Chapter 4 – Groundwater in the Murray Geological Basin

4.1. LOCATION AND EXTENT

The Murray Geological Basin is a large but relatively shallow Cenozoic sedimentary basin, extending over 300,000 km² of south-eastern Australia (Figure 4.1). Some 23,000 km² of the Murray Geological Basin occurs within 150 km of Broken Hill (Figure 3.1), with the north-west margin of the basin adjacent to the fractured rock uplands where Broken Hill is located (Figure 4.2). Contours for the base of the Cenozoic sediment deposits within the basin show a dominant north-east trend, synonymous with the underlying infrabasins of the Tarrara, Menindee and Wentworth Troughs (Chapter 7). These are embayments to the main depositional centre for the Murray Geological Basin, the Renmark Trough, where over 600 metres of Cenozoic sediment has accumulated. The Renmark Trough is bounded to the west by the Hamley Fault, separating it from a smaller depression, called the Canegrass Lobe (Figure 4.2). Smaller north-east trending depressions also separate structural highs, such as the Redan Embayment between the Broken Hill Block and Scopes Range as well as the Bunnerungee Trough between the buried basement ridges of the Lake Victoria and Lake Wintlow Highs (Brodie, 1997). The Neckarboo Ridge, to the east of the Darling River, is a basement high that is traceable on the land surface by elevated dune fields, 10–20 km across.

![Figure 4.1: Location of the ancient Murray Geological Basin and Darling Geological Basin in south-eastern Australia (left-hand panel) compared with the present-day Murray-Darling (surface water) Drainage Basin (right-hand panel).](image)

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4 Both the Murray Geological Basin and the Darling Geological Basin (groundwater basins) differ from the present-day Murray-Darling River Basin (a surface water basin) in terms of their spatial extents, geological histories and hydrological systems. The difference in area and location of these groundwater and surface water basins is shown in Figure 4.1.
Figure 4.2: Structural contours for the base of Murray Geological Basin (MGB) sediments, and locations of underlying infrabasins such as the Menindee Trough. These contours show the variable thickness of sediments in the MGB, and that the north-west margin of the basin abuts the Proterozoic Broken Hill Domain (after Brodie, 1997).
4.2. REGIONAL GEOLOGY

The Murray Geological Basin contains sedimentary sequences formed in aeolian, fluvial, marine and marginal marine depositional environments. Towards the north-west basin margin, in the area of interest for this study (Mallee region of western NSW and South Australia) sediment fill is mostly of fluvio-lacustrine origin and contains extensive sand bodies which are capable of storing and transmitting significant quantities of groundwater (Figure 4.3). These aquifers are separated from limestone aquifers further to the south by marginal marine clays and marls.

Tectonic disruption during the Cenozoic was limited to minor differential subsidence, so that the depositional history of the basin tends to relate more to sea-level fluctuations. The area has had an enduring low-lying and subdued topographic expression that was periodically flooded by shallow epicontinental seas throughout the Cenozoic. Episodes of fluvio-deltaic, paralic and shallow marine sedimentation within the stratigraphic record correspond to periods of relatively high global sea level. This contrasts with erosion and non-deposition during periods of low global sea level. Based on recognition of major depositional and non-depositional events, the Cenozoic sediments of the basin are chronologically divided into three main sequences (Brown, 1989; Brown and Stephenson, 1991):

1. A **Palaeocene to Lower Oligocene sequence**, including the deep fluvio-lacustrine sand, carbonaceous silt and clays of the *Warina Sand* and *Lower Renmark* aquifers;

2. An **Oligocene to Middle Miocene sequence**, where a marine transgression deposited the *Murray Group* platform limestone aquifer, as well as various marginal marine clay aquitards such as the *Etrick Formation*, *Winnambool Formation* and *Geera Clay*. Up-basin, fluvial deposition formed sand, silt and lignite deposits of the *Middle Renmark* and *Upper Renmark*;

3. An **Upper Miocene to Pliocene sequence**, where the sand plain and beach ridges of the *Loxton-Parilla Sands* formed with the retreat of the sea following a short-lived marine transgression. The *Calivil Formation* is the fluvial equivalent found closer to the basin margins, consisting of fine- to coarse-grained quartz sand.

Figure 4.4 summarises the stratigraphic relationships within the Murray Geological Basin. The overlying veneer of Quaternary sediments includes aeolian, fluvial, lacustrine and colluvial deposits. These include the *Shepparton Formation* and *Coonambidgal Formation* aquifers associated with the Murray-Darling River system (Chapter 5).

