GROUNDWATER ALLOCATION PLAN

MURRAY GROUNDWATER AREA

WATER RESOURCE ALLOCATION AND PLANNING SERIES

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MURRAY GROUNDWATER AREA

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with support from the
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Executive summary

The Murray Groundwater Area (MGA) is located east of Mandurah (Figure 1). The MGA was proclaimed on 6 October 1976, under the Rights in Water and Irrigation Act 1914, to assist in the sustainable management of the available groundwater resources. This was created because Alcoa of Australia was establishing at Pinjarra, with large water requirements necessitating management.

These resources are utilised to meet the water requirements of industries, intensive agriculture, fodder crops, horticulture and for public water supply purposes. Almost all developments within the MGA rely upon groundwater. Exceptions include public water supplies for Waroona, Hamel and Pinjarra, and irrigation projects which utilise surface water stored in adjacent dams.

Significant environmental features and conservation reserves found within the MGA are also dependent upon groundwater for sustainability. These include Lake McLarty, Goegrup Lake, Nambeelup Lake, other wetlands and coastal-plain lakes, phreatophytic and damland vegetation, and estuarine banks and remnant vegetation.

This allocation plan aims to ensure the equitable allocation of the available groundwater resources, the prevention of long term depletion and degradation of both groundwater quantity and quality, and the protection and conservation of the environment.
To assist with the management of the groundwater resources, the MGA has been divided into four subareas (Figure 1). The subarea boundaries reflect the geological and hydrogeological features of the area.

Groundwater within the Murray Groundwater Area is present within both unconfined and confined aquifers. The aquifers are, in order of increasing depth, the superficial (unconfined), Leederville and Cattamarra (both confined) (Figure 2).

Total groundwater available for allocation within the MGA has been estimated to be some 69 000 000 kL/year. The sustainable groundwater resources for each aquifer have been estimated within each individual subarea from previous work completed by the Geological Survey of Western Australia and the former Water Authority of Western Australia. Groundwater allocation and management policies based on these estimations have been formulated.

The available groundwater resources of the superficial aquifer are more substantial than the total resources of both the Leederville and the Cattamarra aquifers. The superficial aquifer has significant groundwater resources available for allocation but well yields may vary with the clay content of the soils from which the water is drawn.
The deeper Leederville aquifer has been divided into two distinct zones, the upper and lower Leederville aquifers, by a green clay marker bed that dissect the aquifer. Estimated availabilities for the upper and lower aquifers were based on recharge calculations dependent upon the nature of the surficial soils and the location. At present, approximately 58% and 17% of the total groundwater availabilities from the upper and lower Leederville aquifers have been allocated respectively. There still exists significant potential for groundwater abstraction from the lower Leederville aquifer, specifically within the Coolup, Pinjarra and Waroona subareas.

Owing to the depth of the Cattamarra aquifer, only a small portion of the groundwater well licences issued within the MGA draw groundwater from this aquifer. Recharge to the aquifer is limited, and there exists little potential for further allocation of groundwater from the aquifer. The aquifer does, however, serve as the source for the largest private groundwater allocation within the MGA. Alcoa of Australia are licensed to abstract 2 500 000 kL/year from the Cattamarra aquifer for process water in alumina refining activities. A provision does exist to extend abstraction to 4 000 000 kL/year, by prior notification, in the event of unseasonally low rainfall.

At present the only wellfield supplying scheme water in the MGA is located at Ravenswood. However, the southern portion of the proposed Dandalup Public Water Supply Scheme is located within the Nambeelup subarea. Groundwater has been reserved from the superficial and both the upper and lower Leederville aquifers to meet the future requirements of this scheme.
Currently, insufficient data exist to accurately estimate the groundwater resources available for allocation from the Leederville and Cattamarra aquifers. Additional work is recommended to identify all recharge areas of the aquifers, and such work shall include drilling investigations and subsequent computer modelling. Such monitoring and investigation within the MGA will assist in further refining the allocation policies and principles detailed within the allocation plan.

The essential principles of the Groundwater Allocation Plan: Murray Groundwater Area 1998 were approved by:

- The Board of the Water and Rivers Commission on 27 November 1997.
1. Introduction

1.1 Location

The Murray Groundwater Area (MGA) covers an area of 104,612 hectares east of Mandurah. It is bounded by the Serpentine and Stakehill Groundwater Areas to the north, by the South West Coastal Groundwater Area to the west and by the Darling Scarp to the east.

Along the scarp, the MGA extends from just south of Keysbrook to just north of Yarloop. The northern boundary of the MGA runs along the northern boundary of the Murray Shire, between the Serpentine River and the Darling Scarp. The western boundary of the MGA extends along the banks of the Serpentine River, Peel Inlet, Harvey Estuary, Harvey River and Logue Brook Drain, before heading east towards the scarp along Bancell Road, just north of the Waroona–Harvey shire boundary.

The MGA is situated within the Shire of Murray and the Shire of Waroona. The towns of Pinjarra and Waroona are the largest population centres in the groundwater area. Smaller towns include Hamel, Coolup, North Pinjarra, Ravenswood and Yunderup. The locality plan of the MGA is shown in Figure 1.
1.2 Murray Groundwater Area

The Murray Groundwater Area (MGA) was proclaimed on 6 October 1976, under the Rights in Water and Irrigation Act 1914, as it was recognised that there existed limited potential for further development of groundwater resources in the area. This proclamation appeared in the Government Gazette, WA, on 15 October 1976.

With the addition of land, in the north and south, to what was previously the Murray Groundwater Area, the MGA boundary was modified on 21 June 1988, to that shown in Figure 1. The proclamation appeared in the Government Gazette, WA, on 29 June 1988.

For management purposes, the MGA has been divided into four subareas: Nambeelup, Coolup, Pinjarra and Waroona (Figure 1). These have been created to reflect the geological and hydrogeological features of the area.

1.3 Groundwater overview

The groundwater resources of the MGA comprise both unconfined and confined aquifers. Most development in the MGA is reliant on groundwater for water supply needs. Surface water from dams service public water supplies to Waroona, Hamel and Pinjarra, and some irrigation projects in the MGA that utilise surface water from nearby dams.
The largest use of groundwater in the MGA is for industrial purposes. Groundwater is also used for fodder crops, intensive agriculture, horticulture and public water supply purposes.

The Water Corporation operates a public water supply wellfield in the MGA, which augments the public water supplies to Mandurah (outside the MGA). Proposals exist to develop a future wellfield to the north of the MGA to supplement the Perth Metropolitan Water Supply Scheme.

Usable groundwater resources in the MGA are found in the unconfined superficial aquifer and the deeper confined Leederville and Cattamarra aquifers. However, there is only limited potential for further development of groundwater resources in the area (Deeney, 1988, 1989) as the superficial aquifer is thin and the groundwater salinities in the Leederville and Cattamarra aquifers are relatively high.

1.4 Role of the Water and Rivers Commission

Groundwater resource utilisation and conservation in Western Australian country areas is administered by the Water and Rivers Commission in accordance with the Rights in Water and Irrigation Act 1914 and the Water and Rivers Commission Act 1995.

Under the Rights in Water and Irrigation Act 1914, the right to use, flow and control groundwater is vested in the Crown. This Act requires the compulsory licensing of all artesian wells (wells screened into confined aquifers) throughout Western Australia. In addition, non-artesian wells
within specific areas, proclaimed under the Act as Groundwater Areas, require licensing. Provision exists for exemption, if appropriate, of stock and domestic supplies from licensing requirements.

Groundwater licence administration in the MGA is the principal responsibility of the Water and Rivers Commission’s South West Regional office in Bunbury. The South West Region can obtain specialist advice on groundwater matters from the Water and Rivers Commission’s Allocation Branch located at the Hyatt Centre, East Perth.

All applications for groundwater well licences are made to the Water Resource Management and Planning Section of the Water and Rivers Commission’s South West Regional office.

1.5 Objectives of the allocation plan

The groundwater resources of the MGA are utilised for both public and private purposes and a management strategy is essential to protect users and conserve the resource.

The following allocation plan objectives have been set, in order to meet this management strategy:

1. Quantify the groundwater resources taking into account environmental constraints (i.e. wetlands);
2. Identify areas of beneficial use (i.e. priority areas for public water supply);
3. Identify current and future demands for groundwater; and
(4) Develop policies for managing and allocating the available groundwater resources for public and private purposes.

This allocation plan is intended to clearly state the policies of the Water and Rivers Commission. It reviews the current monitoring, existing allocation and potential availability of the groundwater resources within the groundwater area. Subsequent to this review, the plan proposes management policies for future groundwater allocation within the four designated subareas of the Murray Groundwater Area.

1.6 Principles of groundwater allocation and licensing

The policies and procedures of groundwater licensing in Western Australia are detailed in a report by Ventriss (1990). Groundwater licence allocations are aimed at ensuring equitable use of the State's groundwater resources, while protecting the long term security of those resources and having regard for the economic, social and environmental consequences.

Groundwater should be used efficiently to avoid wastage of the valuable resource. Applicants for groundwater licences should be made aware of this fact and those planning to use large volumes of water should demonstrate that conservative water use has been considered and will be implemented where possible.

Management of the groundwater resource, including regulatory controls on any abstraction, is based on the following objectives:
• To harvest water at a sustainable level, to conserve and protect the long-term security of the groundwater resources of the region and ensure that the use of the resource benefits as many people as possible (*Primary objective*).

• To ensure that, where possible, a reasonable quantity of water is available to existing enterprises, dependent upon a continued supply of good quality groundwater.

• To promote the allocation of the available groundwater resource on a basis which provides the most beneficial use to the community.

• To encourage efficiency in water use through improvements to methods of agriculture and irrigation, and encourage development consistent with regional planning and the landuse objectives for the region.
2. Social environment

2.1 Population

The population in the Shires of Murray and Waroona has expanded rapidly during the last three decades. The average annual growth during this time has been 4.5% in the Shire of Murray and 2.8% in the Shire of Waroona.

There are no accurate estimates of the current population in the MGA. However, in 1993, the Peel Development Commission estimated that the population was 9610 in the Shire of Murray and 3180 in the Shire of Waroona.

Essentially, the Murray Groundwater Area is rural. Administration and commercial centres for the rural areas are the towns of Pinjarra in the north and Waroona in the south. More than 1700 persons reside at Pinjarra, the largest population centre in the MGA.

The rapid expansion of Mandurah has led to increased urban development pressure in the Shire of Murray. As a result, the population in the Shire of Murray is expected to grow significantly in the future when proposed subdivisions near Ravenswood and Furnissdale are developed. Further urbanisation is proposed by Homeswest at Amarillo Farm, although this proposal is currently subject to Public Environmental Review.
The population in the Shire of Waroona is expected to increase only marginally in the future. This is due to the Shire's current policy of retaining large rural lots and limiting the development of small lots to the outskirts of town centres so they may be serviced with ease.

2.2 Landuse

Land usage in the MGA is subject to the planning schemes and strategies that have been set down by the Western Australian Planning Commission (WAPC) and the Shires of Murray and Waroona. These have been established in response to increasing development pressure and the need to zone land appropriately for the different uses within an area.

The WAPC has recently completed a detailed landuse study (Peel Regional Strategy, 1994) which encompasses the MGA. The Shires of Murray and Waroona each have Town Planning Schemes in place which set down the basis for land zoning and development.

The Shire of Murray is subject to a Local Rural Strategy, whereas the Shire of Waroona has a District Planning Strategy. Essentially, these strategies guide the future use and development of rural land in the shires.

Examples of the different landuses in the MGA are Special Rural/Rural Residential Zones (hobby farms), agriculture, horticulture and mining. Groundwater allocations and usage vary depending on the designated landuse. Special Rural/Rural Residential Zones (SRZ) are considered separately to rural landuse and are generally restricted to a groundwater allocation of 1500 kL/year per property.
Currently, the most dominant landuse in the MGA is agriculture. In the future, the number of SRZs and residential subdivisions in the Shire of Murray are likely to increase due to urban development pressure created by the growth of Mandurah. There is unlikely to be significant urban development pressure in the Shire of Waroona because of its distance from Mandurah. Horticultural and mining activities may therefore be pursued in future.

2.3 Industry

Agriculture has traditionally been, and continues to be, an important component of the region's economy. There are approximately 230 farming establishments in the Shires of Murray and Waroona, covering an area of approximately 80,000 hectares. Most of the land in the MGA has been cleared for agriculture.

The main agricultural activities in the Shires of Murray and Waroona are livestock production and crop and pasture production. Production and slaughtering of beef cattle and sheep are major sources of income for the region. There are also extensive piggery operations in the Shire of Murray and the State's largest piggery is located within the shire. Dairy cattle are farmed in the Shire of Waroona, although the industry is not as prominent in the shire as it once was, as dairy farming is relocating farther south.

Hay and fodder crops are grown in the area and market gardens are established in the north and south of the groundwater area. Corn and maize grown for stockfeed purposes and pasture land used
for cattle grazing are watered from the irrigation system in the Shire of Waroona. The high cost of water has curtailed usage of the irrigation system in recent years.

The region is becoming increasingly important as a mineral-producing area. Significant mining and processing operations are located within the Shires of Murray and Waroona. Alcoa has extensive bauxite mining operations and large alumina refineries are located at Pinjarra and Wagerup. The alumina refinery at Pinjarra is reported to be the largest in the world.

Mineral sands are also extracted from the region. Mines located near Waroona and Hamel produce ilmenite, leucoxene and zircon. Mineral sands are very prolific in the Waroona area and are obtained from the Yoganup Formation. This mineral-rich area, which was once a coastline, is referred to as the ‘Waroona Beach’ or ‘Waroona Coastline’.
3. Environmental considerations

3.1 Peel–Harvey Estuarine System

The Peel–Harvey Estuarine System is an important natural resource of Western Australia that has status both on the Register of the National Estate and also wetlands nominated for inclusion as Ramsar wetlands, and therefore entry to the List of Wetlands of International Importance.

Historical landuse and land management practices (catchment clearing and fertiliser use) have contributed to water quality problems in the Peel–Harvey Estuary over the last 15 years. In particular, the estuary has received more phosphorus from the Peel–Harvey Coastal Plain Catchment than it could assimilate. This has resulted in excessive growth of algae, which degrades the estuarine system and creates a serious public nuisance.

Clearing of vegetation in the catchment exacerbated the problem by causing a rise in the watertable and increasing run-off, thus requiring artificial drainage. The replacement of native vegetation with crops requiring increased nutrient applications has greatly contributed to the increased nutrient enrichment of the estuary.
An Environmental Review and Management Programme (ERMP) (Kinhill, 1988) resulted in a strategy to improve the condition of the estuary. This strategy included the construction of the Dawesville Channel to improve flushing, and active catchment management to reduce the nutrients entering the estuary. A proposal in the ERMP led to a general moratorium on clearing and drainage being set as a ministerial condition in 1989.

3.2 Statutory environmental protection

3.2.1 Environmental Protection (Peel–Harvey Estuarine System) Policy 1992

The Environmental Protection Authority (EPA) has prepared an Environmental Protection Policy for the Peel–Harvey Estuarine System which aims to protect the estuary from nutrient enrichment and noxious algal blooms. The major objective of the policy is to guide landuse so that the Peel–Harvey Estuarine System may become cleaner, healthy and resilient.

Protection of the Peel–Harvey Estuarine System will be effected by:

(1) Achieving management targets for phosphorus loads/concentrations to the Peel–Harvey Estuary;

(2) Implementing landuse principles which shall be employed by government agencies and local authorities in landuse planning and development control; and

(3) The Planning Policy which is to be consistent with the purpose and program of the Environmental Protection Policy for the Peel–Harvey Estuarine System.
3.2.2 Peel–Harvey Coastal Plain Catchment Statement of Planning Policy No. 2 1992

The Planning Policy for the Peel–Harvey Coastal Plain Catchment recognises the requirements of the Minister for the Environment in consultation with the Minister for Planning, by ensuring that any landuse changes which are likely to cause environmental damage to the estuary are prohibited through the implementation of planning controls.

Under the provisions of the Planning Policy, all developments in the catchment area should be related to the land capability, and specific management practices (such as effluent treatment, red mud amendment, revegetation and acceptable stocking rates) should be implemented in order to control the export of nutrients to the estuary.

The Planning Policy is implemented through the Town Planning Schemes. To achieve this end, the Western Australian Planning Commission has imposed a policy that all Town Planning Schemes operating within the Peel–Harvey Coastal Catchment shall require development to be subject to the provisions of the Planning Policy.

