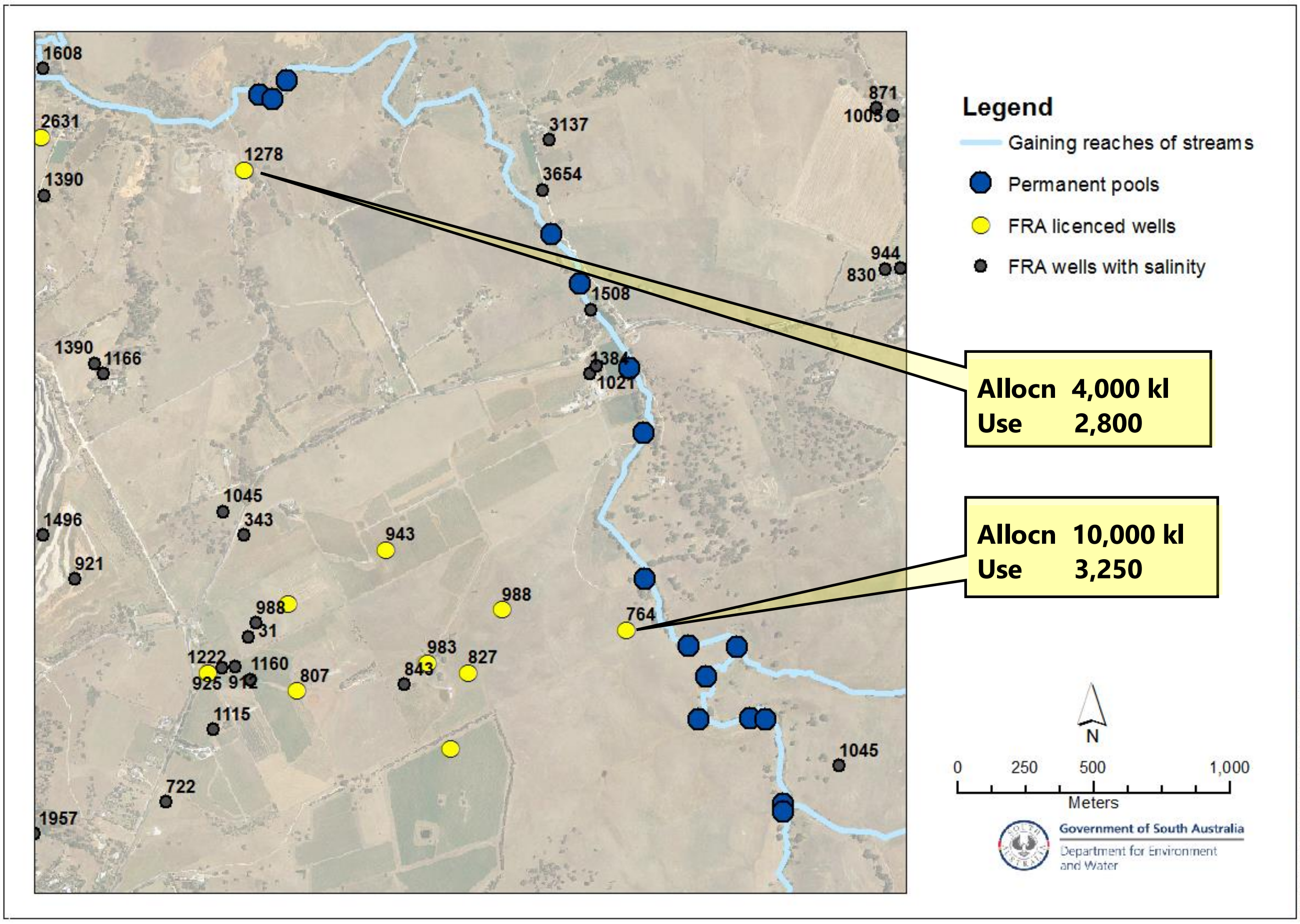
GROUP I

This group of pools has the greatest risk of impact from extractions due to proximity and the higher volume of pumping. The nearest licensed FRA well is about 60 m from a pool at Lindsay Park which is maintained by a large weir. Other licensed wells range up to 300m and 500m from other pools. FRA salinities range from 500 to 1500 mg/L.