4.3. REGIONAL HYDROGEOLOGY

4.3.1. Groundwater Recharge

a. **Regional Processes**

Groundwater systems within the layered sequence of aquifers in the Murray Geological Basin generally flow from the basin margins and structural highs to the basin depocentre, in the vicinity of Renmark. The basin margins are therefore important sites of aquifer recharge. Along a 20–50 km-wide zone parallel to the north-west basin margin the shallow watertable is higher than the head in the deepest aquifer. As shown in Figure 4.5, this is indicated by a negative head difference which commonly exceeds -10 m after correction for density effects due to salinity and temperature. Thus, the potential vertical flow direction is downward. The vertical hydraulic conductivity of the sediments largely determines the extent of recharge.
Figure 4.3: Interpreted cross-section (east-west) through part of the north-western Murray Geological Basin, showing the distribution of the main Cenozoic aquifers in the vicinity of the Menindee Lakes. The west side of the section (left-hand edge) shows the Murray Geological Basin thinning-out as it abuts the Proterozoic basement rocks of the Broken Hill Domain, whereas the eastern side (right-hand edge) shows multiple stacked aquifers of varying groundwater quality and yield in the Menindee area (aquifer symbols are: Ter1 – Lower Renmark Group; Ter2 – Middle Renmark Group; Ter3 – Upper Renmark Group; Tmg – Murray Group; Tps – Pliocene Sands; TQs – Shepparton Formation; Qs – Quaternary Alluvial deposits; Ql – Quaternary lake deposits). This section is based on the hydrogeological mapping of Brodie, 1994.
Figure 4.4: Schematic stratigraphic chart showing temporal and spatial relationships of the various Cenozoic age formations in the Murray Geological Basin. The left-hand side represents the generalised western side of the basin, and the right-hand side shows the eastern side of the basin (after Brown and Stephenson, 1991).
Figure 4.5: Areas of downward groundwater flow and significant recharge in the north-west Murray Geological Basin. The areas of negative head difference (shown by contours) mean that the shallow unconfined (water table) aquifer is at a higher level than the confined head of the deepest aquifer, and hence vertical groundwater flow is directed downwards (hydrogeological mapping after Brodie, 1994 shows variations in groundwater salinity and yield).
The elevated basement ranges surrounding the basin are relatively impermeable and a significant component of a large rainfall event becomes surface run-off. This is channelled by small dendritic streams for 40–60 km into the sand plain of the Murray Basin, typically draining into terminal lakes. Some of the streams, such as Stephens Creek, Pine Creek and Turkey Plain Creek, have significant channels with a sandy bed and thus represent losing streams (to the water table) when they flow. Adjacent to the Broken Hill Block and Scopes Range, the shallow sediments are fluvial and sand-dominated, allowing rapid infiltration which reduces evaporative losses. The drainage off the surrounding basement supplements the direct infiltration of rainfall in the area. The extent of this recharge mechanism is reflected in the relatively low salinities (3,500–5,000 mg/L) found in a corridor bordering the basement highs (Figure 4.5). Isotopic data provides evidence of recharge from surface water flow following summer thunderstorms (Evans and Kellett, 1989).

Further to the south-west and in South Australia, the shallow sediments adjacent to the Benda Range are mostly marginal marine and clay-dominant. Here, infiltration is not as pronounced, and groundwater in the shallow aquifer is saline (> 14,000 mg/L). The equivalent freshwater head difference is also negative over the Lake Wintlow High near Pooncarie. Here, recharge is concentrated at the apices of two alluvial fans developed over the structural high.

b. Local Processes

Further into the basin, recharge also occurs at the local scale. For example, sandy swales can be sites of internal drainage, receiving localised run-off after significant storm events. Rapid infiltration maintains a thin freshwater lens buoyed over the saline regional groundwater. Groundwater mounds developed under irrigation districts are extreme examples of enhanced recharge in this environment.

Recharge studies in the Mallee region have been used to establish links between clearing of native vegetation, enhancement of recharge, watertable rise and salinisation. Field measurements of recharge under native vegetation, including the mallee, belah-rosewood and pine woodland assemblages, indicate very low rates of < 0.3 mm/yr, or about 0.1 % of mean annual rainfall (Cook et al, 1996). Potential recharge can increase dramatically following agricultural development. The magnitude of the change is largely dictated by the land-use and soil type. Where mallee vegetation has been cleared for cropping or annual pastures, recharge through sandy soils (<10 % clay) have been measured at 20–40 mm/yr (Cook et al, 1996). The recharge is typically less than 5 mm/yr in areas where the clay content of the soil exceeds 20 %. However, recharge rates seem not to diminish linearly with further increases in clay content (Kennett-Smith et al., 1994). This is due to percolation between peds, cracks or root channels in clay soils. The magnitude of recharge may also depend on the amount of rainfall. Field data suggests that potential recharge of <1 mm/yr exists for non-cropped sites with mean annual rainfall <250 mm/yr (regardless of soil type) (Kennett-Smith et al., 1994). The threshold for cropped lands is lower.

Another important recharge mechanism is river leakage, e.g., on the Darling River floodplain. Downstream of Menindee, regulation of flow has effectively increased the average river stage, altering the interaction between the river and the underlying fluvial aquifer. A series of piezometer transects indicate that the river is losing water to the shallow aquifer (Stannard, 1981). A dilution aureole is found along most of the river, where shallow groundwater salinities range from 400–4,000 mg/L (Figure 4.5). This contrasts with typical salinities of about 20,000 mg/L in the shallow aquifer away from the lower reach of the river. Downhole conductivity logging (electro-magnetic method) of piezometers indicates a distinct interface between an upper freshwater lens and underlying saline regional groundwater (Williams and Beckham, 1995). The system appears to be dynamic, with the interface moving both laterally and vertically in response to changes in river level (Jewell, 1993).

There is evidence that the groundwater dilution aureole occurred along parts of the floodplain and lake system before the onset of river regulation. Mulholland (1940) recorded water wells obtaining fresh to brackish groundwater flanking river channels and floodplain lakes in the Talyawalka system. Large flood events allow overflow via Teryaweynya Creek into a chain of lakes to the south of the Talyawalka Creek. This resulted in freshening of groundwater (<2,000 mg/L) in the shallow aquifer underlying these lakes (Kellett, 1994). Significantly, water discharging from the Darling River at Wentworth is bicarbonate-dominant rather than chloride-dominant (major anion species), implying relatively low levels of groundwater accessions (Mackay and Eastburn, 1990).
The hydrological regime for the Darling Anabranch is also reflected in the underlying groundwater system. The groundwater salinity in the shallow fluvial aquifer of the Anabranch floodplain progressively degrades downstream from <1,500 mg/L to over 5,000 mg/L (Brodie, 1992). This reflects only sporadic major flood events reaching and hence recharging the bed of the lower reaches. At the turn of the century, numerous soakage wells were sunk along the main channel (Withers, 1994) to access this resource. These wells were typically 6–9 metres deep and were mostly used as a drought reserve. Likewise, the sediments of the upper floodplain lakes (e.g., Mindona and Travellers Lakes) contain better quality groundwater due to the greater frequency of flooding. Recharge from advancing floods is mainly via deep cracks developed in the dry heavy clay of the lake bed.