3.2.3 Swan Coastal Plain Lakes Environmental Protection Policy 1992 (Lakes EPP)

This policy prohibits unauthorised filling, mining, drainage into or out of, and effluent discharge into, specific wetlands identified in the policy. A proposed development is unlikely to receive environmental approval if the development involves such prohibited activities. A breach of the
policy may result in prosecution under Part V of the Environmental Protection Act 1986. Wetlands identified under this policy are afforded the highest level of protection under the Act.

The requirements of wetland conservation can extend beyond reserve or wetland boundaries. Land activities within a catchment can adversely impact on wetlands by changing water levels and water quality. This does not mean that development should not occur or that public acquisition of private land is necessarily required. Development should proceed in a manner that protects the wetland reserves environmental value, and is best controlled through the planning process (EPA, 1993).

3.2.4 Environmental Protection Authority Conservation Reserve System 1993 (System 6, Red Book)

Wetlands of the Swan Coastal Plain are protected from degradation by the Conservation Reserve System recommended by the Environmental Protection Authority (EPA) in their ‘System 6 (Red Book)’. All areas recommended in the Red Book have potential significance for conservation.

Wetlands on the Swan Coastal Plain are generally surface expressions of the shallow unconfined groundwater. The condition of wetlands, remnant phreatophytic vegetation and associated fauna is dependent upon groundwater. The maintenance of natural wetland water regimes is important due to their extreme sensitivity to watertable fluctuations. Groundwater abstraction may result in a localised reduction in the watertable, and such changes in the wetland water regime may affect both flora and fauna.
3.3 Non-statutory protection policies

3.3.1 Water and Rivers Commission wetland mapping, classification and evaluation

The Water and Rivers Commission has also produced a series entitled ‘Wetlands of the Swan Coastal Plain’. This series was produced to assist in effective wetland management, and incorporates wetland-boundary description and delineation, and detailed information concerning groundwater hydrology and groundwater-dependent flora and fauna. Management objectives defined within the documentation are aimed at wetland restoration, conservation and sustainable utilisation.

Further protection of wetlands is currently being investigated by the Department of Conservation and Land Management (CALM) in the form of buffer zones. CALM has recently produced a draft report entitled ‘Guidelines for Design of Effective Buffers for Wetlands on the Swan Coastal Plain, 1993’.

Wetlands and reserves currently identified within the MGA are listed in Table 1 and shown on Figure 2.
<table>
<thead>
<tr>
<th>Identity No.</th>
<th>Conservation Reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td>C50</td>
<td><strong>Peel Inlet</strong>: situated due south of Mandurah. Comprises Reserves B4990 (139 ha) and B24036 (343 ha) (Conservation of Flora and Fauna) and C28087 (891 ha) (Conservation of Fauna), vested in the W.A. Wildlife Authority Act; Reserve C8185 (Recreation), vested in Shire of Mandurah; Reserve C2707 (98 ha) (Public Utility and Conservation of Flora and Fauna); Reserve C7502 (146 ha) (Water); Peel Inlet areas surrounding Reserve C8185 including to the north of Reserve C28087 and west of Reserve B4990, and in entrance to the Inlet; and Coolup A.A. lots 223 (41 ha), 259 (65 ha), 276 (12 ha) to 278, Murray Locations 55, 295 (102 ha), 452 (81 ha), 842 and 1262, and part of Cockburn Sound Locations 5 and 16.</td>
</tr>
<tr>
<td>C51</td>
<td><strong>Harvey Estuary</strong>: Located to the east of Old Coast Road. Comprised of Reserve A23756 (Conservation of Flora and Fauna), vested in the W.A. Wildlife Authority; Reserve A31922 (Recreation), vested in the Shire of Murray; Reserve C2990 (72 ha) (Recreation and Camping), vested in the Mandurah Road Board; Reserves C36126 (31 ha) (Drainage and Conservation of Flora and Fauna) and C860 (Water), both vested in the Minister for Water Resources; Reserve C27528 (Recreation), Reserve C17318 (2 ha) (Public Utility), and part of Reserves C15028 and C25391 (Drainage); southern portion of Harvey Estuary; and Murray Locations 77, 733, 1209, 1275, 1496, 2320, 2986 and parts of Murray Locations 437, 479, 613, 720 and 793.</td>
</tr>
<tr>
<td>C52</td>
<td><strong>Lakes McLarty and Mealup</strong>: Situated on the eastern side of the Harvey Estuary, about 16 km south-west of Pinjarra. Consists of Reserve A24739 (Conservation of Flora and Fauna), vested in the W.A. Wildlife Authority; Reserve C6627 (Watering Place for Stock); vacant Crown land; Murray Locations 252, 306, 349, 402, 427, 430, 431 and 504, and parts of Murray Locations 350, 605, 699, 730, 750, 1154 and 1155.</td>
</tr>
<tr>
<td>C53</td>
<td><strong>Coolup Reserves</strong>: Situated adjacent to South Western Highway, 12 km south of Pinjarra. Consists of Reserves A20585 (8 ha) (Stopping Place), C31437 (12 ha) (Government Requirements), C31438 (6 ha) (Camping) and C31439 (17 ha) (Drainage).</td>
</tr>
<tr>
<td>C58</td>
<td><strong>Reserve A23172, Harvey River</strong>: Situated adjacent to Harvey River. Consists of Reserve A23172 (58 ha) (Camping), vested in the Shire of Waroona.</td>
</tr>
<tr>
<td>C59</td>
<td><strong>Reserve C22199, Wagerup</strong>: Located 7 km south-west of Wagerup. Contains Reserves C22199 (301 ha) (Conservation of Flora and Fauna), vested in the W.A. Wildlife Authority.</td>
</tr>
</tbody>
</table>
3.4 Guidelines for New Horticultural Developments

The (Draft) Guidelines for New Horticultural Developments within the Peel–Harvey Catchment have been prepared by the Department of Agriculture in conjunction with the Peel Horticultural Landcare Group. The Guidelines are based on the best information available at the time and may require updating pursuant to further test results and new technologies.

The Guidelines aim to:

(1) Prevent the development of environmentally unacceptable horticultural properties within the Peel–Harvey Catchment;

(2) Streamline the process required for obtaining permission for horticultural developments; and

(3) Solve problems relating to proposed developments, before investments are made.

These Guidelines apply to the development of new horticultural properties and the expansion of existing properties. However, they do not apply to existing horticultural enterprises.

3.5 Peel Inlet Management Authority

The Peel Inlet Management Authority (PIMA) was established in 1977, under the provisions of the Waterways Conservation Act 1976, to maintain the Peel waterways. The Peel Inlet Management Authority is now under the jurisdiction of the Water and Rivers Commission.
The specific duties of PIMA are:

(1) To preserve and enhance the quality of the environment and amenity of the waters of the Peel Inlet and associated land;

(2) To control, and wherever practicable to prevent, any act or omission which causes or is capable of causing pollution of those waters or that land;

(3) To provide advice and disseminate knowledge on the conservation and good management of the Peel–Harvey System; and

(4) In so far as is practicable, to act in concert with, consult, and make arrangements with relevant local government authorities, residents and other persons affected under the Waterways Conservation Act 1976.

Located in Mandurah, the Peel Inlet Management Authority works in co-operation with other State and Local Government Authorities to perform their role. In fulfilling their duties, PIMA has released a revised Peel Inlet Management Programme which will guide the future use of the waterway.

3.6 Community Catchment Centre

The Community Catchment Centre has been established in Pinjarra to provide an operational focus for the Peel–Harvey catchment management program. The Centre's main objective is to improve
the overall sustainability of landuse in the catchment by developing operational strategies that will reduce the phosphorus load entering the Peel–Harvey Estuary.

Significant programs developed through the Centre include the modification of the regional drainage system to increase nutrient filtering, the use of bauxite residue as a soil amendment to reduce fertiliser loss and increase pasture production, the use of effluent management systems for intensive animal industries, and the provision of advice and assistance with tree planting programs.

The Community Catchment Centre has been successful in raising community awareness of the estuary nutrient problems and in developing practical strategies that are effective in reducing phosphorus loads. This work has been performed in conjunction with local landowner groups and Local Government Authorities in the catchment. The Department of Agriculture has been strongly involved in the Community Catchment Centre by providing funding, administrative support and staff to the Centre.

3.7 Dawesville Channel

The Dawesville Channel has been constructed in an attempt to improve the quality of water in the Peel–Harvey Estuary as part of a suite of measures implemented to address the algal problems experienced in the waterway in recent years.
This channel is designed to inhibit the growth of blue-green micro algae, such as *Nodularia*, by exporting excess nutrients to the Indian Ocean. The channel should serve to maintain a more consistent marine regime through improved flushing.
4. Physical environment

4.1 Climate

The MGA has a Mediterranean climate, experiencing mild, wet winters and hot, dry summers. Figure 3 shows the long-term annual rainfall for Mandurah, Pinjarra and Waroona. Monthly rainfall data for Mandurah, Pinjarra and Waroona are presented graphically in Figure 4.

The annual rainfall is approximately 900 mm near the coast and it increases to about 1100 mm at the Darling Scarp. Isohyets in the area generally trend north to south. Rainfall normally exceeds evaporation during the five months from May to September. The average annual evaporation is approximately 1400 mm.

4.2 Geomorphology

The slope and relief of the land and nature of the soils are basic considerations in planning. They determine, to a large extent, how the land may be used and the ease or difficulty associated with various activities. Regional geology has a major influence on the pattern of landform–soil units and provides the basis for primary classification.

The geomorphology (landform–soil relationships) of the region has been previously covered in detail by several authors (McArthur and Bettenay, 1960; Playford et al., 1976; Seddon, 1972). Figure 5 illustrates the geomorphology of the MGA.
Two geomorphological provinces have been identified in the groundwater area. These are:

- The Swan Coastal Plain of eolian and fluviatile sediments
- The Darling Plateau of Archaean crystalline rocks

4.2.1 Swan Coastal Plain

In the vicinity of the groundwater area, the Swan Coastal Plain is about 25 km wide. The deposits in the plain generally show a progressive decrease in elevation and age from east to west. The oldest (and highest) deposits occur at the foot of the Darling Scarp, whereas the youngest adjoin the present coast. The deposits occur in bands which are generally parallel to the present coastline.

There are several geomorphological units in the Swan Coastal Plain. These are:

- The Coastal Belt
- The Bassendean Dunes
- The Pinjarra Plain
- The Ridge Hill Shelf

Coastal Belt

The Coastal Belt contains the Quindalup and Spearwood Dune systems. The Quindalup Dunes do not feature in the MGA and will not be described.
The Spearwood Dunes consist of yellow to white (slightly calcareous) quartz sand that has been leached from the underlying limestone. The contact between the sand and unleached limestone is irregular, with rounded pinnacles of limestone extending upwards into the sand. The dunes form a gently undulating landscape that has been consolidated by rainwater solution to form hills of relatively low relief. The Spearwood Dunes exist in the MGA near the junction of the Peel Inlet and Harvey Estuary.

**Bassendean Dunes**

The Bassendean Dunes lie between the Coastal Belt and the Pinjarra Plain in a zone up to 11 km wide. The dunes form a gently undulating landscape of eolian sand. Swampy areas and small lakes commonly occupy the interdunal depressions.

The Bassendean Dunes are generally oriented parallel to the present coastline and probably accumulated as shoreline deposits and coastal dunes in the Early to Middle Pleistocene during interglacial periods of high sea level. These deposits originally consisted largely of lime sand with smaller proportions of quartz sand, but the carbonate has been almost entirely leached out in most areas.

The present shape of the dunes has been largely inherited from that of the original coastal dunes, but the relief has been significantly diminished as a result of leaching and differential wind erosion. The Bassendean Dunes occur quite extensively in the western part of the MGA.
Pinjarra Plain

The Pinjarra Plain is a piedmont and valley-flat alluvial plain, developed in front of the Darling Scarp and along the main river courses. It consists predominantly of clayey alluvium that has been transported by rivers and streams from the Darling Plateau. The Pinjarra Plain is bordered by the Bassendean Dunes in the west and by the Ridge Hill Shelf in the east.

The Pinjarra Plain is generally 5 km wide, although it is about 15 km wide (in an east–west direction) near the Peel Inlet. It is quite extensive in the eastern part of the MGA and reaches a maximum elevation of about 80 m above sea level near the Darling Scarp. The plain is surfaced mainly by clays and loams in the valleys and by poorly sorted clayey sands and gravels in the piedmont zone and has abundant seasonal swamps.

Ridge Hill Shelf

The Ridge Hill Shelf is the most easterly landform of the Swan Coastal Plain and is bounded by the Darling Scarp in the east and by the Pinjarra Plain in the west. This landform comprises the colluvial slopes which form the foothills of the Darling Plateau. It represents the dissected remnants of a sand-covered, wave-cut platform.

The Ridge Hill Shelf is approximately 2 km wide and exists in a thin band (oriented north–south) near the eastern boundary of the MGA.
4.2.2 Darling Plateau

The Darling Plateau, immediately east of the Swan Coastal Plain, is an ancient erosion surface that has an average elevation of 300 m above sea level. The Archaean bedrock is capped by extensive laterite that has been partially dissected by the present drainage. The plateau is bounded to the west by the Darling Scarp, the fault-line scarp of the Darling Fault. The Darling Scarp formed coastal cliffs during the late Tertiary or early Pleistocene when shoreline deposits were laid down.

4.3 Geology

Regional setting

The MGA is located on the southern part of the Perth Basin, a deep linear trough of sedimentary rocks extending north-south for some 1000 km in the southwest of Western Australia beneath the coastal area, continental shelf and continental slope. The basin covers an area of 45 000 km² onshore and 55 000 km² offshore.

The Perth Basin is essentially a half-graben (down-faulted block) bounded to the east by the north-south trending Darling Fault, some 1000 km long, which separates the basin from the Archaean crystalline rocks of the Yilgarn Craton. The eastern limits of the MGA extend onto the Darling Plateau, a laterite-capped plateau overlying the Archaean rocks immediately east of the Perth Basin.
The total thickness of Phanerozoic sedimentary rocks in the Perth Basin could reach a maximum of 15,000 m. However, the total thickness of these rocks in the MGA may be only 5000 m (Deeney, 1989). Exposure of rock outcrop is poor throughout the Perth Basin with much of the geological information based on interpretation of exploratory drilling and geophysical data. There is an extensive Quaternary cover (sand, silt, clay and limestone) over the basin which masks much of the underlying geology.

**Structure**

The structure of the Perth Basin is dominated by faulting with the overall structure of the basin having been described as that of an intensely faulted half-graben (Playford et al., 1976). The basin is defined to the east by the Darling Fault and limited to the west (for the most part) by the continental slope.

In the groundwater area, as with much of the basin, there is a network of faults in the earliest Cretaceous and older rocks. However, much of this complex fault pattern is not seen at the surface owing to the extensive cover of Quaternary deposits. The positions of most faults have been determined by seismic surveys and deeper exploratory holes.

The MGA is within the Dandaragan Trough, which is the largest and deepest section of the Perth Basin. The trough, which becomes shallower to the south of the Perth Basin, is bounded by the Darling Fault in the east and by the Harvey Ridge in the south.
The present form of the Dandaragan Trough was established at the end of the Neocomian Stage. However, during the intra-Neocomian break-up of the Indian and Australian plates and the onset of sea-floor spreading, widespread uplift and erosion occurred.

The uplift and erosion has been greatest at the Harvey Ridge and this action caused the Late Jurassic Yarragadee Formation to be uplifted and eroded from most of the groundwater area.

Folding and faulting of the Dandaragan Trough has resulted in low-angle dipping of the Cattamarra Coal Measures and Eneabba Formation. The formations have been block faulted along northeasterly and northwesterly trending faults and they have also been downfaulted against Precambrian granitic rocks of the Yilgarn Craton by the Darling Fault.

In the north of the MGA, the Cattamarra Coal Measures has been unconformably overlain by the Gage Formation, the South Perth Shale and the Leederville Formation. The Leederville Formation, deposited after the Neocomian break-up, is unfaulted and has been gently folded. A broad synclinal structure near the Harvey Ridge may have formed as a result of flexure and differential compaction of the sediments over faults.