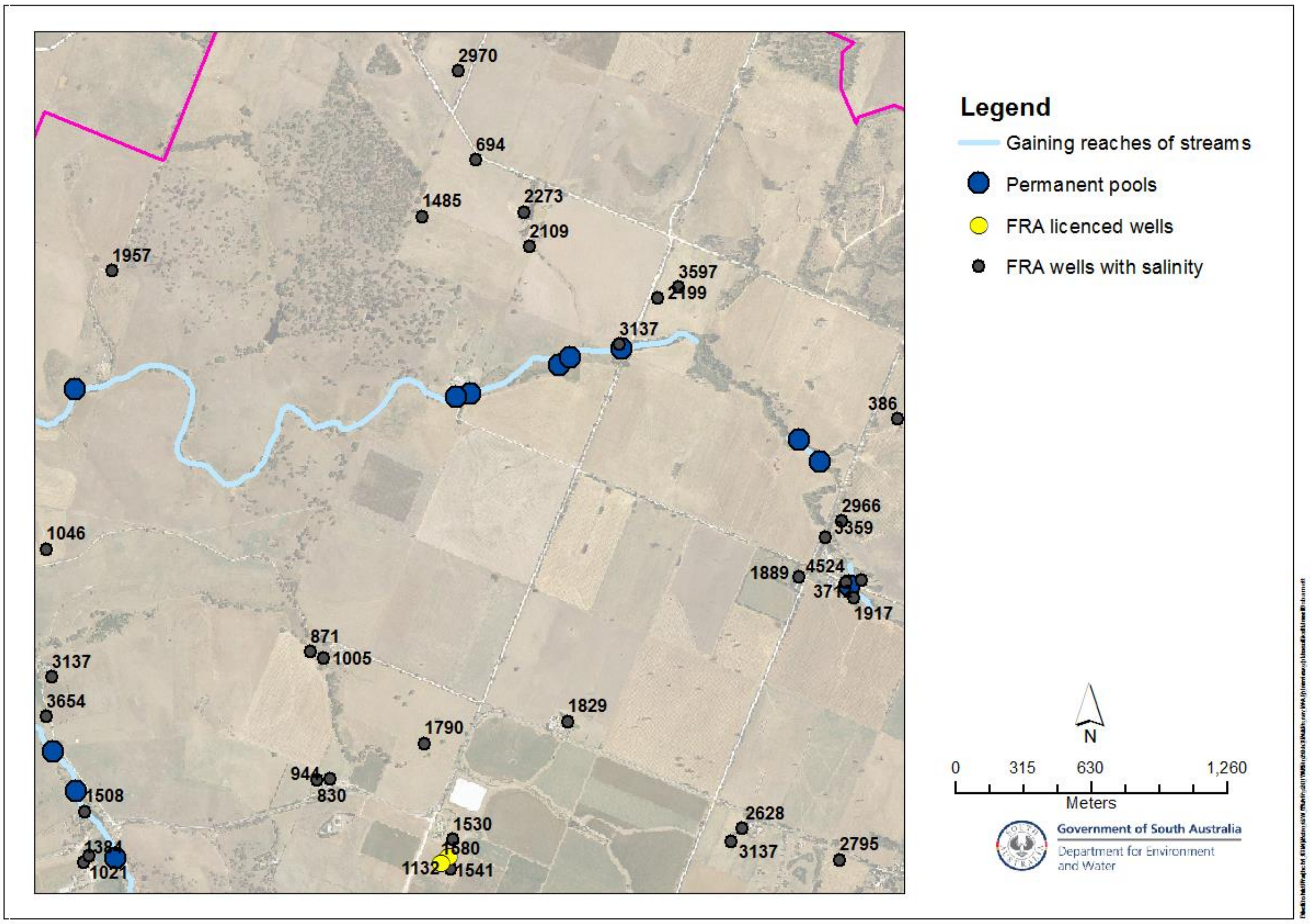
GROUP J

This group of pools has a moderate risk of impact from extractions due to proximity; however, the volumes of pumping are low. The nearest licensed FRA wells are about 250 and 300m from the pools. FRA salinities range from 1500 to 2500 mg/L.



GROUP K

The nearest licensed FRA well is about 2 km from the pools. FRA salinities range from 1500 to 2500 mg/L.



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