The use of the Menindee Lakes as water storages has had a significant impact on the underlying groundwater system. A groundwater mound is evident over the lake system, creating a density-corrected head difference between the shallow aquifer and the deepest Tertiary aquifer of over ten metres (Brodie, 1992). Downward leakage is indicated by the level of dilution apparent in the deeper aquifers. There is potential for the watertable within depressions down-gradient from the storages (such as Emu Lake and Lake Tandou) to rise and cause salinisation problems (Bish and Salotti, 1996).

4.3.2. Groundwater Discharge

a. Regional Processes

Groundwater flows from the basin margins to the regional discharge zone located near Renmark. Here, the potential vertical groundwater flow is upwards, driven by high heads in the deeper aquifers. This is defined by a positive equivalent freshwater head difference which progressively increases down the flow path (Figure 4.6). The head in the basal Lower Renmark aquifer is up to 20 m higher than the head in the shallow Murray Group Limestone aquifer. Near Waikerie, bores located in topographic lows which tap the confined Lower Renmark aquifer are commonly artesian.

Regional groundwater discharge is expressed as numerous salinas entrenched into the sand plain. These are particularly evident in a ~50 km-wide corridor north of Lake Victoria to Lake Popiltah and bounded to the east by the Darling Anabranch (Figure 4.6). This low-lying region overlies the regional depocentres of the Renmark and Tarrara Troughs, which were focal zones for tectonic subsidence and differential compaction. The control on the distribution of salt lakes in this area is two-fold. Firstly, they are located in depressions within swale and ridge systems. This reflects deposition during the Pliocene of Loxton-Parilla Sand beach ridges, separated by broad swales and local palaeochannels. In these lows, the regional watertable intersects the land surface and discharge conditions prevail. Secondly, the discharge zones tend to occur near the basin-ward edge of the marginal marine deposits. Here, the Geera Clay and Winnambool Formation are thinner, allowing greater opportunity for upward leakage from the pressurised basal aquifer.

b. Local Processes

Local geological structures facilitate upward leakage of groundwater. Nulla Spring Lake, for example, is fault-bounded to the west with the underlying Blanchetown Clay displaced by nearly 10 m (Ferguson and Radke, 1992). The Scotia complex is located on the up-thrown side of the Hamley Fault where the upwarped Parilla Sand and Blanchetown Clay are relatively thin.
Figure 4.6: Areas of upward groundwater flow and significant discharge in the north-west Murray Geological Basin. Major discharge sites are defined here by the areas of greatest groundwater head difference (shown by the contour lines), e.g., up to 20 m variation around Waikerie. In the Broken Hill area the greatest head difference is <5 m (hydrogeological mapping showing variations in groundwater salinity and yield after Brodie, 1994).
The Murray River traverses the regional discharge zone and mostly gains saline groundwater. River regulation, irrigation development and the practice of maintaining off-river storages in adjoining riverine lakes have resulted in significant changes to flow dynamics. Irrigation around Mildura caused the shallow watertable to rise by over 10 metres, resulting in significant displacement of saline groundwater into the river (Rural Water Commission, 1991). A series of interception bores along both sides of the river now operate to reduce the salt impact. Similar groundwater mounds have developed under the irrigation districts in South Australia (Barnett, 1991). An average daily salt return to the river is estimated at 104 tonnes at Waikerie/Golden Heights, 146 tonnes at Berri/Cobdogla and 80 tonnes at Loxton (Smith and Watkins, 1993). Hydraulic loads, causing displacement of saline groundwater, are also imposed by water storages (e.g., Lake Victoria), river locks and evaporation basins located within or near the floodplain.

4.4. AQUIFERS

4.4.1. Lower Renmark Group Aquifer

a. Geological Context

The basal sequence of the Murray Geological Basin is the Warina Sand, deposited during Palaeocene to Eocene times. Deposition involved partial infilling of the major sedimentary troughs with medium- to coarse-grained quartz sands and minor interbeds of carbonaceous-bearing, fine sand, silt and clay. The sequence is thickest (150–250 m) in the main depocentre of the Renmark Trough, and absent over the basement highs. The sand deposits are muscovite-rich, implying that metamorphic rocks of the Curnamona Province were a significant source of material. The sands also contain pyritised wood fragments and are partially lithified by siliceous or dolomitic cement. The thick, homogenous sand bodies indicate high rates of sediment discharge associated with deposition in large braided or anastomosing river systems.