**Stratigraphy**

Information on the stratigraphy of the sedimentary rocks within the MGA has been gathered from the logs of numerous boreholes. Stratigraphic cross sections traversing the Perth Basin in an east-west direction have been determined by the Geological Survey of Western Australia at numerous locations between the Darling Scarp and the Indian Ocean.
The most recent investigations have been referred to and these include:

- Bulletin 142, Perth Region *Line D-D'* (Davidson, 1995)
- Harvey Borehole Line (Deeney, 1989)
- Superficial formations between Pinjarra and Bunbury (Deeney, 1988)
- Hydrogeology of the Mandurah–Pinjarra Area, Perth Basin, W.A. (Commander, 1975)

Detailed descriptions of the lithology and stratigraphic sequence are found in the reports listed above.

The full stratigraphic sequence is summarised in Table 2, which includes an indication of the aquifer potential. Subsurface geology and structure are shown in Figure 6 and geological cross sections from the borehole lines are provided in Figures 7, 8, 9 and 10.
Table 2. Sedimentary stratigraphic sequence of the Perth Basin

<table>
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<tr>
<th>Formation</th>
<th>Member</th>
<th>Aquifer</th>
<th>Comments</th>
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</thead>
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<tr>
<td>Superficial formations</td>
<td>Safety Bay Sand</td>
<td>superficial aquifer</td>
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<td></td>
<td>Beecher Sand</td>
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<td></td>
<td>Tamala Limestone</td>
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<td></td>
<td>Bassendean Sand</td>
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<td></td>
<td>Gnangara Sand</td>
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<tr>
<td></td>
<td>Guildford Clay</td>
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<td>May contain sand lenses</td>
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<tr>
<td></td>
<td>Yoganup Formation</td>
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<td>superficial aquifer</td>
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<td></td>
<td>Ascot Formation</td>
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<td>Rockingham</td>
<td>aquifer</td>
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<tr>
<td>Osborne Formation</td>
<td>Kardinya Shale</td>
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<tr>
<td></td>
<td>Member</td>
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<tr>
<td>Leederville Formation</td>
<td>Pinjar Member</td>
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<td>Wanneroo Member</td>
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<td></td>
<td>Mariginup Member</td>
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<tr>
<td>South Perth Shale</td>
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<td>Yarragadee</td>
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<td>Parmelia Formation</td>
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<td>Yarragadee Formation</td>
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<td></td>
<td>Cattamarra Coal Measures</td>
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<td>aquifer in MGA)</td>
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<tr>
<td></td>
<td>Eneabba Formation</td>
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</tbody>
</table>

Confining layer

The formations relevant to this allocation plan (i.e. those with major aquifer potential/development) are described briefly below in order of increasing age.

Superficial formations

The 'superficial formations' is the collective name used to describe surface or near-surface sediments on the Swan Coastal Plain (Section 4.2) which, despite varying lithologies, form a single, predominantly unconfined aquifer system (Allen, 1976). The sediments consist of a laterally and
vertically variable sequence of sand, limestone, silt and clay (Table 2). They are of Cainozoic age (principally Quaternary) and unconformably overlie sediments of Mesozoic age. The superficial formations between Pinjarra and Bunbury range in thickness from about 12 to 90 m and rest on a gentle westerly sloping erosional surface (Deeney, 1988).

The Leederville Formation lies unconformably below the superficial formations throughout most of the groundwater area. In the northwest, the superficial formations unconformably overlie the Osborne Formation and Rockingham Sand. However, in the northeast, the superficial formations unconformably overlie the Cattamarra Coal Measures.

Rockingham Sand

The Rockingham Sand (Passmore, 1967) consists of medium- to coarse-grained subangular quartz sand which is slightly silty and felspathic. It is of shallow marine origin and has a maximum thickness of about 50 m in the MGA. The Rockingham Sand occupies an eroded channel incised into the Leederville Formation (Wanneroo Member) and is unconformably overlain by the superficial formations.

Osborne Formation

The Osborne Formation (McWhae et al., 1958) consists of interbedded sandstone, siltstone and shale. It is characteristically glauconitic (an indicator of a very slow sedimentation rate) and is of shallow marine origin.
In the MGA, the Osborne Formation occurs only near the Peel Inlet. It is unconformably overlain by the superficial formations and is unconformably underlain by the Leederville Formation. The formation has importance as a confining bed, separating the higher salinity water of the Peel Inlet from the Leederville Formation.

**Leederville Formation**

The Leederville Formation (Cockbain and Playford, 1973) consists of interbedded sandstone, siltstone and shale which were laid down during the Early Cretaceous in both marine and non-marine depositional environments. The percentage of sandstone in the formation increases westwards from about 40% near the Darling Scarp to about 80% near the coast (Deeney, 1989). The individual sandstone beds are about 6 m in thickness east of the Harvey River Main Drain and are up to 20 m thick to the west.

The Leederville Formation generally thickens westwards, from a thickness of about 40 m near the Darling Scarp to about 180 m thick in the centre of the Harvey Borehole Line adjacent to the southern boundary of the Waroona subarea. The formation reaches a maximum thickness of approximately 270 m adjacent to the Harvey Estuary.

The Leederville Formation comprises three distinct and mappable units which are described, for the first time, as members of the formation (Davidson, 1995). In order of deposition these are the Mariginiup Member, the Wanneroo Member and the Pinjar Member.
The new nomenclature has been used as far south as the South Dandalup River (Davidson, 1995), and despite this revision of the Leederville Formation not encompassing the entire MGA, the new nomenclature has been adopted within this allocation plan.

Previous hydrogeological investigations have recognised the existence of a green clay marker bed within the Leederville Formation, and this is now correlated with the boundary between the Wanneroo and Mariginiup members. This clay marker consists of glauconitic and calcareous sands, silts and pebble beds.

In the eastern part of the groundwater area, the Leederville Formation is unconformably overlain mainly by the superficial formations, and in the northwest by the Osborne Formation and Rockingham Sand.

In the north of the MGA, the formation is conformably underlain by the South Perth Shale and is unconformably underlain by the Yarragadee Formation and the Cattamarra Coal Measures. However, in the south of the MGA, the formation is unconformably underlain by the Cattamarra Coal Measures and the Eneabba Formation.

**South Perth Shale**

The South Perth Shale (Playford et al., 1976) is predominantly of shallow-marine origin and consists mainly of thinly interbedded siltstone and shale with minor thin, sandy beds and locally, thin calcareous beds.
The South Perth Shale has been distinguished only in the northwestern part of the groundwater area and conformably overlies the Gage Formation. The unit unconformably overlies the Cattamarra Coal Measures and the Yarragadee Formation (where present). The South Perth Shale is overlain with conformable and transitional contact by the Leederville Formation. It forms an aquiclude between the Leederville and Yarragadee / Cattamarra Coal Measures Formations.

**Gage Formation**

The Gage Formation (Davidson, 1995), which was formerly referred to as the Gage Sandstone Member of the South Perth Shale, consists of interbedded sandstones, siltstones and shales. The sandstone beds are of variable thickness and range from 3 to 30 m. They consist of fine- to coarse-grained sand, similar to that of the Yarragadee Formation, from which they probably originated by erosion.

The Gage Formation exists only in the northwestern part of the groundwater area and unconformably overlies the Cattamarra Coal Measures and the Yarragadee Formation (where present). It is overlain with conformable and abrupt contact by the South Perth Shale.

**Yarragadee Formation**

The Yarragadee Formation (Playford et al., 1976) consists of laterally discontinuous interbedded sandstones, siltstones and shales which were laid down during the Middle to Late Jurassic in a non-marine depositional environment. The formation occurs in fault blocks, faulted into juxtaposition with the underlying Cattamarra Coal Measures (Allen, 1979).
The Yarragadee Formation has been completely eroded from most of the MGA. The formation exists only in the northern part of the MGA (in juxtaposition with the Cattamarra Coal Measures) and has a maximum thickness in the groundwater area of about 300 m. The formation is unconformably overlain by the Gage Formation and possibly by the South Perth Shale and the Leederville Formation.

**Cattamarra Coal Measures**

The Cattamarra Coal Measures, a former member of the Cockleshell Gully Formation, has been given formation status in the Perth Region (Mory et al., 1996). The Cattamarra Coal Measures consists of interbedded sandstone, siltstone, shale and coal.

In the northern part of the MGA, the Cattamarra Coal Measures has been block faulted upwards into juxtaposition with the Yarragadee Formation. The underlying Eneabba Formation is absent within these northern parts of the groundwater area. In the north of the MGA, the Cattamarra Coal Measures is unconformably overlain by the Gage Formation, the South Perth Shale and the Leederville Formation.

The Cattamarra Coal Measures extends throughout the MGA, and despite significant erosion of the formation in the southern parts of the groundwater area, the allocation plan has adopted and incorporated the previously described stratigraphic nomenclature changes.

**Eneabba Formation**
The Eneabba Member, previously a constituent of the formerly defined Cockleshell Gully Formation, has been given formation status, and is therefore termed the Eneabba Formation. The new nomenclature has been included within the allocation plan. The Eneabba Formation consists of interbedded sandstone, siltstone, shale and minor carbonaceous matter.

The Cattamarra Coal Measures and Eneabba Formation were laid down during the Early to Middle Jurassic in a non-marine depositional environment. Individual beds of sandstone in the formations are up to 40 m thick; however, near the Darling Scarp, the sandstone beds are only about 5 m thick (Deeney, 1989).

To the south of the MGA, the Eneabba Formation has been block faulted upwards into juxtaposition with the Cattamarra Coal Measures, although most of the Cattamarra Coal Measures has been eroded. The base of the Eneabba Formation was not encountered, although it is believed that the Eneabba Formation reaches a maximum thickness of about 2000 m in the area (Playford et al., 1976). In the south, the Eneabba Formation is unconformably overlain by the Leederville Formation.
5. Hydrogeology

5.1 Groundwater occurrence

Groundwater occurs in the superficial formations beneath the Swan Coastal Plain and the underlying geological formations of the Perth Basin. The various aquifers in the MGA are identified in Figure 8. The most important aquifers, containing the largest volumes of groundwater, are found within the 'superficial formations' and the Leederville Formation and Cattamarra Coal Measures.

Groundwater availability and quality information, on a subarea basis, is detailed in Chapter 9. A general overview of each aquifer system is provided below.

5.2 Superficial aquifer

The superficial formations form an unconfined aquifer system which is bounded to the east by the Darling Scarp and to the west by the ocean (Deeney, 1988). The superficial aquifer consists predominantly of clay and sand in the east and of sand and limestone in the west. It is a multilayered aquifer which is inhomogeneous and anisotropic. The Guildford Clay is particularly clayey in the east, adjacent to the Darling Fault, where it tends to act as an aquitard.
Test pumping analyses indicate that vertical hydraulic conductivities are much less than horizontal hydraulic conductivities because of the stratification and lithological variation of the aquifer.

The watertable is generally within 1 to 2 m of the ground surface on the Pinjarra Plain, although beneath the Bassendean and Spearwood Dunes it can be up to 30 m below the surface. The watertable fluctuates seasonally and intersects the ground surface in many parts of the area during the winter months to maintain numerous wetlands.

Generally, the seasonal range in the watertable elevation is about 1 to 2 m. The largest seasonal range occurs close to the Darling Scarp and the smallest in the Tamala Limestone.

**Groundwater recharge**

Recharge to the aquifer system is by direct infiltration of rainfall with lesser amounts from runoff. Recharge rates vary across the coastal plain as a result of the variation in lithology, depth to watertable and topographic gradient. Generally, recharge rates are likely to be higher in the western and central parts of the coastal plain, rather than in the east, owing to the lower clay content of the sediments and low topographic gradient.

Downward flow through the Guildford Clay is generally low. South of Waroona, flood irrigation and leakage from irrigation channels provide additional sources of recharge to the Guildford Clay and this may cause temporary waterlogging during summer.
Most recharge to the Yoganup Formation in the superficial aquifer occurs in a discontinuous zone along the foot of the Darling Scarp, where the formation is exposed or the overlying sediments are thin.

Generally, there is a downward-head difference between the watertable and the base of the superficial aquifer. However, upward-head differences are present near discharge boundaries and in other areas because of the confinement of the aquifer by the Guildford Clay or the clay in the Jandakot Beds of the Ascot Formation (Kendrick et al., 1991).

Widespread significant head differences reflect the vertical anisotropy of the aquifer. The predominance of downward-head differences indicate that regular recharge occurs throughout the area. However, in the drained areas that cover most of the coastal plain, much of the water that is recharged is probably intercepted by the drains before it reaches the lower part of the aquifer.

Inflow to the superficial aquifer may occur locally by upward leakage from the Leederville aquifer. This occurs in the western part of the MGA, where there are increasing hydraulic heads with depth and where there are no confining beds between the underlying aquifer and the superficial aquifer.
Groundwater Flow

The presence of watercourses, lakes and inlets has resulted in the formation of a complex groundwater flow regime. Three regional flow systems are recognised in the superficial aquifer between Pinjarra and Bunbury (Deeney, 1988). These are the Serpentine, Waroona and Myalup flow systems. Only the Serpentine and Waroona flow systems feature in the MGA and will be described. These are shown in Figure 11.

Waroona flow system

The Waroona flow system is bounded by the Peel Inlet, the Harvey Estuary and the Harvey River in the west, the Murray River in the north and east, and the Darling Scarp in the east.

The eastern part of the Waroona flow system consists predominantly of clay. The western part of the flow system consists mainly of sand, although limestone exists near the Peel Inlet and the Harvey Estuary. The aquifer transmissivity in the Waroona flow system is variable and ranges from 100 m²/day in the eastern part of the flow system to about 500 m²/day in the northwest, where sand is prevalent.

Groundwater in the Waroona flow system generally flows in a westerly direction from the Darling Scarp to the Harvey River. However, towards the north of the flow system, groundwater flows in a northwesterly direction from the groundwater divide (which is adjacent and parallel to the Murray River) to the Peel Inlet and Harvey Estuary. The saturated thickness of the aquifer is generally 20 to 30 m, although it decreases to about 10 m along the southern margin of the Peel Inlet.
Serpentine flow system

The Serpentine flow system is bounded by the Serpentine River in the west, the Murray River in the south, and the Darling Scarp in the east. The southern part of the Serpentine flow system has been described by Deeney (1988) and the northern part of the system has been covered by Davidson (1995).

The southern part of the Serpentine flow system (south of the South Dandalup River) consists almost entirely of clay. Here, the aquifer transmissivity is low and is estimated to be less than 100 m²/day.

Groundwater in the southern part of the Serpentine flow system flows in a westerly direction from the Darling Scarp to the Murray River. The saturated thickness is generally about 20 m, although it decreases near the scarp.

The northern part of the Serpentine flow system consists predominantly of clay; however, sand is also present in the central area. Aquifer transmissivities range from 200 to 300 m²/day.

Groundwater in the northern part of the Serpentine flow system generally flows in a westerly direction from the Darling Scarp to the Serpentine River. However, towards the south of the northern flow system, the groundwater tends to flow in a west-southwest direction towards the Murray River. The saturated thickness of the aquifer is generally about 10 m but increases in the west near the Serpentine River and in the northeast near the Darling Scarp.
Groundwater discharge

Groundwater discharges from the superficial aquifer into the major watercourses, inlets and coastal lakes that form the boundaries of the flow system. Groundwater also discharges to the large number of drains and smaller rivers which are present in the central and eastern parts of the area.

The presence of the Guildford Clay prevents groundwater discharge from the basal section of the aquifer to the rivers and drains which flow across it. The Murray River has completely eroded the Guildford Clay to expose the Yoganup Formation and groundwater discharges directly into the river from both the Waroona and Serpentine flow systems.

Significant quantities of groundwater are lost by evapotranspiration from the wetlands and areas where the watertable is at a shallow depth. Groundwater discharge from the Guildford Clay is mainly by evapotranspiration.

Discharge to the deeper aquifers by downward leakage occurs locally throughout most of the project area, in zones where downward hydraulic gradients exist and confining beds are absent. Adjacent to and west of the Darling Scarp the surficial sediments are thin, and discharge to the underlying Leederville aquifer constitutes the principal recharge mechanism of the Leederville aquifer in these areas.
Groundwater salinity

The groundwater salinity in the MGA has been investigated by Deeney (1988) and Davidson (1995). The groundwater salinity of the superficial aquifer in the MGA is illustrated in Figures 12 and 13. It is variable and ranges from less than 250 mg/L total dissolved solids (TDS) to more than 7000 mg/L. Groundwater with salinity less than 500 mg/L is primarily restricted to discontinuous zones near the Darling Scarp, in the Waroona and Serpentine flow systems.

A saline interface is present near the western boundary of the Waroona flow system and extends about 0.5 to 1.0 km inland at the base of the aquifer. Groundwater is saline (greater than 7000 mg/L) near the Peel Inlet and Harvey Estuary due to the close proximity of the salt-water interface.

Groundwater salinity at the base of the aquifer is generally less than 1500 mg/L, except near the Peel Inlet, Harvey Estuary and Harvey River. Salinities higher than 1500 mg/L also occur on the eastern side of the Murray River.

The salinity of the groundwater at the watertable is varied. Groundwater with salinity less than 500 mg/L occupies an elongated zone parallel to the Harvey Estuary and Harvey River. A region of higher salinity (in excess of 3000 mg/L) in the eastern part of the Waroona flow system may be attributed to irrigation methods practised in the region.
Groundwater salinity to the north of the South Dandalup River is generally less than 1000 mg/L, except along the Serpentine River near Lake Goeegrup and the Peel Inlet (Davidson, 1995).

Salinity generally increases in the direction of groundwater flow. However, other factors strongly influence the salinity distribution and these include variations in permeability, evapotranspiration from the shallow watertable, irrigation in the Waroona area, downward leakage through the Guildford Clay, and upward leakage locally from the Mesozoic sedimentary strata.

The groundwater salinity is generally higher in the Guildford Clay than in the underlying strata. Variations in salinity of more than 1000 mg/L may be recorded in the Guildford Clay because of seasonal changes in the position of the watertable and this may result in the deposition of stored salt on a seasonal basis. The clayey sediments of the Guildford Clay inhibit rainfall infiltration, resulting in high evaporation rates and concentration of salts.

5.3 Rockingham Sand aquifer

The Rockingham Sand is a semi-unconfined aquifer, which is confined locally by the discontinuous clay lenses at the base of the superficial aquifer. The two aquifers are in hydraulic connection where the clay lenses are absent.
The Rockingham sand aquifer is recharged by downward leakage from the superficial aquifer and by upward leakage from the Leederville aquifer. Groundwater in the aquifer flows over a salt-water interface to the ocean. Upcoming of the salt-water interface may readily occur as a result of groundwater abstraction from high yielding wells. Groundwater salinity is highly variable and may range from about 500 mg/L to more than 3000 mg/L TDS.

5.4 Leederville aquifer

In the MGA, the Leederville aquifer consists only of the Leederville Formation. The Leederville aquifer is a multilayered groundwater flow system consisting of discontinuous interbedded sandstones, siltstones and shales. The percentage of sandstone in the aquifer increases westwards from about 40% near the Darling Scarp to about 80% near the coast. The aquifer has a maximum thickness of some 270 m, decreasing to about 40 m near the Darling Scarp and 80 m near the coast at Lake Preston.

Previous hydrogeological investigations have recognised the existence of a distinctive green clay bed within the Leederville Formation. The green clay bed subcrops beneath the superficial sediments approximately 4 km west of North Dandalup to the north, and about 1 km west of Pinjarra through the central margin of the MGA (Figure 14). The thickness of the green clay ranges from 6 m in the east to 4 m in the west, and is a bright green, sandy, silty clay commonly in association with shells and granitic pebbles (Commander, 1975).
The green clay bed divides the Leederville Formation into two distinct members, previously designated the 'upper' and 'lower' Leederville aquifers and now correlated with the Wanneroo and Mariginiup Members. The upper Leederville aquifer occurs only west of the green clay marker subcrop, and only the lower Leederville aquifer is present east of the clay marker (Figure 9).

A previous study detailing the safe yield of the Leederville aquifer within the Mandurah area adjacent to the MGA observed that the hydrostatic heads within the Leederville aquifer above and below the green clay bed were different. Heads below the green clay bed were approximately 4 m greater than those within the upper section of the aquifer. The differences in hydrostatic head indicate that in the northern extent of the MGA, the green clay marker may act as a semi-continuous confining layer.

The natural seasonal variation in potentiometric head within the aquifer is 0.5 to 1.0 m (Deeney, 1989). In areas of high groundwater abstraction, the seasonal variations may be more than 10 m. The horizontal hydraulic conductivity of sandstone beds in the Leederville aquifer may locally reach 10 m/day, and that of the siltstone and shale is about $1 \times 10^{-6}$ m/day.

**Groundwater recharge**

The Leederville aquifer is recharged by downward leakage from the superficial aquifer. This occurs in areas where there is direct contact and hydraulic connection between the two aquifers. Recharge due to direct infiltration from the overlying superficial formations occurs mainly along the central and eastern margins of the Swan Coastal Plain where downward hydraulic heads prevail.
The two-aquifer system is such that the upper and lower Leederville aquifers are in hydraulic connection, and therefore downward and lateral leakage from the upper aquifer partially constitutes the recharge mechanism of the lower aquifer. However, adjacent to the Darling Scarp where the designated upper Leederville aquifer is not present, downward leakage of groundwater from the superficial formations constitutes the recharge mechanism of the lower Leederville aquifer.

Recharge to the upper and lower Leederville aquifers has been inferred in regions with watertable contours in excess of 5 m AHD. In areas with sufficient dynamic head to drive the vertical groundwater flow, such flow is permitted from the overlying strata that typically consist of sand and are devoid of clay.

Pumping has reduced the hydraulic heads within the aquifer, increasing the area over which recharge is occurring. By further increasing the groundwater abstraction from the Leederville aquifer, the hydraulic gradient between the superficial and Leederville aquifers will increase, thereby inducing additional groundwater recharge to the Leederville aquifer. Previous studies have postulated that the aquifer is ‘full’, and that recharge rates are dependent upon the rate of groundwater abstraction (Wharton, 1990).

**Groundwater flow**

Groundwater in the Leederville aquifer flows westwards to discharge offshore. To the north of the MGA, the upper Leederville aquifer of the Nambeelup subarea contributes throughflow to recharge
the Rockingham Sand aquifer north of Mandurah, where it exists in channels eroded into the
Leederville Formation.

**Groundwater discharge**

Discharge to the underlying Cattamarra aquifer may occur by downward leakage where the South
Perth Shale is absent and where downward hydraulic gradients exist. There may be some upward
discharge to the superficial aquifer in zones where the potentiometric heads in the Leederville
aquifer are higher than those in the superficial aquifer and the two aquifers are hydraulically
connected

**Groundwater salinity**

The salinity of the groundwater in the upper part of the Leederville aquifer ranges between 500 and
2000 mg/L TDS. In the lower part of the aquifer, the salinity is generally less than 3000 mg/L.
However, near the Harvey River Main Drain, groundwater salinity may exceed 7000 mg/L. Near
the Peel Inlet, saline groundwater extends into the Leederville aquifer.

The groundwater salinity north of the South Dandalup River is generally less than 3000 mg/L TDS.
Salinity at the base of the aquifer increases from east to west from approximately 500 mg/L near the
scarp to more than 3000 mg/L near the coast.
5.5 Cattamarra aquifer

In the Murray Groundwater Area, the Cattamarra aquifer has been defined to consist of the Cattamarra Coal Measures and Eneabba Formations. However, the Yarragadee Formation and the Gage Sandstone Formation are also present in the northern part of the groundwater area. In these northern parts, consistency in potentiometric heads across the formations indicates that the Cattamarra aquifer is in hydraulic connection with the Yarragadee and Gage Sandstone Formations, and therefore they may be represented as a single aquifer.

The Cattamarra aquifer consists of interbedded sandstone and siltstone or shale. The percentage of sandstone in the aquifer increases from about 50% near the scarp to around 70% near the coast. Individual beds in the aquifer are up to 40 m thick, although near the scarp the sandstone beds are only about 5 m thick. The base of the aquifer has not been encountered, but it is believed to reach a maximum thickness of about 2000 m.

The seasonal variations in potentiometric head are less than 1.0 m and are generally the result of variations in head in the overlying aquifers. The horizontal hydraulic conductivity of the aquifer has been determined from pump tests to be about 0.7 m/day.

Groundwater recharge

Recharge to the Cattamarra aquifer (north of the South Dandalup River) is by downward leakage near the Darling Scarp where the South Perth Shale is absent and where downward heads are
prevalent. It is possible that this recharge zone (near the Darling Scarp) extends several kilometres south of Pinjarra.

Distant from the zone delineated adjacent to the Darling Scarp, recharge to the Cattamarra aquifer is likely to be limited, due to the high percentage of siltstones and shales in the overlying Leederville aquifer which inhibit downward leakage (Deeney, 1989).

**Groundwater flow**

The apparent groundwater flow direction in the Cattamarra aquifer is westwards. Groundwater movement is considered to be very slow at depth, where the groundwater is saline. It is likely that most of the groundwater flow occurs in the top 500 m of the aquifer (Davidson, 1995).

**Groundwater discharge**

Groundwater in the Cattamarra aquifer generally discharges offshore. Some discharge to the Leederville aquifer may occur near the Harvey River Main Drain, where upward hydraulic heads are present, but such discharge north of the South Dandalup River is restricted by the presence of the South Perth Shale.
Groundwater salinity

Groundwater salinity in the Cattamarra aquifer is generally brackish to saline. Brackish groundwater with a salinity in the range 2300 to 7000 mg/L TDS extends to a depth of -300 m AHD (along the Harvey Borehole Line). Fresh groundwater with salinity less than 500 mg/L exists near the Darling Scarp (north of the South Dandalup River) in the recharge zone. The low-salinity zone may extend several kilometres south of Pinjarra, adjacent to the Darling Scarp.
6. Groundwater use

6.1 Beneficial use

Beneficial use of a groundwater resource is the identified present or future community use that should receive priority over other potential uses. The priority beneficial uses will determine the criteria for protection of water quality and quantity.

Private abstraction must not detrimentally affect neighbouring users with respect to water levels or water quality. This general policy applies to all users. Excessive abstraction that exceeds throughflow and recharge may cause decreasing water levels. Rising groundwater salinity may also be a problem.

In many instances, the individual user will be the first to be affected by salinity rises or decreasing yields, particularly in the case of upcoing of saline water. In cases where large private abstractions or combined abstractions induce horizontal movement of saline water (e.g. the migration of the salt water interface near the coast), the neighbouring users may be influenced first. Neighbouring users must be protected from the effects of over-abstraction.

Groundwater must also be allocated to the environment; a portion of groundwater throughflow is required to maintain general groundwater quality and regional water levels (for instance, in and around wetlands). This includes preventing any inland movement of the saltwater interface and maintaining adequate water for vegetation and water courses.
Groundwater abstraction is generally constrained or restricted within and adjacent to conservation reserves and wetlands. There is a presumption against the allocation of groundwater for abstraction within and adjacent to conservation areas that are recommended for the conservation of flora, fauna, wetlands or recreational potential, unless the proposal has been referred to the EPA, and necessary assessments have been initiated and subsequent approval granted.

6.2 Existing groundwater use

General groundwater usage in the MGA has been grouped into seven categories in Table 3. Whilst exact amounts of groundwater abstraction are constantly changing, a number of general trends concerning groundwater consumption are evident.

- The four largest groundwater uses are: industrial supply (51.4%), plant production (28.4%), public water supply (6.8%) and recreation (7.2%).
- The largest individual groundwater abstraction (4,000,000 kL/year) within the Pinjarra subarea is for industrial purposes and equates to about 39% of the total groundwater usage.
- Only 13.9% of the total groundwater usage occurs in the Waroona subarea. The remaining draw is distributed between the Coolup, Nambeelup and Pinjarra subareas. Groundwater usage within the Pinjarra subarea represents 42.2% of the total groundwater consumption within the MGA, and the Coolup and Nambeelup subareas contribute 18.2% and 25.7% of the total consumption respectively.
• Groundwater abstraction from the superficial, Leederville and Cattamarra aquifers is 2,900,000 kL/year, 3,200,000 kL/year and 4,200,000 kL/year respectively.

• Approximately 70% of groundwater licences for the MGA are issued for crop production (35%) and domestic water supply (35%).

• Approximately 89% of groundwater licences for the MGA are issued for abstraction from the Nambeelup subarea (59%) and the Coolup subarea (30%).

• The three smallest groundwater uses are: miscellaneous (0.2%), domestic water supply (1.4%) and animal production (4.6%).

<table>
<thead>
<tr>
<th>Groundwater use</th>
<th>Subarea</th>
<th>Coolup</th>
<th>Nambeelup</th>
<th>Pinjarra</th>
<th>Waroona</th>
<th>Total percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public water supply</td>
<td></td>
<td>0.00</td>
<td>0.70</td>
<td>0.00</td>
<td>0.00</td>
<td>6.8%</td>
</tr>
<tr>
<td>Domestic supply^1</td>
<td></td>
<td>0.02</td>
<td>0.10</td>
<td>0.01</td>
<td>0.02</td>
<td>1.4%</td>
</tr>
<tr>
<td>Industrial supply^2</td>
<td></td>
<td>0.01</td>
<td>0.00</td>
<td>4.00</td>
<td>1.30</td>
<td>51.4%</td>
</tr>
<tr>
<td>Crop production^3</td>
<td></td>
<td>1.35</td>
<td>1.38</td>
<td>0.10</td>
<td>0.10</td>
<td>28.4%</td>
</tr>
<tr>
<td>Animal production^4</td>
<td></td>
<td>0.04</td>
<td>0.42</td>
<td>0.00</td>
<td>0.01</td>
<td>4.6%</td>
</tr>
<tr>
<td>Recreation^5</td>
<td></td>
<td>0.45</td>
<td>0.05</td>
<td>0.24</td>
<td>0.00</td>
<td>7.2%</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.2%</td>
</tr>
<tr>
<td>(x 10^6 kL/year)</td>
<td>1.88</td>
<td>2.65</td>
<td>4.35</td>
<td>1.44</td>
<td>100.0%</td>
<td></td>
</tr>
</tbody>
</table>

1 Includes Special Rural/Rural Residencial Zones (SRZ)
2 Includes mining, ore processing, etc.
3 Includes gardens, orchards, pasture, flower production, etc.
4 Includes fisheries, stock, poultry, marron farming, etc.
5 Includes golf courses, race courses, public open space, etc.

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Subarea</th>
<th>Total percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>superficial</td>
<td></td>
<td>73.6%</td>
</tr>
<tr>
<td>Leederville - upper</td>
<td></td>
<td>11.6%</td>
</tr>
<tr>
<td>Leederville - lower</td>
<td></td>
<td>13.8%</td>
</tr>
<tr>
<td>Cattamarra</td>
<td></td>
<td>1.2%</td>
</tr>
<tr>
<td>No. of licences</td>
<td></td>
<td>100.0%</td>
</tr>
</tbody>
</table>
Table 4 illustrates the number of licences issued from each aquifer within the individual subareas. Within the Coolup subarea, approximately 55% of licences currently issued draw from the superficial aquifer. Figures indicate that much of the groundwater abstraction from the Leederville aquifers (upper and lower) occur within the Coolup and Nambeelup subareas. It is evident that only a small portion of the licences issued are from the Pinjarra and Waroona subareas, with approximately 59% of all licences issued within the Nambeelup subarea.

A large portion (74%) of the groundwater well licences are issued for abstraction from the superficial aquifer. The Leederville aquifer contributes the next largest quantity of groundwater well licences, with approximately 12% and 14% of all licences issued drawing from the upper and lower Leederville aquifers respectively.

6.3 Current and proposed public water supply

Currently, there is one existing Public Water Supply Scheme in the MGA, administered by the Water Corporation. This scheme at Ravenswood draws 700,000 kL/year from the Leederville aquifer to supplement the water supply for the City of Mandurah, which is located outside the groundwater area.

In addition to possible further developments of the existing Ravenswood wellfield, there are proposals to locate a new groundwater scheme, the Dandalup scheme, whose southern portion will lie within the Nambeelup subarea. The additional groundwater supplies will cater for the large
population increase and associated developments expected along the coast. Some groundwater may be used to supply scheme water to the Perth Metropolitan area.

Planning for the proposed water supply scheme has recently been initiated by the Water Corporation. Full development of the scheme will probably not occur until well into the next century and approval is dependent on the scheme satisfying social and environmental impacts.

Currently, it is anticipated that the Dandalup scheme will yield around 13 000 000 kL/year, of which 6 000 000 kL will be drawn from the superficial aquifer and the remainder (7 000 000 kL) from the Leederville aquifer. Of the estimated 13 000 000 kL, approximately 8 600 000 kL is to be drawn from the MGA.