The Lower Renmark Group sediments represent the continuation of fluvio-lacustrine deposition into the Early Oligocene. Like the Warina Sand, the geometric architecture is controlled by the north-east trending depressions, with thicknesses reaching 150–200 m in the Renmark and Tarrara Troughs, and 80–120 m in the Menindee Trough. The unit is absent over basement highs. Sediments include fine- to medium-grained quartz sand and carbonaceous silt and clay. Carbonised and pyritic plant remnants, including fossil logs and interbedded lignite seams, are characteristic. Palynological studies place most of the sequence in the Middle Eocene to Early Oligocene Nothofagidites asperus zone (Kellett, 1989). Deposition of the silt- and clay-rich deposits occurred in extensive floodplains and lakes, with sands deposited in meandering channels. Hence, the sequence contains more laterally discontinuous and finer-grained units than the underlying Warina Sands. In the Mallee region, the Lower Renmark Group is more sand-rich than equivalent sequences on the Riverine Plain to the east, reflecting a coarser, quartz-rich provenance.

b. Groundwater Processes

The Lower Renmark Group aquifer, inclusive of the Warina Sands, is confined to the major troughs of the Murray Geological Basin (Figure 4.7). In the Blantyre, Menindee and Tarrara Troughs, groundwater tends to flow down-basin to the west and south-west, parallel to the trough margins. Hydraulic gradients in this area are low, about 5–10 cm/km. Along the north-west margin of the aquifer, the flow direction is initially to the south or south-east, orthogonal to the margin. Coupled with a relative freshening of the groundwater (about 6,000 mg/L), this suggests downward leakage from the overlying aquifers. Groundwater flow is directed towards the Murray River, near Woolpunda. Here, artesian conditions prevail, particularly for bores located in topographic depressions.
Figure 4.7: Hydrogeological map of the Lower Renmark Group aquifer in the north-west Murray Geological Basin, showing the spatial extent of the aquifer, the groundwater flow directions and the variations in groundwater salinity and yield (after Brodie, 1994).
c. Groundwater Quality

Groundwater in the Lower Renmark Group is suitable for stock use only within a 5–60 km zone parallel to the north-west margin of the aquifer (Figure 4.7). Here, typical salinities are 11,000–13,000 mg/L with some isolated pods of fresher water having total dissolved solids (TDS) < 6,000 mg/L. To the north, in the Menindee and Blantyre Troughs the groundwater is more saline, ranging from 14,000–40,000 mg/L. This may relate to the finer-grained nature of the sediments which lessen groundwater through-flow. In this area, recharge is mostly via bed leakage from the Darling River further to the north (Kellett, 1994). The Lower Renmark aquifer in the upper parts of the Wentworth Trough also contains saline groundwater in relatively fine-grained sediments.

d. Aquifer Characteristics

Aquifer yields are generally high and commonly exceed 5 L/s. This reflects significant thicknesses of interbedded fine- to medium-grained micaceous quartz sands in the fluvial sequences. Aquifer yields of over 50 L/s are estimated for the central basin axes, particularly the in Menindee, Tarrara and Renmark Troughs due to partial filling of the troughs by medium to coarse quartz sands of the Warina Sand.

4.4.2. Murray Group Limestone Aquifer

a. Geological Context

The Murray Group Limestone aquifer is the collective name for a series of Late Oligocene to Middle Miocene platform limestones in the Murray Basin. Isopach maps show two accumulations; the main depocentre of the Renmark Trough where thicknesses exceed 140 m, and a subordinate accumulation centred on Waikerie with 100–120 m of limestone (Figure 4.8). Localised thickening of the sequence is also apparent along the axes of the Tarrara and Wentworth Troughs. In the west, the limestone tends to be a skeletal calcarenite, becoming finer-grained and marl-bearing to the north and east. In South Australia, the sequence is subdivided into a series of limestone units (Mannum, Morgan and Pata) and is exposed along the walls of the Murray River gorge. The upper surface of the Murray Group Limestone shows a distinct ridge trending north-east from Woolpunda. To the west of this ridge lies a depression centred over the Renmark Trough.

The basin depocentres largely define the extent of the Murray Group Limestone. The Geera Clay and Winnambool Formation form a lateral permeability barrier between the Murray Group Limestone aquifer and the Middle Renmark aquifer to the north-east (Figure 4.4). These marginal marine sediments are finer-grained and also store a significant amount of salt. The Ettrick Formation forms a thin (10–30 m) aquitard between the limestone and the underlying Lower Renmark aquifer.

b. Groundwater Processes

Groundwater flow in the Murray Group Limestone is directed towards the reach of the Murray River between Renmark and Morgan (Figure 4.9). West of the Hamley Fault in this area, the limestone platform is elevated and the formation is the shallow unconfined aquifer. Natural groundwater mounds have developed on both sides of the Woolpunda Reach between Waikerie and Overland Corner, because of upward leakage from the Lower Renmark aquifer. The main mechanism for this is the dramatic thinning of the deeper aquifer on the up-thrown western block of the Hamley Fault. The Ettrick Formation between the two aquifers also thins to <10 m over the structural high, allowing greater upward movement of groundwater from the Lower Renmark aquifer. The groundwater mounds have steepened the gradients towards the river from a regional average of 20cm/km to 1–2 m/km, resulting in inflows of 200 tonnes/day of salt (Barnett, 1992). The Woolpunda Interception Scheme operates to remove saline groundwater before it reaches the river, pumping it to the Stockyard Plain Disposal Basin.
Figure 4.8: Thickness contours for the Murray Group Limestone in the north-west of the Murray Geological Basin, showing that this aquifer is not an important groundwater-bearing system within the Broken Hill study area (after Brodie, 1994).
Figure 4.9: Hydrogeological map of the Murray Group Limestone in the north-west of the Murray Geological Basin showing spatial variations in the salinity and yield of groundwater within this aquifer. Note the dominant groundwater flow direction towards the discharge areas along the River Murray near Waikerie (after Brodie, 1994).
Irrigation development along the riverine corridor has also created localised groundwater mounds in some parts of the unconfined limestone aquifer. For example, irrigation practices around Berri and Barmera have elevated the watertable by over six metres, steepening flow gradients towards the floodplain and Lake Bonney. Another salt interception scheme is located between the groundwater mound underlying the Waikerie Irrigation Area and the Murray River, removing ~105 tonnes/day of salt from the aquifer.