Investigations will need to be carried out into the viability of the scheme, including detailed drilling and hydrogeological explorations to determine aquifer properties and characteristics, and studies evaluating the environmental and social concerns associated with the development of the scheme.

A water reserve boundary around the scheme has been proposed in order to protect the quality of the water resources to be utilised in the scheme. The proposed water reserve boundary is shown in Appendix 1. The reserve has not been proclaimed to date, although when proclaimed, protection of the water reserve will be implemented under the Country Areas Water Supply Act 1947.

The water reserve is likely to be a Priority 2 Source Protection Area. This level of protection should maintain the risk of groundwater contamination at the lowest practical levels. Acceptable land uses in designated P2 areas are listed in Appendix 2.
A further future public water supply source is to be located at the proposed Point Grey development site, located within the Coolup subarea. The expected maximum total population at the site, some 50 years after the initial development date, is estimated to be approximately 7000. This corresponds to an estimated annual groundwater demand of some 1 000 000 kL. Figure 1 shows the location of the proposed Point Grey development site.

6.4 Future private groundwater use

It is expected that demand for the groundwater resources in the MGA will grow substantially in the future. This will be mainly due to predicted population increases in the Shire of Murray as land zoned for residential development becomes scarce in the proximity of Mandurah.

Such increases may necessitate the expansion of the existing groundwater scheme and possibly the development of the proposed Dandalup public water supply scheme to satisfy local demand and supplement the increasing demand from the Perth metropolitan area. It is expected that the new scheme may be developed well beyond the year 2000.

New residential developments proposed for the groundwater area in the near future include subdivisions at Ravenswood, Furnissdale, Point Grey and Amarillo Farm. Additional Special Rural/Rural Residential Zones are also likely to be developed in the Furnissdale, Ravenswood and Coolup areas, and near the Serpentine River.
The Murray area has traditionally been renowned for its agricultural (i.e. crop, pasture and livestock) and mining activities and the pursuit of these is likely to continue in the foreseeable future. However, agricultural and horticultural pursuits will be carefully regulated to avoid further nutrient release to the polluted Peel–Harvey estuarine system. The demand for groundwater is also likely to increase in order to sustain these industries.

Current activity by Agriculture Western Australia within the Peel–Harvey Catchment is aimed at developing and implementing sustainable outcomes for agriculture and rural communities. As previously discussed, agriculture is an important economic activity within the Peel Region, and the Peel Development Commission considers agriculture as a sustainable industry in the long term.

Such initiatives may affect future water requirements within the Murray Groundwater Area, owing to the expected greater demand for groundwater from agricultural pursuits. Agriculture Western Australia envisage that more intensive agricultural practices such as horticulture, intensive animal production and innovative enterprises such as emu husbandry, aquaculture and agroforestry may increase within the area.

Other major uses of the groundwater resources in future may include

- Recreational, mainly near the Peel–Harvey Estuary,
- Industrial.
The environment may be viewed as a competitor for the groundwater resources, as groundwater is required to facilitate conservation and protection of environmental concerns (e.g. wetlands). In the future, the demand for environmental allocation of groundwater may increase as public awareness of the significance and importance of environmental features increases. However, it is envisaged that the environmental water requirements and environmental allocations evaluated within the allocation plan closely reflect the actual quantities necessary to ensure the protection and conservation of environmental features within the area.

Such an increase in public awareness may be attributed to the expected expansion of landuse practices (i.e. agriculture, mining etc.) which have the potential to significantly alter the natural environment. Environmental issues do, however, already have high priority in the Peel–Harvey catchment area because of the eutrophication problems which have been experienced in the estuarine system in recent years.
7. Monitoring program

The monitoring network of the MGA consists of wells, drilled to various depths, which were originally designed to monitor the local and regional aquifer systems and provide geological and hydrogeological information. **Figure 15** depicts the monitoring network of the MGA, with the locations of the monitoring wells shown together with the aquifers they monitor.

Monitoring data are stored on the State Water Resources Information System (SWRIS). Plots presented in this report are plots of all data presently available on SWRIS.

The wells being monitored can be grouped into a number of programs (as originally drilled) and are detailed below.

7.1 Monitoring wells

**Harvey Shallow Project (HS Series)**

Approximately 80 wells drilled as part of the Harvey Shallow Project are located in the central and southern parts of the MGA. These wells were drilled at about 40 sites and are screened at various depths in the superficial aquifer. The water levels in these wells are generally recorded every six months. Water quality analyses are performed annually.
Artesian monitoring wells (AM Series)

Several artesian monitoring wells are located in the northern part of the MGA and these are screened at various depths in the Leederville and Cattamarra aquifers. Since 1990, the water levels in these wells have been recorded approximately every six months.

Harvey Borehole Line (HL Series)

Several wells drilled as part of the Harvey Borehole Line are located in the south of the MGA. These wells are located at two sites and are screened at various depths within the Leederville and Cattamarra aquifers. The water levels in these wells are generally recorded every six months.

Town water supply wells

The town water supply wells at Ravenswood, which are screened in the lower Leederville aquifer, are regularly monitored by the Water Corporation. The Corporation is required to provide monitoring data from their wellfield and make regular aquifer assessments, pursuant to the conditions of their groundwater well licence. Production wells are monitored monthly for water levels, two monthly for conductivity, and a major chemical component analysis is carried out annually. Water levels in the observation well are also monitored monthly.
North Dandalup Superficial Series (NDSS Series)

The North Dandalup Superficial Series wells were drilled in 1992 to assess the downstream groundwater impacts and the regulated flow regime of the North Dandalup Dam. They are currently monitored by the Water Corporation, and water levels are the focus of the program. The Commission believes that, owing to the scarcity of superficial aquifer water level and salinity data within the northern portion of the groundwater area, the continued monitoring of these wells is essential, and it is envisaged that the monitoring of these wells may become the responsibility of the Commission.

Thomsons Lake Limnology Study Series (T Series)

These wells were drilled to examine the interaction of the unconfined aquifer with Lake Thomson. The investigation also supplied information concerning the geology of the area. These series of wells extend as far south as the northern half of the Nambeelup subarea.

Private wells

Groundwater licensees with water allocations exceeding 500 000 kL/year are required to provide monitoring data from their wellfields and make regular aquifer assessments. These private wells should be monitored by the licensee to record water level and water quality changes that may be occurring in response to large local abstractions.
7.2 Current monitoring frequency

Monitoring of most Commission monitoring wells within the MGA is limited to water level or potentiometric head recording. In certain areas where abstraction rates are high, the current frequency of water level recording may be insufficient.

Salinity data are infrequent and often not available, and it appears that the data available are generally restricted to those collected when the wells were drilled.

The current monitoring program for each aquifer is shown in Table 5.

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Water levels</th>
<th>Conductivity</th>
<th>Water quality analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>superficial</td>
<td>biannual</td>
<td>-</td>
<td>annual</td>
</tr>
<tr>
<td>Leederville</td>
<td>biannual</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cattamarra</td>
<td>biannual</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

7.3 Proposed monitoring program

The proposed monitoring program utilises the existing monitoring wells to record any changes in the main aquifer systems. The proposed monitoring frequency for each aquifer is displayed in Table 6. The monitoring of production and monitoring wells of town water supply schemes and private wells should be conducted by the licensee pursuant to the operating strategy and groundwater well licence conditions.
Table 6. Proposed monitoring frequency

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Water levels</th>
<th>Conductivity</th>
<th>Water quality analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>superficial</td>
<td>biannual</td>
<td>-</td>
<td>5 yearly</td>
</tr>
<tr>
<td>Leederville</td>
<td>biannual</td>
<td>-</td>
<td>5 yearly</td>
</tr>
<tr>
<td>Cattamarra</td>
<td>biannual</td>
<td>-</td>
<td>5 yearly</td>
</tr>
</tbody>
</table>

The water levels in wells monitored biannually should be taken during the months of April/May and September to record the annual troughs and peaks respectively. The main change to the monitoring program is a decrease in the frequency of water quality sampling of the superficial wells, although there is now a requirement to sample the confined wells every 5 years. This is consistent with the Commission's recent rationalisation of the groundwater monitoring program in the South West Region.

Before a well is sampled for conductivity or water quality, it should be airlifted and three casing volumes should be displaced. This method will minimise any stratification of the water in the well and will enable more representative data to be produced. To monitor for parameters such as iron and manganese, a pumped air-free sample should be taken.

7.4 Additional monitoring wells required

The Commission should undertake additional exploratory drilling in the northern part of the MGA to provide hydrogeological information and monitoring facilities in the superficial and Leederville aquifers. Organisations supplying scheme water may assist in the drilling program, specifically
within the central and eastern margins of the Nambeelup subarea, through their necessity to investigate the feasibility of the proposed Dandalup public water supply scheme.

It is also recommended that additional exploratory drilling be carried out in the Coolup and Pinjarra subareas of the MGA to provide hydrogeological data and monitoring facilities in the Leederville and Cattamarra aquifers. This is considered necessary as detailed hydrogeological information on these aquifers in this area is scarce, and the current understanding of the recharge/discharge mechanisms of the aquifers is inadequate.

It is envisaged that the Groundwater Investigation Branch, in consultation with the Allocation Branch, will undertake exploratory drilling to provide the required hydrogeological data and monitoring facilities to increase the understanding of the confined aquifers.

The drilling to be completed involves four sites, at each of which wells to an estimated maximum depth of 300 m will be constructed. An accompanying shallow monitoring bore will be constructed at each site to a depth of approximately 50 m. The objectives of the investigation are to establish water level and water quality monitoring bores, to obtain accurate representative samples of the geology of the area, to locate aquifers, and to assess potential yields of the aquifers encountered. These geological and hydrological data will compliment those derived from past projects within the area.

The information is required to help locate, and define the vertical and lateral extent of, the green clay marker within the Leederville aquifer. The data collated will permit refinement of current estimations concerning the extent to which the green clay layer subcrops the Leederville aquifer.
This will assist in future availability estimates and groundwater licensing practices within the upper and lower Leederville aquifers.

There has also been consultation between the Commission and the Water Corporation concerning groundwater exploration during the investigation phase of the proposed Dandalup public water supply scheme. The commissioning of such a scheme would require extensive hydrogeological investigation to determine the groundwater availability and sustainability of the area.

The effect on the Leederville and Cattamarra aquifers of large-scale groundwater abstraction from the Cattamarra aquifer by Alcoa has been reviewed in past years. Observations suggest that this abstraction has not had any significant adverse effects on the Cattamarra aquifer. The most recent aquifer performance review submitted by Alcoa of Australia concluded that a stable drawdown cone exists around the production wells, and that historical hydrographs do not imply long-term declines in groundwater levels.

Alcoa constantly review their groundwater monitoring program, and following consideration of the aquifer performance reviews and subsequent numerical groundwater modelling, a revised monitoring program will be formulated between Alcoa and the Water and Rivers Commission. Alcoa have also agreed to provide monitoring data to the Commission in digital form for inclusion into the Commission’s SWRIS database.
8. Aquifer performance

Available monitoring data to determine the performance of the aquifers in the MGA are somewhat limited. Artesian monitoring of the Leederville and Cattamarra aquifers is conducted on wells located only in the north and south of the groundwater area. There are numerous shallow wells screening the superficial aquifer and these are scattered mainly in the central and southern parts of the groundwater area. Serious recording of water levels in the wells commenced in the late 1980s.

8.1 Superficial aquifer

Water levels

There are numerous wells screened in the superficial aquifer of the MGA. Groundwater levels in all wells have varied seasonally, with seasonal variations ranging from around 1 m to as much as 4 m. In general, seasonal watertable ranges are 1–2 m although, as seen in Figure 16, the greatest seasonal ranges of 2–4 m occur adjacent to the Darling Scarp. The smallest range (0.2–0.8 m) is recorded in the Bassendean Sands fringing the Peel Inlet and Harvey Estuary.

Groundwater levels across the MGA have been plotted to indicate the difference in summer and winter levels between 1996 and 1990 (Figure 19). Within the diagrams, areas marked in green represent water level variations of less than 0.2 m, areas in orange denote falls in excess of 0.2 m, and those shaded blue indicate water level rises greater than 0.2 m.
The water level contours indicate that levels remained relatively steady through the western fringe and central margins of the groundwater area, with variations less than 0.4 m. A large portion of the central and eastern parts of the groundwater area exhibited declining groundwater levels between the summers of 1990 and 1996. This may be attributed to reduced rainfall recharge associated with below-average rainfall for the three-year period concluding 1995. Larger reductions in water levels (~0.8 m) were observed within the central-eastern regions of the MGA, and may be attributed to the very low rainfall during the winter of 1989.

Winter water levels have not declined and have, in fact, increased through the central margins of the area. Rainfall in 1996 exceeded that in 1990, and 1996 water levels therefore exceeded the winter levels of 1990 due to the greater recharge derived from the higher rainfall. The winter difference plots indicate the rapid recovery of the aquifer following a modest rainfall. Following the below-average rainfall of 1995, 1996 summer water levels were low compared with those of 1990. However, following the steady rainfall during winter 1996, the aquifer was well recharged and water levels recovered accordingly.

Wells selected in Figure 16 are superficial wells screened both at the watertable and deeper into the aquifer. Hydrographs indicate that the response of the bores screened at the base of the aquifer generally correspond closely with the response of the watertable bores.

Figure 16 shows hydrographs of a selection of wells monitoring the superficial aquifer. These hydrographs indicate that within the Nambeelup and Coolup subareas, groundwater levels have
remained relatively constant since the commencement of monitoring in 1998. Groundwater levels within the central and eastern parts of the Coolup subarea experienced slight declines during 1994, 1995, and the summer of 1996, reflecting in each case the consecutive below-average rainfall of the preceding years. Water levels recovered in response to the sound rainfall of 1996, and the further ample rainfall in 1997, will see water levels approaching the established long term averages.

_Caution must be paid to conclusions drawn from the difference plots of Figure 19, which take two sampling dates and plot the groundwater level differences between those respective dates. They are indicative only of the difference between the data values of the two sampling dates chosen. Moreover, as hydrograph peaks and troughs occur approximately 1 to 3 months after the respective peaks and troughs in the rainfall histograms, discretion must also be exercised in their interpretation._

**Salinity**

Groundwater salinity within the superficial aquifer is variable throughout the Murray Groundwater Area. Salinity is seen to vary from greater than 5000 mg/L TDS near the Peel Inlet to around 500 mg/L adjacent to the Darling Scarp, an increase in the direction of groundwater flow. Recorded salinity data are quite irregular with no discernible trends.

Available data show sound correlation with the assumed salinity ranges defined above. Conductivity monitoring of observation wells HS52A, HS40B and HS22A, located a few kilometres west of the Darling Scarp, show groundwater salinities less than 500 mg/L TDS, consistent with previous salinity records.
8.2 Leederville aquifer

Potentiometric head levels

Data for water level monitoring of the Leederville aquifer are restricted to a small number of monitoring wells located in the north and south of the MGA. Hydrographs of the artesian wells screened in the Leederville aquifer (see Figure 17) indicate a decline in the potentiometric surface within the Nambeelup subarea.

During the last five years water levels have declined by approximately 2 m in well AM70A and by approximately 1.5 m in AM68A (west of AM70). The potentiometric heads of wells AM65 and AM56A, situated to the north of the Nambeelup subarea, have experienced lesser declines since 1990, with well AM65 remaining relatively constant since 1989. The hydrographs also indicate a seasonal variation in water levels, the magnitude being more evident in well AM56A.

It is possible that the Leederville aquifer in the north of the groundwater area has been affected by the large groundwater abstraction from the Cattamarra aquifer near Pinjarra. The hydrostatic head reduction in well AM68A may have been in response to the Water Corporation's abstraction from the Leederville aquifer at their Yunderup wellfield.

Potentiometric heads in confined wells (screened in the Leederville aquifer) in the south of the groundwater area vary seasonally as indicated by the hydrograph of well HL4B. There appears to
be a slight decline in the groundwater levels in well HL4B in the early part of 1995. The reason for this decline is unknown as abstraction from the Leederville aquifer in the area is small. However, this water level behaviour reflects that within the superficial wells of the area, and it is deduced that the aquifers are hydraulically connected in this region. Abstraction from the superficial aquifer may be inducing upward discharge from the Leederville aquifer.

There is limited information on well HL3A1 as the data recorded prior to 1993 appear erroneous. Seasonal variation in the potentiometric heads are evident in this well after 1993.