**c. Groundwater Quality**

Groundwater in the Murray Group Limestone is mostly too saline for beneficial use, with TDS commonly >20,000 mg/L (Figure 4.9). However, ephemeral recharge from the Burra and Newikie Creeks has freshened groundwater in the south-western extreme of the aquifer, allowing it to be partly used for stock-watering (Barnett, 1994). Also, a marginal groundwater resource (<14,000 mg/L) occurs along the northern bounds of the aquifer where the enveloping marine sediments are relatively coarser, allowing downward leakage from shallower aquifers.

**d. Aquifer Characteristics**

Aquifer yield increases down-basin with thickening of the platform limestone unit. The aquifer is particularly low yielding (< 0.5 L/s) along the eastern landward margin where the limestone is interbedded with marginal marine clays. However, bore yields in most of the aquifer exceed 5 L/s.

**4.4.3. Middle Renmark Group Aquifer**

**a. Geological Context**

From the Oligocene to the Mid-Miocene when the limestones of the Murray Group were formed, fluvio-lacustrine conditions persisted up-basin. Hence, the Middle Renmark Group represents the terrigenous equivalents deposited by river systems, deltas and coastal swamps. This has resulted in a wedge of fluvio-lacustrine sediments constrained by the basin margin to the north-west and north, and by marine deposits to the south-east; similar sediments also partially cover the Neckarboo Ridge (Figure 4.10) The surface contours of the upper Middle Renmark Group mimic the underlying basement profile, with a major low superimposed over the Tarrara, Menindee, Wentworth and Blantyre Troughs. The thickness of the unit is consistently 40–80 m, increasing to 100–160 m in the troughs. Due to high base levels during this time, a low energy depositional environment resulted in the Middle Renmark being the finest grained member of the Renmark Group sedimentary package. Grey carbonaceous and micaceous silt, black humic clay, lignite and fine quartzose sand are typical sediments.

**b. Groundwater Processes**

The Middle Renmark Group aquifer extends over the Lower Renmark aquifer in the north, pinching out down-basin by a thickening marginal marine sequence (Figure 4.4). Like the Lower Renmark aquifer, groundwater flow is towards the south-west, directed by the basin structure of troughs and ridges (Figure 4.10). In the north-west, groundwater flow is controlled by the margins of the Broken Hill Block and the Scopes Range, along the axis of the Redan Embayment. The regional groundwater flow system is also overprinted by a groundwater mound developed under the Menindee Lakes. The Neckarboo Ridge acts as a groundwater divide, with groundwater flow directed to the west and north-west, away from the ridge flanks.

**c. Groundwater Quality**

Groundwater quality deteriorates southwards along the flow path (Figure 4.10). The freshest groundwater, with a typical salinity of 2,000 mg/L occurs along the western margin of the Scopes Range. A dilution effect by the Menindee Lakes and Darling River is also apparent for the Middle Renmark aquifer. The main factor controlling the down-gradient increase in salinity is the increasing thickness of the Geera Clay. For example, the Geera Clay is absent from northern parts of the aquifer abutting the Broken Hill Block and thus has livestock quality groundwater (3,500 mg/L). Southwards along the margin where the Geera Clay progressively thickens, salinity increases to around 10,000 mg/L. Sulphate levels can also exceed 1,000 mg/L and borehole corrosion is commonly a problem. Groundwater salinities exceed 35,000 mg/L along the basin-ward margin of the aquifer.
Figure 4.10: Distribution of the Middle Renmark Group aquifer in the north-west part of the Murray Geological Basin. This map also depicts variations in groundwater parameters such as salinity, yield, flow direction and standing water level (after Brodie, 1994).
**d. Aquifer Characteristics**

Aquifer yields are typically low (<0.5 L/s) where the aquifer thins out over the basement margins. This reflects a reduction in aquifer thickness and decreased sediment grain size. The sediment pile becomes coarser and thicker where significant fluvial deposits have developed along a corridor defined by the Blantyre, Menindee and Tarrara Troughs; higher aquifer yields predominate in these areas (5–50 L/s).

**4.4.4. Upper Renmark Group Aquifer**

**a. Geological Context**

The south-western retreat of the sea during the Mid-Miocene resulted in deposition of the Geera Clay and Winnambool Formation over the Murray Group Limestone aquifer (Figure 4.4). Similarly, the youngest part of the Renmark Group sediments, the Upper Renmark Group, prograded over the Geera Clay. The maximum basin-ward extent of this relationship is shown by the structural contours for the top of the Upper Renmark Group (Figure 4.11). The sequence pinches out towards the north-west onto the basement highs but, with the exception of areas around scattered Devonian outcrops, covers the Neckarboo Ridge. Similar Miocene fluvial sediments also extend northwards onto the Darling floodplain, as indicated by groundwater supply investigations near Wilcannia (Woolley et al., 2004). Thickness varies from 40–60 m in the Wentworth and Tarrara Troughs to <20 m over structural highs. Although the Upper Renmark is the thinnest of the Renmark Group aquifers, it has considerable lateral extent (Figure 4.11). The sediments are generally coarser-grained than the Middle Renmark and consist of grey fine to medium ligneous quartz sand, micaceous silt and green-grey plastic clay. The sequence corresponds to the Mid- to Late-Miocene *Triporopollenites bellus* zone (Kellett, 1989).