To assess the aquifer's performance accurately, additional drilling of wells monitoring the Leederville aquifer is required throughout the MGA.

Salinity

Due to the limited monitoring of the Leederville aquifer within the MGA, salinity data are sparse and infrequent. Wells HL3A1 and HL4B of the Harvey Borehole Line have not been regularly monitored but salinities of around 2300 mg/L TDS and 1350 mg/L respectively have been recorded in these wells: To the north of the groundwater area, salinity data from wells of the Artesian Monitoring Series indicate that salinity increases from east to west at the base of the aquifer, from approximately 500 mg/L (well AM70A) close to the Darling Scarp to around 3000 mg/L (well AM65) adjacent to the Serpentine River.
8.3 Cattamarra aquifer

Potentiometric head levels

Hydrographs of artesian wells screened in the Cattamarra aquifer (Figure 18) indicate a decline in the potentiometric surface in the north of the groundwater area. During the last five years the hydrostatic heads have declined by approximately 3 m in wells AM69 and AM70, and by approximately 2 m in AM68. The hydrographs also indicate a seasonal variation in heads, the magnitude being more evident in well AM68 owing to the constant rate of decline in water levels between 1988 and 1994. It is highly likely that this depressurisation of the aquifer is due to the large groundwater abstraction from the Cattamarra aquifer near Pinjarra.

Production zones within the Cattamarra aquifer at Alcoa’s Pinjarra borefield are believed to be absent to the west and south of Alcoa’s property boundary. Alcoa suggest that potentiometric drawdown within the Cattamarra aquifer caused by abstraction may be attenuated both to the west and the south, owing to the presence of low permeability strata. However, the effects of the abstraction are propagated more readily to the north towards Commission monitoring wells AM68, AM69 and AM70.

Water level data for 1996 from Alcoa’s Cattamarra aquifer monitoring wells shows potentiometric head recovery in response to a reduction in groundwater abstraction. A similar delayed response may be expected within the Artesian Monitoring (AM) Series wells located several kilometres to the north of the borefield.
Groundwater levels in artesian wells (screened in the Cattamarra aquifer) in the south of the groundwater area are relatively steady as indicated in well HL3A2. Similarly, hydrostatic heads in well HL4A1 have fluctuated only minimally. However, the seasonal variation in the groundwater levels is more evident in this well because of its location near the Darling Fault, and the associated boundary effects. No abstraction from the Cattamarra aquifer exists in the vicinity of these wells.

**Salinity**

Salinity data are limited from wells screened into the Cattamarra aquifer. From the monitoring wells available, groundwater salinity of the aquifer is generally brackish to saline. Wells AM68 and AM70, located close to the Darling Scarp in the recharge area of the aquifer, have salinities indicating fresh water. However, wells HL3A2 and HL4A1, situated to the south of the Waroona subarea, are brackish with salinities exceeding 6000 mg/L TDS.
9. Groundwater availability

Groundwater availability, or the long-term safe supply, depends on a number of factors, including the maintenance of water levels, water quality and induced recharge. As each aquifer has its own hydraulic parameters and recharge mechanisms, availabilities vary between aquifers. Groundwater availability from each aquifer is described below.

9.1 Availability from the superficial aquifer

Water quality in the superficial aquifer is extremely variable and groundwater storage and availability depends on the proportion of sand to clay. High proportions of clay are usually associated with poor-quality groundwater and low yields.

Although in most areas of the MGA the superficial aquifer is thin, it contains significant groundwater resources. Groundwater in this aquifer also supports environmental features such as wetlands and native vegetation. Concerns associated with the retention of such environmental features limit the quantity of groundwater that may be drawn.

Recharge

Estimating groundwater availability in the superficial aquifer using throughflow or recharge methods is extremely difficult because of
• The lack of a strongly defined regional flow system,
• The presence of numerous rivers, drains and wetlands,
• The variable sediments which range from clays to sand and limestone,
• The variable thickness of the formation,
• The varying impact of the underlying aquifers, which range from the clays of the Leederville aquifer to the sands and sandstone of the Cattamarra aquifer. The clay, when present, forms an impervious layer.

Owing to this extreme diversity, it is not possible to provide a regional estimate of the groundwater availability from the aquifer. Instead, the dominant characteristics and the likely yields are described in broad terms.

It is believed that the best method of estimating groundwater availability is from the percentage of rainfall that becomes groundwater. This belief follows detailed computer modelling studies of the Swan Coastal Plain aquifers and the results of experimental studies. These studies tend to indicate that the groundwater availability based on the annual rainfall recharge is generally higher than that based on throughflow calculations.
The main factors having the most impact on recharge are listed below

(a) *Vegetation cover*

Rainfall recharge varies significantly between that of a natural banksia woodland (15–30% recharge), dense pine plantation (≤8% recharge) and pasture (50–60% recharge). These estimates are based on CSIRO experimental studies (Sharma et al., 1988) on the Gngara Mound.

The results of these studies are expected to be directly transferable to the MGA, although the actual recharge estimates may vary with differing soil conditions.

(b) *Depth to watertable*

The depth to the groundwater table has a significant impact on the net recharge. There is less recharge when the watertable is near the surface because of the combined impact of increased evapotranspiration and reduced storage capacity. This is the case in the MGA.

(c) *Surface soil*

Recharge will decrease significantly as the clay or silt content of the surface increases. Some areas of the MGA have a high clay content at or near the surface, which reduces the amount of rainwater recharging the aquifer.
(d) Land use

Land use also affects groundwater recharge. Buildings (houses, sheds etc.) and roads tend to result in a significant increase in recharge as long as excess water is not routed out of the catchment. Irrigated pasture tends to have a higher recharge than non-irrigated pasture.

As groundwater recharge is dynamic and relates to the activities undertaken on the land, it is not possible without detailed computer modelling to provide accurate estimates of groundwater availability. Instead, subjective estimates of recharge have been made after considering the various interplaying factors.

The soils of the MGA can be roughly divided into areas where the sand content is high or, alternatively, where the clay content is high. An average annual rainfall of 900 mm over the whole of the groundwater area has been assumed, together with an annual rainfall recharge rate of 10% for areas consisting mainly of sand and 3% for areas consisting mainly of clay. As a comparison, Davidson (1995) determined that the annual rainfall recharge for the Serpentine flow system (north of the South Dandalup River) is 6%.

The groundwater resources and groundwater availability in the superficial aquifer of the MGA are given in Tables 7 and 8 respectively.
Table 7. Current groundwater resources of the superficial aquifer

<table>
<thead>
<tr>
<th>Subarea</th>
<th>Area of mostly sand (km²)</th>
<th>Area of mostly clay (km²)</th>
<th>Total recharge area (km²)</th>
<th>Annual groundwater recharge (kL/year × 10⁶)</th>
<th>Groundwater salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolup</td>
<td>273</td>
<td>87</td>
<td>360</td>
<td>26.9</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Nambeelup</td>
<td>157</td>
<td>110</td>
<td>267</td>
<td>17.11</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Pinjarra</td>
<td>0</td>
<td>127</td>
<td>127</td>
<td>3.4</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Waroona</td>
<td>67</td>
<td>155</td>
<td>222</td>
<td>10.2</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Total</td>
<td>497</td>
<td>479</td>
<td>976</td>
<td>57.6</td>
<td></td>
</tr>
</tbody>
</table>

The quantity of groundwater available for abstraction is limited to 75% of the annual groundwater recharge. This allows some water in the weak regional flow systems to flow through to the estuary, thereby preventing the ingress of saline water farther inland. The ‘Total allocation limits’ of Table 8 have incorporated the environmental allocation as described.

In calculating the current allocations, a number of separate allocations have contributed to the final estimate. Existing private and scheme allocations, and proposed future scheme allocations were incorporated within the assessment, and the allocations were summed to form an aggregate allocation termed the ‘Existing and proposed allocation’, as seen in Table 8. Similarly, an assigned allocation (1,000,000 kL/year was prescribed from the Nambeelup, Waroona and Pinjarra subareas as recharge to the underlying Leederville aquifer (this will be discussed further in Section 9.3), thereby reducing the ‘Total recharge’ figures within Table 8.

Large variations in individual well yields may be expected, as yields are dependent on the local saturated thickness of the aquifer and the proportion of sand and clay within the soil.
Table 8. Groundwater availability of the superficial aquifer

<table>
<thead>
<tr>
<th>Subarea</th>
<th>Total allocation limit (kL/year×10^6)</th>
<th>Existing and proposed allocations (kL/year×10^6)</th>
<th>Estimated unallocated resources (kL/year×10^6)</th>
<th>Groundwater salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolup</td>
<td>20.2</td>
<td>0.6</td>
<td>19.6</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Nambeelup</td>
<td>11.8^6</td>
<td>5.5</td>
<td>6.3</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Pinjarra</td>
<td>1.5^6</td>
<td>0.1</td>
<td>1.4</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Waroona</td>
<td>6.6^6</td>
<td>1.4</td>
<td>5.2</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Total</td>
<td>40.1</td>
<td>7.6</td>
<td>32.5</td>
<td></td>
</tr>
</tbody>
</table>

^ These 'Total allocation limit' figures represent the 'Annual groundwater recharge' figures of Table 7 minus the prescribed 1 000 000 kL allocation from the Nambeelup, Pinjarra and Waroona subareas to the underlying Leederville aquifer.

Groundwater quality

The quality of groundwater in the superficial aquifer is extremely variable. Water quality is directly dependent on the proportion of sand and clay in the soils. Generally, the higher the clay content the higher the accumulation of salts, and therefore the greater the salinity.

Other factors affecting the salt content in the superficial aquifer include the existence of lakes, rivers and wetlands which induce high evaporation rates, the depth to the watertable, upward leakage from the underlying aquifers, recirculation of salts due to overfertilising, and the existence of a salt water interface near the Peel–Harvey estuarine system.

In the MGA, the groundwater salinity near the estuarine system exceeds 3000 mg/L TDS, mainly due to the high evaporation rates from the wetlands in the area. The salinity decreases to the east to less than 500 mg/L near the Darling Scarp. Groundwater salinity at the watertable is greater than
3000 mg/L near Waroona, possibly because of irrigation practices in the area. Groundwater salinities exhibit an apparent increase in the direction of groundwater flow.

9.2 Availability from the Rockingham Sand aquifer

The Rockingham Sand aquifer exists only in the northwestern part of the groundwater area and is found at shallow depth owing to the thin nature of the superficial sediments overlying it. The aquifer reaches a maximum thickness of some 50 m in the groundwater area. Groundwater salinity is highly variable, ranging from about 500 mg/L to more than 3000 mg/L.

Groundwater in the aquifer flows over a salt-water interface to the ocean. Upcoing of the salt-water interface may readily occur as a result of groundwater abstraction from high-yielding wells. Abstraction from this aquifer is not recommended, and therefore the groundwater availability has not been evaluated.

Owing to the limited extent of the Rockingham Sand aquifer in the MGA, that aquifer has been coupled with the superficial aquifer in this report, enabling them to be considered (and managed) as a single unit.

9.3 Availability from the Leederville aquifer

The Leederville aquifer extends throughout the MGA, is readily accessible, and is found at shallow depth as the overlying superficial sediments are thin. Groundwater in the Leederville aquifer flows
generally from east to west, discharging into the ocean. However, some groundwater from the Leederville aquifer also discharges into the Rockingham aquifer (where present).

As detailed in Chapter 5 (Section 5.4), gamma and geophysical logs have defined the existence of a green clay marker within the Leederville aquifer. The green clay marker, which acts as an aquitard, divides the Leederville aquifer into two separate systems, designated here the ‘upper’ and ‘lower’ Leederville aquifer.

Although the green clay horizon subcrops the Leederville aquifer throughout the groundwater area, the division applies essentially to the Coolup and Nambeelup subareas.

**Availability**

The approach adopted, and assumptions made to assess the groundwater availabilities in the Leederville aquifer, are described below.

**Rainfall recharge**

Recharge to the Leederville aquifer occurs in areas where downward heads are prevalent. Davidson (1995) indicates that the percentage recharge is approximately 2 to 3% of the total annual rainfall over the recharge areas. Leakage to the Leederville aquifer from the superficial aquifer is the principal mechanism of groundwater recharge throughout the Leederville aquifer (Commander, 1981). The report suggests that recharge resulting from
hydraulic head difference between the superficial and Leederville aquifers may also be occurring near the Darling Scarp.

Recharge areas contributing to the upper and lower Leederville aquifers were selected to be those areas for which the watertable within the superficial aquifer was greater than the 5 m AHD contour. The designated recharge areas are illustrated in Figure 14.

Using a method similar to that adopted for determining recharge to the superficial aquifer, assigned recharge rates were based primarily on surface geology. Annual rainfall recharge rates of 3% for areas consisting predominantly of sand and 0.5% for areas consisting mainly of clay were assumed for designated recharge areas of both the upper and lower aquifers, and were applied to an annual average rainfall of 900 mm.

Induced recharge

Within the MGA, the groundwater system is essentially full. Potentiometric levels within the Leederville aquifer are high, and hence recharge to the aquifer through downward leakage from the overlying superficial aquifer is limited due to the small hydraulic gradient between the aquifers. It is anticipated that with increased abstraction from the Leederville aquifer, potentiometric heads will be effectively lowered and the hydraulic gradient may steepen between the aquifers, thereby inducing additional recharge to the Leederville aquifer.
The induced recharge for the upper and lower Leederville aquifers was calculated utilising the method used in evaluating the rainfall recharge availabilities of the aquifers. The soils within the individual subareas were classified as either sandy or clayey soils, and recharge rates of 3% and 0.5% were applied respectively to the average annual rainfall of 900 mm.

Existing and proposed allocations

Current allocations licensed for abstraction from the Leederville aquifer were compiled from the Water and Rivers Commission's Water Resources Licensing Database. Allocations were assigned to the upper and lower Leederville aquifers based on information attained from well log data entered upon the database, and current knowledge concerning the location and depth of the green clay marker. The information compiled is as accurate as possible given the current deficiency in detailed hydrogeological information.

In addition, allocations have been made for the proposed public water schemes as well as additions to the existing public water supply schemes. For the existing Yunderup scheme, located within the Nambeelup subarea, a prospective allocation of 300 000 kL to meet the impending demand was made from the lower Leederville aquifer. Within the Coolup subarea, the long-term groundwater demand of the imminent Point Grey Development of around 1 000 000 kL was allocated from the upper Leederville aquifer.

Similarly, an allocation of 4 000 000 kL from the upper Leederville aquifer was reserved for the proposed Dandalup scheme. It was estimated that 5 600 000 kL of the proposed
7 000 000 kL required from the Leederville aquifer for the Dandalup scheme would be drawn from wells situated within the Nambeelup subarea. Not all of this 5 600 000 kL of groundwater for the Dandalup scheme was reserved from the Leederville aquifer. Instead, some 4 000 000 kL of groundwater was reserved for public water supply purposes to facilitate the availability of resources from the upper Leederville aquifer for future private allocation.

As detailed in Section 9.2, an allocation was made from the superficial aquifer adjacent to the Darling Scarp to the underlying lower Leederville aquifer. Owing to the thin veneer of surficial sediments overlying the Leederville aquifer adjacent to the Darling Fault, abstraction from the lower Leederville aquifer in these parts essentially draws groundwater from the superficial aquifer, as the aquifers are in hydraulic connection.

These eastern margins of the Swan Coastal Plain, where downward heads are prevalent, can be represented as a single aquifer system, and allocations have therefore been appointed to the lower Leederville aquifer from the superficial aquifer. Allocations of 1 000 000 kL have been made to the lower Leederville aquifer of the Nambeelup, Pinjarra and Waroona subareas from the total resource availability estimates of the superficial aquifer in the respective subareas (Table 8). These additional allocations apply to a 4 km zone delineated inland of the base of the Darling Scarp, and are therefore applicable to the lower Leederville aquifer.
No groundwater from the Leederville aquifer has been allocated as throughflow to the South West Coastal Groundwater Area (SWCGA). Groundwater flow from the upper Leederville aquifer, west of the green clay marker, discharges to Peel Inlet, which acts to invade the upper Leederville aquifer in the coastal subareas of the SWCGA. Wells screened in the Leederville aquifer of the SWCGA ‘mine’ the fresh groundwater reserves within the aquifer, and are likely to induce progressively more saline groundwater within the wells. This groundwater will then migrate and propagate in a westerly direction from the salt-water interface beneath the Harvey Estuary.