**b. Groundwater Processes**

In the study area groundwater flow is generally to the south-west, following the structural trend of the basin (Figure 4.12). Only the southern half of the Neckarboo Ridge forms a groundwater divide, where the aquifer is unconfined. The ridge is breached to the north, particularly with through-flow in the Baden Park Depression which separates the Manara Hills from the Cobar Block. Under the Menindee Lakes and nearby floodplain, groundwater flow is directed radially from a mound generated by enhanced recharge. A similar radial pattern is evident to the south, between the Darling River and Travellers Lake. Here, this is not related to enhanced recharge but reflects groundwater flow away from a ridge-like structural feature termed the Lake Wintlow High.

**c. Groundwater Quality**

Groundwater useful for livestock supply occurs along the north-west margin of the aquifer where it receives recharge from basement run-off. Here, the middle and upper components of the Renmark Group are difficult to differentiate and typically form a single aquifer unit with groundwater salinity about 3,500 mg/L. Salinities of about 5,000 mg/L occur under the Menindee Lakes. Groundwater dilution aureoles are also apparent in the aquifer; for example, under the Darling River floodplain upstream of Burtundy (TDS of 4,000–7,000 mg/L), and to a lesser extent, for the Anabranch floodplain and lake system north of Bunnerungee. In the lower river reaches, the freshwater aureoles are surrounded by very saline (> 35,000 mg/L) regional groundwater. Periodic outflow from Sandy Creek onto the sand plain has resulted in localised freshening of groundwater to about 6,000 mg/L.

**d. Aquifer Characteristics**

Aquifer yields tend to be low (<0.5 L/s) along the basin margins due to the fine-grained nature of sediments in the Upper Renmark Groups. In addition, a low-yielding aquifer zone protrudes into the basin from the north-west margin. This corresponds with finer silts and clays deposited over a south-east trending pre-Miocene ridge. Towards the basin the Upper Renmark Group also thins and becomes interbedded with marginal marine clays, resulting in a low-yielding belt along the south-west margin of the aquifer.
Figure 4.11: Structural contours for the top of the Upper Renmark Group. This aquifer occurs widely in the north-western Murray Geological Basin within 150 km of Broken Hill.
Figure 4.12: The Upper Renmark Group aquifer contains mostly brackish quality groundwater in the Menindee Lakes area, as depicted by this hydrogeological map for the northwestern part of the Murray Geological Basin. Note the variable groundwater flow directions for this aquifer.
4.4.5. Pliocene Sands Aquifer

a. Geological Context

The Pliocene Sands aquifer is a composite of two sand-dominated sequences of the marginal marine Loxton-Parilla Sands and the fluvial Calivil Formation. The Loxton-Parilla Sands were deposited as an extensive sheet-like deposit during marine regression in the Pliocene. The sediments are dominantly yellow-brown, weakly cemented, and fine- to coarse-grained quartz sands containing trace mollusc and pelecypod casts and bioturbation features. The sands also contain disseminated concentrations of heavy minerals, including economic deposits of zircon, tourmaline, ilmenite, leucoxene and rutile. Poorly sorted micaceous quartz sand, silt and clay are subordinate sediments. Clay constitutes less than 15% of these units but tends to increase with depth (Ferguson and Radke, 1992).

The Loxton-Parilla Sands is interpreted to have formed in marine shelf to strandplain environments, such as shallow marine, beach, barrier bar and estuarine systems intersected by younger rivers. Regressive upward-coarsening sequences with lenses of disarticulated shells and heavy minerals provide evidence of these depositional environments (Ferguson and Radke, 1992). The top surface of the Loxton-Parilla Sands is characterised by north-west trending arcuate ridges, which are the remnants of former coastal dunes with intervening swales (Figure 4.13). The Millewa Ridge, south of Lake Victoria, is the largest of these local strand-lines and has an elevation >50 m. The sands form an extensive cover into the Menindee and Blantyre Troughs and over the southern half of the Neckarboo Ridge (Figure 4.13). The average thickness is 40–50 m, increasing to 70–80 m in the Renmark Trough and decreasing to 10–20 m over structural highs.

Fluvial-lacustrine environments prevailed in the north and east of the basin during the Pliocene. This resulted in the deposition of the Calivil Formation along the margins of the basin and into the Darling floodplain, including most of the northerly half of the Neckarboo Ridge (Figure 4.13). The top surface of the formation is characterised by palaeochannel systems which drain the surrounding basement ranges. Typical sediments of the Calivil Formation are pale yellow, white or brown kaolinised fine- to coarse-grained quartzose sand with interbedded clays and silts. The bleached, kaolinitic material may reflect active erosion of basement rocks which were deeply weathered in the Late Miocene (Mologa Surface). The sands are partly to strongly ferruginised and silcrete hardpans also occur. These sediments are similar to the underlying Upper Renmark Group, but have less abundant lignite and a greater coarse sand component. The unit has an average thickness of 30–40 m, with a maximum thickness of 50–60 m developed in a large palaeochannel system along the axial trend of the Blantyre and Wentworth Troughs (Figure 4.13)

b. Groundwater Processes

The composite Pliocene Sands aquifer has a relatively large lateral extent across the basin (Figure 4.14). In South Australia, the sand sheet becomes unsaturated due to a combination of upwarping over the Hamley Fault and a deeper watertable. Here, the Loxton-Parilla Sands is underlain by the Bookpurnong Beds which impedes connectivity with the deeper Murray Group Limestone aquifer. Much of this area is also covered by a thin mantle of Blanchetown Clay which can act as an upper confining layer. The unit is unsaturated over the southern half of the Neckarboo Ridge and also around outcrops of Devonian age rocks further to the north. To the east and north, the depositional environment was mostly fluvial and the Calivil Formation aquifer tends to be hydraulically connected with the underlying Upper Renmark aquifer.