Following the application of the approach detailed above, the groundwater resources and availabilities of the upper and lower Leederville aquifers were calculated for the subareas of the MGA. Until a comprehensive hydrogeological investigation of the Leederville aquifer has been completed to determine the hydrodynamics and re-evaluate the groundwater resources of the Leederville aquifer, the groundwater availability governing groundwater licensing from the aquifer is as set out in Tables 9 and 10.

### Table 9. Groundwater availability of the upper Leederville aquifer

<table>
<thead>
<tr>
<th>Subarea</th>
<th>Total availability (kL/year×10^6)</th>
<th>Existing and proposed allocations (kL/year×10^6)</th>
<th>Estimated unallocated resources (kL/year×10^6)</th>
<th>Groundwater salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolup</td>
<td>3.5</td>
<td>1.4</td>
<td>2.1</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Nambeelup</td>
<td>6.0</td>
<td>4.2</td>
<td>1.8</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Pinjarra</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Waroona</td>
<td>Not found</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Total</td>
<td>9.6</td>
<td>5.6</td>
<td>4.0</td>
<td></td>
</tr>
</tbody>
</table>
Table 10. Groundwater availability of the lower Leederville aquifer

<table>
<thead>
<tr>
<th>Subarea</th>
<th>Total availability (kL/year×10^6)</th>
<th>Existing and proposed allocations (kL/year×10^6)</th>
<th>Estimated unallocated resources (kL/year×10^6)</th>
<th>Groundwater salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolup</td>
<td>4.5</td>
<td>0.8</td>
<td>3.7</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Nambeelup</td>
<td>3.0</td>
<td>1.9</td>
<td>1.1</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Pinjarra</td>
<td>2.5</td>
<td>0.2</td>
<td>2.3</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Waroona</td>
<td>7.5</td>
<td>0.1</td>
<td>7.4</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Total</td>
<td>17.5</td>
<td>3.0</td>
<td>14.5</td>
<td></td>
</tr>
</tbody>
</table>

It is therefore estimated that the Leederville aquifer has significant potential as a future groundwater resource within the MGA. The unallocated groundwater resources of the upper Leederville aquifer have been estimated to be 4 000 000 kL/year, with most groundwater available from within the Coolup and Nambeelup subareas.

As is evident from Table 10, allocation from the lower Leederville aquifer has been minimal, and significant groundwater resources are available for abstraction from this aquifer.

**Groundwater quality**

The quality of groundwater in the Leederville aquifer is generally variable. The salinity of the groundwater apparently increases with depth and near the bottom of the aquifer the salinity may be greater than 3000 mg/L TDS.

Near the Peel Inlet, the groundwater in the upper portion of the Leederville aquifer also has a salinity of more than 3000 mg/L.
Salinity less than 500 mg/L is recorded near the Darling Scarp in the north of the groundwater area within the lower Leederville aquifer. Recharge is believed to take place here and this low-salinity zone may continue along the scarp for several kilometres south of Pinjarra.

9.4 Availability from the Cattamarra aquifer

The Cattamarra aquifer extends throughout the MGA and is found at shallow depth near the Darling Scarp. Groundwater in the Cattamarra aquifer flows generally from east to west, discharging into the ocean. The base of the Cattamarra aquifer has not been intercepted by drilling, although it is estimated to be about 2000 m.

Recharge

Recharge to the Cattamarra aquifer occurs in areas where downward heads are prevalent. Davidson (1995) contended that most of the groundwater flow takes place in the top part of the aquifer, at least in the top 500 m. Below this depth, the increasing groundwater salinity indicates a lack of flushing, implying limited groundwater flow.

There has not to date been a detailed study of the Cattamarra aquifer, south of South Dandalup River, to determine the location of the recharge areas.
(a) Between the northern and southern Murray Shire boundary (Nambeelup, Pinjarra and Coolup Subareas)

No thorough investigations to determine the recharge to the Cattamarra aquifer in the area have been performed. However, it is believed that the aquifer is recharged in the low-salinity zones at a rate equivalent to 1 to 2% of the total annual rainfall. Preliminary results of numerical flow modelling of the superficial, Leederville and Cattamarra aquifer systems carried out by Alcoa support the estimated annual rainfall recharge rates to the Cattamarra aquifer of 1–2%.

Davidson (1995) estimates that the area contributing to recharge north of the South Dandalup River is approximately 120 km². Commander (1981) arrives at the same figure for the area recharging the Cattamarra aquifer south of the South Dandalup River. The annual recharge to the Cattamarra aquifer is therefore estimated to be 3 200 000 kL/year, based on a recharge percentage of 1.5% of the total annual rainfall.

Not all of the groundwater recharged may be utilised in the groundwater area. A component of the total groundwater recharge should be allowed to flow through to the aquifer within the South West Coastal Groundwater Area to maintain potentiometric levels in the aquifer.

An allocation of 600 000 kL/year is set aside for this purpose. Therefore, 2 600 000 kL/year is remaining for use in the (combined) Nambeelup, Coolup and Pinjarra subareas of the
MGA, of which 4 300 000 kL/year has already been utilised. It therefore appears that the aquifer in this area may be overdrawn.

This increased pumping has affected water levels in the Cattamarra aquifer north of the South Dandalup River, which have declined by approximately 5 m. However, artesian monitoring of the Cattamarra aquifer south of South Dandalup River has suggested that the large draw within the Pinjarra subarea has had minimal adverse effects on historical water levels.

(b) Between the northern and southern Waroona Shire Boundary (Waroona Subarea)

Data from the Harvey Borehole Line (Deeney, 1989) imply that the main recharge area for the Cattamarra aquifer is west of the Harvey River Main Drain (outside the MGA), where the Leederville aquifer consists predominantly of sand and the heads are downward. The extent of this recharge area is not known.

Recharge east of the Harvey River Main Drain is considered to be negligible due to the predominance of siltstone and shale in the Leederville aquifer. Therefore, the amount available for use in the Waroona subarea of the MGA is negligible and no groundwater is being drawn from this aquifer.

Artesian monitoring during the last five years has indicated that the groundwater levels are subject to seasonal fluctuation. This is evident particularly in the easternmost well of the Harvey Line. The hydrographs suggest that the aquifer potentiometric levels are steady.
The groundwater availability of the Cattamarra aquifer for the subareas of the MGA is shown in Table 11. Note that a portion of the groundwater from the Nambeelup, Coolup and Pinjarra subareas must be allowed to flow through to the South West Coastal Groundwater Area to maintain the potentiometric heads of the aquifer.

Additional recharge to the Cattamarra aquifer may be induced near the Darling Scarp (east of Pinjarra) as a result of abstraction from the aquifer. However, the additional recharge may only be sufficient to supply the existing users when surface water sources are inadequate (based on an existing licensing agreement).

Table 11. Groundwater availability of the Cattamarra aquifer

<table>
<thead>
<tr>
<th>Subarea</th>
<th>Total availability (kL/year×10^6)</th>
<th>Current allocations (kL/year×10^6)</th>
<th>Estimated unallocated resources (kL/year×10^6)</th>
<th>Groundwater salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolup</td>
<td>small</td>
<td>0.1</td>
<td>small</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Nambeelup</td>
<td>small</td>
<td>0.0</td>
<td>small</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Pinjarra</td>
<td>2.6</td>
<td>4.2</td>
<td>small</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Waroona</td>
<td>small</td>
<td>0.0</td>
<td>small</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Total</td>
<td>2.6</td>
<td>4.3</td>
<td>small</td>
<td></td>
</tr>
</tbody>
</table>

Groundwater quality

The quality of groundwater in the Cattamarra aquifer is generally variable. East of Pinjarra, near the Darling Scarp, the Cattamarra aquifer has groundwater of salinity less than 1000 mg/L TDS. This low salinity zone extends northwards beyond the northern boundary of the MGA.
Groundwater of the western and southern portions of the MGA has salinity greater than 3000 mg/L. The salinity also increases with depth so that below 500 m the salinity is generally greater than 3000 mg/L TDS.
10. Groundwater management issues

10.1 Groundwater quantity

Within proclaimed Groundwater Management Areas, controls are applied to limit abstractions to sustainable levels consistent with the State conservation strategy to prevent any adverse impacts due to abstraction. In line with this objective, regulatory controls are aimed at

- Maintaining abstraction at a level sustainable by the aquifer over the long term without any unacceptable deleterious effects
- Allocating available resources for beneficial public and private purposes, while meeting environmental needs such as maintaining wetland ecosystems
- Sharing the resource equitably in a non-contentious manner.

In areas of great demand for groundwater, regulation may allow a short-term reduction of the aquifer storage provided that the impact to the aquifer is judged to be acceptable. However, this needs to be within the context of an approved allocation plan for the resources concerned.

The total annual availability for the MGA is estimated to be about 84 300 000 kL/year of which approximately 35 000 000 kL/year (or 42%) has already been committed. While there may be adequate resources to cater for the growth in demand on a regional basis, in certain areas there are limited groundwater resources for further allocation because of the existing level of use.
In some aquifers, excessive abstraction may lead to a depletion of potable groundwater resources, which in turn may cause saltwater from the Peel Inlet to intrude into the aquifer. If this occurs, it may cause irreversible damage to the aquifer.

All groundwater users in the Murray Groundwater Area require a groundwater well licence to abstract groundwater. Included in this category are all private users. Groundwater abstraction from the superficial aquifer of less than 1500 kL/year for stock and domestic purposes shall be exempt from licensing. Consistent with recent water industry reforms, the Water Corporation has been required to obtain a licence for its groundwater abstraction within the MGA.

Licences within the MGA should be issued with a two-year development clause. If the licensed allocation has not been fully utilised within that period, then the unused allocation may be redistributed unless the licensee can demonstrate that the development will occur.

10.2 Groundwater quality

Groundwater pollution may be caused by activities such as waste discharge by industry, agricultural activities, human-waste disposal or storage-tank leakage.
Two forms of groundwater pollution exist. These are

- Point sources (e.g. petrol tanks, factories etc.)
- Diffuse sources (e.g. fertilisers)

The superficial aquifer has a higher risk of being polluted from either point sources or diffuse sources than have the Leederville or Cattamarra aquifers.

Diffuse sources of pollution present the highest risk to the groundwater resources in the MGA. Phosphorus and nitrogen may find their way into the superficial aquifer from farming activities. Nutrients in the groundwater then move in the direction of flow to discharge into natural or artificial drains and wetlands, causing nutrient enrichment and subsequent algal problems.

Where pollution does occur, it generally forms a plume moving in the direction of groundwater flow. The shape and rate of plume migration depends on the aquifer characteristics. Usually, the pollution plume will move away from its source, contaminating a much larger area. Groundwater contamination from fertiliser application within areas of intensive horticulture and recreation is of concern. Continued groundwater quality monitoring is required to observe any groundwater impacts from the Wagerup and Pinjarra alumina refinery operations.

A feature of groundwater pollution is that once it has occurred, it can rarely be remediated completely without very large expense. It is, however, impracticable to avoid and ameliorate all pollution, particularly in agricultural areas where pollution from diffuse sources may be prominent.
10.3 Environmental issues

To limit any environmental damage that may be brought about by lowering of the water levels due to pumping, this allocation plan limits abstraction from the superficial aquifer to 75% of the total annual rainfall recharge. Land use management adjacent to these wetlands is also considered a significant threat to the natural wetland ecosystem.

The wetlands of the Swan Coastal Plain have a direct affiliation with groundwater and the effects of human impacts (Balla, 1993). Poor groundwater management within the MGA may result in adverse impacts on prominent and environmentally sensitive wetlands and watercourses such as Goeegrup Lake, Nambeelup Pool, Lake McLarty and the Peel–Harvey Estuary.

Other environmental issues in the MGA include the sand-mining and alumina processing operations. Effluent from the processing plants is directed through a series of containment ponds and has the potential to contaminate groundwater resources if it is not effectively managed.

10.4 Subarea management

The Murray Groundwater Area is subdivided into 4 subareas (Figure 1) to allow efficient management of the groundwater resources. Groundwater flow system boundaries, Shire boundaries and main rivers in the MGA were the main criteria used for determining the subarea boundaries.
The subareas in alphabetical order are

- Coolup
- Nambeelup
- Pinjarra
- Waroona

Information relevant to the management of the groundwater resources in each subarea is presented in the fact sheets of Chapter 12. The description of water quality is very general and is based on the following:

- fresh: < 1000 mg/L TDS
- marginal: 1000–1500
- brackish: 1500–3000
- saline: > 3000

There may exist, within each subarea, areas of better or poorer quality groundwater and the groundwater salinity may vary with depth. Insufficient wells exist in the area to be able to determine with confidence how salinity varies with depth in a specific area.
11. Groundwater licensing process

11.1 Application for a groundwater well licence

The process of issuing a groundwater well licence commences when an application for a groundwater well licence upon a prescribed form is submitted to a Water and Rivers Commission office. An application is required under the following circumstances

- the well is defined as artesian under Section 26A of the Rights in Water and Irrigation Act 1914; and

- the property upon which a non-artesian well is to be situated lies within a Groundwater Area proclaimed under Section 26B of the Rights in Water and Irrigation Act 1914.

In either of the above circumstances, an applicant must gain approval in the form of a groundwater well licence to commence constructing, enlarging, deepening, altering or drawing groundwater from any well. A person in breach of these requirements, or found to be in contravention of a licence condition, may be liable to a fine.

Provisions do exist within the Rights in Water and Irrigation Act 1914 to exempt groundwater abstraction within non-artesian (unconfined) aquifers from licensing requirements within specified proclaimed Groundwater Areas.
11.2 The approval process

Applications for a groundwater well licence within the Murray Groundwater Area are made to the South West Regional Office of the Water and Rivers Commission. In many cases, the Regional Office can directly approve and issue a groundwater well licence if the licence complies with the policies within the Murray Groundwater Area Allocation Plan (1998).

However, prior to the issue of a groundwater well licence, it is required that all other necessary planning (e.g. Murray Shire) and environmental (e.g. Department of Environmental Protection, Agriculture WA) approvals be granted. It is the applicant's responsibility to ensure that all necessary approvals have been obtained.

In addition, in order to demonstrate legal access, the licence applicant may be required to submit to the Water and Rivers Commission a certified copy of the Certificate of Title or a Lease Agreement for the property where the development is to occur.

The Water and Rivers Commission may issue a Letter of Intent to an applicant prior to the granting of all other necessary approvals if the proposed abstraction conforms with policies as detailed within the Murray Groundwater Area Allocation Plan (1998). The letter forwarded to the applicant provides an assurance that a groundwater well licence will be issued upon confirmation of the granting of all relevant approvals. The letter does not, however, authorise the applicant to commence groundwater abstraction.
Licence applicants aggrieved by a decision related to an application, such as the conditions attached to a groundwater well licence or its refusal may, within 30 days of notification of refusal or the imposition of conditions, appeal to the Minister for Water Resources. The Minister is then required to direct an inquiry into the matter.

A three-person inquiry panel, having heard all the evidence, makes a recommendation to the Minister. The Minister is not obliged to follow the recommendation. Consistent with the Rights in Water and Irrigation Act 1914 there exists no further right of appeal by either party.

In all cases, however, the appeal is discussed informally with the applicant in an attempt to reach agreement prior to a formal appeal and inquiry.

11.3 Water Resources Allocation Committee

The Water Resources Allocation Committee (WRAC) is a committee established to advise the Water and Rivers Commission on water resource allocation issues, policies and procedures. The functions of the Water Resources Allocation Committee (WRAC) in relation to groundwater resources are

- To guide the Water and Rivers Commission on the development of its policies and operations in relation to the allocation and management of groundwater resources across the State; and
To consider groundwater abstraction licence applications that the Water and Rivers Commission proposes to refuse, and recommend refusal or other appropriate action to the Board of the Water and Rivers Commission.

WRAC reviews groundwater allocation plans and, following approval, forwards them to the Board of the Water and Rivers Commission for final endorsement.
12. Allocation guidelines and principles

Groundwater allocation policies serve to facilitate the equitable and sustainable allocation of available groundwater within the Murray Groundwater Area. This chapter focuses on the development of policies applicable to, and governing groundwater management within the entire groundwater area. Groundwater allocation policies specific to individual subareas are included in the ensuing chapter.