Like the deeper aquifers, groundwater flow is predominantly to the south-west, directed along the structural depressions (Figure 4.14). Along the north-west margin, flow is initially to the south-east orthogonal to the aquifer boundary. A major palaeochannel/deltaic system overlying the Blantyre, Menindee and Tarrara Troughs captures this flow and directs it south-west. Likewise, groundwater flow away from the Neckarboo Ridge is initially to the north-west, perpendicular to the structural high. Further away, groundwater flows south-west, down the axis of the adjacent Wentworth Trough. Although the Neckarboo Ridge is a groundwater divide in the south, the aquifer receives groundwater across the northern half, particularly in the Baden Park Depression.
Figure 4.13: Structural contours for the top of the Pliocene Sands aquifer in the north-western Murray Geological Basin, showing the wide spatial distribution of this aquifer and the variations in sediment thickness (after Brodie, 1994).
Figure 4.14: The freshest groundwater in the Pliocene Sands aquifer occurs in the vicinity of the Darling River, due to leakage through the sandy river bed and into the underlying geological formations. Away from the river groundwater salinity may approach that of seawater (hydrogeological mapping after Brodie, 1994).
The Lake Wintlow High, the ridge separating the two major depressions, the Blantyre-Menindee-Tarrara and the Wentworth, acts as a local groundwater divide. The most obvious effects of this ridge are the groundwater mounds developed on either side of the Darling River near Pooncarie. A linear groundwater mound occurs at the Menindee Lakes and along the upstream section of the Darling River, maintained by enhanced leakage from the river. Irrigation development along the Murray River, specifically at Mildura, Loxton and Berri-Barmera has also caused significant increases in local groundwater levels. The Berri-Barmera area represents the sink for regional groundwater flow in the Pliocene Sands aquifer.

c. Groundwater Quality

One of the most distinctive groundwater features of the aquifer is the dilution effect caused by recharge from the Darling River (Figure 4.14). The freshest groundwater (600–900 mg/L) occurs in a 2–10 km-wide corridor centred along the Darling River channel upstream of Burtundy Weir. In a broader zone defined by the surrounding floodplain, Talyawalka Creek and the upper reaches of the Darling Anabranch, groundwater is slightly more saline (1,300–2,500 mg/L). This reflects the lower frequency of flooding for outer parts of the river system. For example, outliers of relatively poor quality groundwater (5,000–7,000 mg/L) occur within the floodplain on higher terraces which are rarely flooded. The dilution aureole dramatically decreases in width from 40–50 km near Menindee to 10–15 km near Pooncarie. This is a function of the river system’s geomorphic structure, as the width of the floodplain decreases downstream. To the north-west, the groundwater dilution aureole borders groundwater freshened by periodic run-off from the Broken Hill Block and Scopes Range. Here, salinities range from 2,500–5,000 mg/L. Useable water can also be found beneath Sandy Creek and as isolated pods along the Neckarboo Ridge. The raising of the Murray River by Lock 6 has also caused localised flushing of the aquifer in the Chowilla floodplain (Barnett, 1994).

The remainder of the aquifer contains saline groundwater, with TDS above 14,000 mg/L (threshold for marginal stock use) and commonly >20,000 mg/L. Hundreds of bores have previously been drilled in these areas, but were abandoned due to high salinities. Some boreholes have encountered thin freshwater lenses overlying the saline regional groundwater (Kellett, 1994). These are located in sandy depressions, where collection and rapid infiltration of overland flow occurs. The mixing of the freshwater lens with the underlying saline groundwater is minimised due to the density contrast and cemented horizons of the upper aquifer. The lenses are usually less than 5 m thick and sensitive to overpumping.

Towards the end of the south-west directed groundwater flow path, the watertable is relatively shallow (< 30 m) and the Pliocene Sands represent the shallow watertable aquifer. Groundwater salinities commonly exceed sea water concentrations (35,000 mg/L) and may become hypersaline (>100,000 mg/L) under salt lakes. The groundwater in the aquifer can also be highly stratified. For example, near Nulla Lake east of Lake Victoria, drilling has identified increasing salinity with depth, from 72,000 mg/L at 29 m, to 94,000 mg/L at 39 m and 106,000 mg/L at 59 m depth. Hydrochemical studies of the aquifer suggest three stratifications - a saline lower Parilla zone, an upper Parilla zone and a relatively low salinity uppermost lens (Ferguson and Radke, 1992).

d. Aquifer Characteristics

Aquifer yield increases down-basin. Along the margins of the aquifer, the unit thins and is finer-grained and thus low yielding (< 0.5 L/s). Low yields are also associated with silts and clays deposited on the western margin of the Lake Wintlow High. To the north-east, most of the aquifer consists of kaolinised fine- to coarse-grained quartzose sands with interbedded clays and silts of the Calivil Formation, yielding <5 L/s. However, yield exceeds 5 L/s in the thicker and coarser-grained sediments within the troughs. Higher yields are also found in the apex of the alluvial fan developed by Sandy Creek. Down-basin, the Loxton-Parilla Sands is relatively clean and well-sorted, with bore yields commonly > 5 L/s.

4.5. GROUNDWATER USE AND MANAGEMENT

Salinity is the major constraint for groundwater extraction from the aquifers in the north-west part of the Murray Geological Basin. There are numerous livestock supply bores, particularly in the northern region, which access groundwater with salinities <14,000 mg/L (threshold for sheep use). Most of these
are equipped with windmills, and some use submersible or surface pumps. Bore flow rates tend to be low (<0.5 L/s) and intermittent, supplying storage tanks that service troughs. Due to the relatively low water usage and bore density (typically >2–5 km apart), the overall impact on the groundwater resource is considered minimal.

The most significant sites of groundwater extraction are associated with salt interception schemes established to reduce saline groundwater discharge into the River Murray (Table 4.1). These schemes are focused along the length of the Murray between Mildura and Morgan, coinciding with the regional groundwater discharge zone for the Murray Geological Basin (Section 4.3.2). The Woolpunda Reach, between Waikerie and Overland Corner, is a particular priority, as upwarping and thinning of the deeper confined aquifer has contributed to significant upward leakage into the shallow aquifer and ultimately, into the River Murray (Lindsay and Barnett, 1989). The Woolpunda Groundwater Interception Scheme consists of 49 extraction bores located along transects on both sides of the river that collectively extract 15 ML/day of saline groundwater. The scheme is designed to intercept 170 tonnes/day of salt and reduce average river salinity by 40–50 µS/cm. Similar schemes have also been established to reduce the impacts associated with groundwater mounds developed under irrigation areas. Pumped saline groundwater is diverted to evaporation basins for disposal.

Table 4.1: River Murray salt interception schemes (source: Murray Darling Basin Commission, 2007).

<table>
<thead>
<tr>
<th>SCHEME</th>
<th>SCHEME CAPITAL COST ($M)</th>
<th>2005–06 EXTRACTION (GL/Y)</th>
<th>AVERAGE SALINITY (US/CM)</th>
<th>ESTIMATED 2030 EXTRACTION (GL/Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waikerie</td>
<td>4.08</td>
<td>25,800</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>Woolpunda</td>
<td>5.09</td>
<td>30,000</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Bookpurnong</td>
<td>11.2</td>
<td>0.79</td>
<td>28,163</td>
<td>1.7</td>
</tr>
<tr>
<td>Rufus River</td>
<td>3.3</td>
<td>1.01</td>
<td>33,000</td>
<td>1.1</td>
</tr>
<tr>
<td>Buronga</td>
<td>2.82</td>
<td>47,265</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Mildura–Merbein</td>
<td>1.53</td>
<td>49,208</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Mallee Cliffs</td>
<td>2.20</td>
<td>52,800</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

The aquifers of the Murray Geological Basin were previously assessed as part of a basin-wide study commissioned by the Murray-Darling Basin Commission (Skelt et al., 2004a). For reporting purposes, the Lower and Middle Renmark Group aquifers were combined into the Renmark groundwater subsystem, whereas the Upper Renmark was combined with the overlying Pliocene sands aquifer because of the reasonable degree of hydraulic continuity. The Loxton-Parilla and Calivil aquifers were reported separately. Water level monitoring suggests relatively constant conditions (Skelt et al., 2004a).

These aquifers are not currently designated and administered as individual groundwater management units in western NSW, due to low development levels caused by high groundwater salinities. In western New South Wales, the Renmark Group aquifers, the Pliocene Sands and the Shepparton Formation (Chapter 5.1) have been combined into the Western Murray Porous Rock groundwater management unit (GMU N612). The regional extraction limit for this GMU is 663.8 GL/yr, with current annual extraction (2004/05) estimated at 4.5 GL (CSIRO, 2008).

4.6. STATISTICAL ANALYSIS OF MURRAY GEOLOGICAL BASIN BORES IN THE BROKEN HILL REGION

According to the NSW Groundwater Works database 672 bores in NSW are drilled into the Murray Geological Basin. Within the database, bores are not assigned to particular aquifers; thus, our statistical analysis reports only on general trends at the basin-level (Table 4.2).

Of the 672 bores, only 44 have bore yield data; yields range from 0.13 to 12.5 L/s, with a median of 2 L/s. Some 311 bores have salinity data recorded, although these are provided only in broad categories of 0–500 mg/L, 0–1000 mg/L, 0–14,000 mg/L, 1000–10,000 mg/L and 10,000–100,000 mg/L, rather than specific measurements. About half of the bores have salinity levels exceeding 10,000 mg/L. Measured
groundwater levels (standing water level or SWL) also vary between 1 and 62 m below the land surface (Table 4.2).

Table 4.2: Water bore statistics for Murray Geological Basin aquifers.

<table>
<thead>
<tr>
<th></th>
<th>BORE DEPTH (M)</th>
<th>YIELD (L/S)</th>
<th>SWL (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>582</td>
<td>44</td>
<td>236</td>
</tr>
<tr>
<td>Mean</td>
<td>78</td>
<td>3.2</td>
<td>14</td>
</tr>
<tr>
<td>Median</td>
<td>53</td>
<td>2.0</td>
<td>12</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.5</td>
<td>0.13</td>
<td>1</td>
</tr>
<tr>
<td>Maximum</td>
<td>1,229</td>
<td>12.5</td>
<td>62</td>
</tr>
<tr>
<td>SD</td>
<td>96</td>
<td>3.2</td>
<td>10</td>
</tr>
</tbody>
</table>

Analysis of the Murray Geological Basin bore data supports our conceptual understanding of groundwater resources within this system. Groundwater is mostly brackish to saline, and rarely within potable limits except where flushed with surface water from parts of the Darling River. Bore yields are variable and mostly range from low to moderate, with the highest yielding bores capable of supplying around 10 L/s. Watertable depths (SWL) are commonly <20 metres below the surface.

Given the thickness and lateral extent of aquifer systems with favourable hydraulic properties, a significant volume of groundwater could be extracted from the Murray Geological Basin. However, the highly saline nature of most of this resource, coupled with the potential for negative impacts associated with extraction, e.g., on connected surface water systems, are critical factors which currently limit the usefulness of this groundwater system. Alternatively, some aquifers (or parts thereof) could be used as underground water storage areas, applying the principles of Managed Aquifer Recharge (MAR), as further discussed in Chapter 9.