The management guidelines and policies of the groundwater allocation are presented in four distinct sections

(1) Groundwater Allocation (Policies 1–6)
(2) Licensing Conditions (Policies 7–12)
(3) Environmental Protection (Policies 13–15), and
(4) Landuse (Policies 16–18).

Individual policies are assigned numbers, thereby allowing their referencing within all correspondence relating to that policy. The policy number is prefixed with the letters ‘MUR-’ denoting the MGA. The prefix is followed by a number (e.g. MUR-2) which permits the referencing of the policy in subsequent correspondence. Lowercase letters a, b, c etc. may be used in future correspondence to represent revisions of, amendments to, and replacement of existing policies (e.g. MUR-2a).
Policies specific to individual subareas stated within the subarea factsheets of Chapter 12 have the same format as the common policies; however, the nomenclature includes an attachment ‘sp’ which identifies the policies as specific subarea policies.

12.1 Groundwater allocation

12.1.1 Priority use of groundwater

Within the Murray Groundwater Area there are several environmentally significant wetlands and waterways, as identified within the EPA System 6 Report, the Coastal Plain Lakes Environmental Protection Policy, and the joint WRC/DEP publication entitled 'Wetlands of the Swan Coastal Plain'. Wetlands and phreatophytic vegetation are groundwater-dependent ecosystems, and without sustainable groundwater allocation and management, excessive groundwater abstraction may adversely impact on these sensitive environments. Policies have been formulated for the protection of wetlands from excessive groundwater abstraction.

Priority beneficial use of a groundwater resource identifies present or future use that should receive priority over other potential uses. The priority beneficial use will determine the criteria for management and regulation of groundwater allocation.
MUR-1  Priority beneficial uses in Murray Groundwater Area are:

(1)  Environment

(2)  Public use, and

(3)  Private use.

12.1.2 Aquifers

Within the Murray Groundwater Area, three prominent aquifers are utilised for both public and private groundwater requirements. Policies have been developed to govern groundwater abstraction from these sources.

Superficial aquifer

The superficial aquifer represents a large source of groundwater, within the MGA west of the Darling Fault, belonging to the Serpentine and Waroona groundwater flow systems. The superficial aquifer has the largest groundwater availability of the aquifers, although well yields within areas of the MGA may be low. Abstraction is therefore encouraged from the superficial aquifer, and is the preferred source given suitable quality and quantity.

MUR-2  Groundwater shall be allocated from the superficial aquifer in preference to the confined aquifers if the required resource is available, environmentally acceptable, of suitable quality, and if the project is economically practical.
A further policy has been developed to assess applications for significant groundwater abstractions from the superficial aquifer. The policy enables accurate assessment and effective management of groundwater-intensive pursuits.

- **MUR-3** Applications for abstraction greater than 100,000 kL/year from the superficial aquifer should be referred for assessment and approval to the Allocation and Use Efficiency (South) Section of the Allocation Branch.

**Leederville aquifer**

The Leederville aquifer extends throughout the MGA. The existence of a green clay marker separates the aquifer into two principal aquifer zones, described as the 'upper' and 'lower' Leederville aquifers. The following delineates the policies adopted to allow appropriate management of groundwater allocation from both the upper and lower Leederville aquifers.

- **MUR-4** Licensees proposing to draw groundwater from the Leederville aquifer are instructed that subsequent to an encounter with the green clay, the Commission 'shall deem them to be drawing from the 'lower' Leederville aquifer, and allocation will be licensed accordingly.
◆ MUR-5  All new licence applications or applications to significantly increase current licences drawing from the Leederville aquifer should be referred for review and assessment to the Allocation and Use Efficiency (South) Section of the Allocation Branch.

Cattamarra aquifer

Limited resources are available from the Cattamarra aquifer. Little detailed hydrogeological investigation of the Cattamarra aquifer has been carried out. This is reflected by the development of a conservative policy in allocating groundwater from this aquifer.

◆ MUR-6  Pending further investigation, no new licences are to be issued which allocate groundwater from the Cattamarra aquifer. Consideration will be given to abstraction from the Cattamarra aquifer if applicants prove the sustainability of the aquifer to the satisfaction of the Water and Rivers Commission.

12.2 Licensing conditions

A multitude of conditions exist within a groundwater well licence. These take the form of both general conditions and conditions specific to a particular licence.
12.2.1 Exemptions

Groundwater licensing exemptions exist for designated usages and declared areas. The following details the exemptions applicable to the Murray Groundwater Area.

- **MUR-7**  *Groundwater abstraction from the superficial aquifer of less than 1500 kL/year for stock and domestic purposes shall be exempt from licensing.*

12.2.2 Cement grouting

Wells screened within the confined aquifers must be pressure cement grouted. When drilling a well beneath the superficial aquifer, a risk exists that groundwater will flow within the annulus between the borehole casing and the aquifer, resulting in the intermixing of varying quality groundwaters. The cement grouting of wells screened below the superficial aquifer mitigates such mixing, and acts to provide borehole stability and prevent casing corrosion.

The construction of a well into the Leederville and Cattamarra aquifer, and therefore one requiring cement grouting, must be performed by an individual possessing a Class 2 Water Well Driller’s Certificate issued by the Australian Drilling Industry Association (ADIA, 1996).

- **MUR-8**  *Wells screened within the confined aquifers, below the bottom of the superficial aquifer, must be pressure cement grouted.*
12.2.3 Hydrogeological assessment

Owing to the limited hydrogeological information available, especially for the Leederville and the Cattamarra aquifer, the Water and Rivers Commission may ask applicants requiring large quantities of groundwater from these aquifers to carry out an investigation. In these cases, an exploratory groundwater licence is issued allowing the applicant to investigate the groundwater resources and to determine how the requirement will be achieved.

At the conclusion of the investigation, a hydrogeological report is submitted to the Water and Rivers Commission for assessment. The following is the Commission’s policy relevant to large groundwater applications within the MGA.

**MUR-9** Proponents of a proposal to abstract 500 000 kL/year or more are required to submit to the Water and Rivers Commission a hydrogeological report assessing the possible local and regional impacts of the proposed abstraction on the hydrology, environment and other groundwater users in support of a groundwater well licence application. The report is to be prepared by a competent groundwater professional and is to be completed at the applicant’s expense.
12.2.4 Metering

To adhere to current policy adopted throughout the State, the metering of large abstractions is required, and is an essential tool in the management of the groundwater resources.

♦ MUR-10  **Groundwater allocations equal to or greater than 500 000 kL/year require the metering of groundwater abstraction as a condition of licence. This volume is to be reported annually to the Water and Rivers Commission.**

In particular circumstances, the Commission may require that licensees install meters for allocations less than 500 000 kL/year.

12.2.5 Water-use efficiency

Groundwater is an essential requirement and a valuable resource for many developments within the Murray Groundwater Area. It is necessary that applicants for large quantities of groundwater be required to demonstrate that the proposed development has considered all practical water conservation and efficiency methods, and that commitments to ensure the implementation of these have been made.

♦ MUR-11  **Groundwater should be used efficiently, utilising best practice techniques and irrigation methods.**
Advice may be sought from Agriculture WA and the Irrigation Association of Australia.

12.3 Environmental protection

Wetlands

Most wetlands and groundwater-dependent ecosystems of the Murray Groundwater Area exist as surface expressions of the watertable, and are therefore susceptible to adverse impacts if excessive abstraction occurs in their vicinity.

As stated previously, legislation has been enacted ensuring the protection and conservation of these wetlands and conservation areas. The following is a policy that will dictate careful consideration of proposals that may impact on wetlands, conservation areas, and flora and fauna reserves.

* MUR-12 Applications for a groundwater well licence within 1 km of a System 6 Reserve or EPP Coastal Plain Lake identified within Figure 15 of the Murray Groundwater Area Allocation Plan shall be referred for assessment to the Allocation and Use Efficiency (South) Section of the Allocation Branch.

Peel–Harvey Catchment

Through various forms of legislation, including the Peel–Harvey Estuarine System Environmental Protection Policy and Peel–Harvey Coastal Plain Catchment Planning Policy, and other
requirements as stipulated within the Guidelines for New Horticultural Developments within the Peel-Harvey Catchment (draft), landuse management mechanisms exist to prevent further degradation of the Peel–Harvey Estuarine System.

Existing and future landuse activities in the Peel–Harvey Catchment must therefore be guided with the aim of minimising and reducing nutrient runoff and input to the estuarine system. The following policies recognise such initiatives and objectives.

♦ **MUR-13**  *All groundwater well licence applications for horticultural development within the Murray Groundwater Area concerning developments with the potential to cause nutrient enrichment of groundwater/surface water must, subsequent to completion of a Horticultural Development Application Form, be referred to Department of Environmental Protection.*

♦ **MUR-14**  *If deemed necessary by the Water and Rivers Commission, Groundwater Well Licence applications may be referred to the Department of Environmental Protection for the assessment of any significant impacts upon the Peel–Harvey Estuarine system.*
12.4 Landuse

Project approvals

On receipt of a groundwater well licence application for a development which is likely to warrant assessment by other regulatory agencies (e.g. Environmental Protection Authority, Agriculture WA, Murray Shire etc.), the application should be referred to the relevant agencies for appraisal.

The Water and Rivers Commission cannot, however, issue a groundwater well licence prior to approval being given for the project. The applicant should be advised of the requirement to obtain all necessary approvals (e.g. planning, environmental) prior to licence issue and subsequent project commencement.

The following policies refine the above concerns.

♦ MUR-15 *Project approval is required from local council and other relevant government agencies prior to the issue of a groundwater well licence.*

♦ MUR-16 *Applications associated with a landuse change to intensive agriculture (as defined in SPP No.2) within the Peel–Harvey Catchment are to be referred to Agriculture WA for their assessment of the landuse suitability.*
13. Groundwater management by subareas

13.1 Coolup subarea

<table>
<thead>
<tr>
<th>Coolup subarea description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
</tr>
<tr>
<td>Geomorphic regions</td>
</tr>
<tr>
<td>Shire</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hydrogeology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>superficial aquifer</strong></td>
</tr>
<tr>
<td>• The average saturated thickness of the sediments in this area are approximately 30 m.</td>
</tr>
<tr>
<td>• The aquifer consists mainly of sandy sediments.</td>
</tr>
<tr>
<td>• The watertable is generally very shallow and numerous drains have been constructed through the area.</td>
</tr>
<tr>
<td>• Groundwater may be saline near the Peel Inlet / Harvey Estuary.</td>
</tr>
<tr>
<td><strong>Leederville aquifer</strong></td>
</tr>
<tr>
<td>• The Leederville aquifer exists throughout the subarea.</td>
</tr>
<tr>
<td>• The existence of a green clay marker, of approximate thickness of 5–10 m, separates the aquifer into two principal aquifer zones, described as the ‘upper’ and ‘lower’ Leederville aquifers. This aquifer division has been employed for management purposes.</td>
</tr>
<tr>
<td>• The green clay marker is assumed to outcrop the Leederville aquifer horizon in an approximate southeasterly direction, effectively separating the aquifer into the ‘upper’ Leederville located through the northwest, and the ‘lower’ located to the southeast.</td>
</tr>
<tr>
<td>• The top of the Leederville aquifer may be encountered at a depth of about 30 m.</td>
</tr>
<tr>
<td>• The salinity of the Leederville aquifer ranges from fresh to brackish. Salinity may be high beneath the Peel Inlet, due to leakage of saline water from the overlying superficial aquifer.</td>
</tr>
<tr>
<td>• Upward leakage may occur in the western part of the area to the superficial aquifer.</td>
</tr>
<tr>
<td><strong>Cattamarra aquifer</strong></td>
</tr>
<tr>
<td>• The Cattamarra aquifer exists throughout the subarea.</td>
</tr>
<tr>
<td>• Negligible recharge is expected to occur in this area due to the presence of the overlying confining South Perth Shale.</td>
</tr>
<tr>
<td>• The top of the Cattamarra aquifer may be encountered at depths of about 150 to 200 m. The depth increases in a westerly direction.</td>
</tr>
<tr>
<td>• The Cattamarra aquifer is likely to be saline in the western half of the area.</td>
</tr>
</tbody>
</table>
**Groundwater resources**

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Superficial (kL/year×10^5)</th>
<th>Leederville (kL/year×10^5)</th>
<th>Cattamarra (kL/year×10^5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper</td>
<td>Lower</td>
</tr>
<tr>
<td>Groundwater quality</td>
<td>fresh / brackish</td>
<td>fresh / brackish</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Total allocation limit</td>
<td>20.2</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Current private allocations</td>
<td>0.6</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Current scheme allocations</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Future scheme allocations</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Unallocated resources</td>
<td>19.6</td>
<td>2.1</td>
<td>3.7</td>
</tr>
</tbody>
</table>

**Groundwater use**

- **Superficial aquifer**: Used primarily for industrial purposes, horticulture production and domestic supply.
- **Leederville aquifer**: Mainly used for recreational purposes and plant production.
- **Cattamarra aquifer**: Essentially used for industrial purposes.
- **Constraints**: The Environmental Protection (Peel–Harvey Estuarine System) Policy will place constraints on the acceptable land uses, to prevent eutrophication of the estuarine system. There will be constrained usage within and adjacent to System 6 reserves and EPP Coastal Plain Lakes.
## Coolup subarea (cont.)

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Well (SWRISS No.)</th>
<th>Potentiometric surface or range (m AHD)</th>
<th>Salinity (TDS) (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>superficial</td>
<td>G61330050 HS30A</td>
<td>4.9 m, slight decline</td>
<td>1573–1584, stable</td>
</tr>
<tr>
<td></td>
<td>G61330051 HS31B</td>
<td>5.0 m, slight decline</td>
<td>3751–4416, stable</td>
</tr>
<tr>
<td></td>
<td>G61330052 HS32A</td>
<td>8.7 m, slight decline</td>
<td>503–566</td>
</tr>
<tr>
<td></td>
<td>G61330053 HS32B</td>
<td>9.5 m, slight decline</td>
<td>63–563, rising</td>
</tr>
<tr>
<td></td>
<td>G61330055 HS33A</td>
<td>12.6 m, slight decline</td>
<td>1041–1144, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61330056 HS33B</td>
<td>13.0 m, falling</td>
<td>1194–1216, stable</td>
</tr>
<tr>
<td></td>
<td>G61330057 HS34A</td>
<td>18.9 m, slight decline</td>
<td>786–838, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61330058 HS34B</td>
<td>20.0 m, falling</td>
<td>3421–3954, slight rise</td>
</tr>
<tr>
<td></td>
<td>G61330059 HS35A</td>
<td>25.0 m, slight decline</td>
<td>172–218, stable</td>
</tr>
<tr>
<td></td>
<td>G61330060 HS35B</td>
<td>25.0 m, 4 m range, slight decay</td>
<td>94–105, stable</td>
</tr>
<tr>
<td></td>
<td>G61330061 HS36A</td>
<td>5.2 m, slight decline</td>
<td>988–990, stable</td>
</tr>
<tr>
<td></td>
<td>G61330062 HS36B</td>
<td>6.0 m, slight decline</td>
<td>313–983</td>
</tr>
<tr>
<td></td>
<td>G61330063 HS37B</td>
<td>8.0 m, slight decline</td>
<td>647–960, stable</td>
</tr>
<tr>
<td></td>
<td>G61330064 HS37C</td>
<td>9.3 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>G61330065 HS38A</td>
<td>13.0 m, falling</td>
<td>601–729, stable</td>
</tr>
<tr>
<td></td>
<td>G61330066 HS38B</td>
<td>13.5 m, slight decline</td>
<td>434–763</td>
</tr>
<tr>
<td></td>
<td>G61330068 HS39A</td>
<td>17.2 m, 4 m range, slight decay</td>
<td>535–545, stable</td>
</tr>
<tr>
<td></td>
<td>G61330069 HS39B</td>
<td>17.5 m, 3 m range, slight decay</td>
<td>228 (Sep. 1988)</td>
</tr>
<tr>
<td></td>
<td>G61330070 HS41A</td>
<td>0.2 m slight rise</td>
<td>9581–25335</td>
</tr>
<tr>
<td></td>
<td>G61330071 HS41B</td>
<td>0.5 m, slight decline</td>
<td>563–913, slight rise</td>
</tr>
<tr>
<td></td>
<td>G61330072 HS42A</td>
<td>4.5 m, slight decline</td>
<td>1320–1573, slight rise</td>
</tr>
<tr>
<td></td>
<td>G61330073 HS42B</td>
<td>no data</td>
<td>413–504, rising</td>
</tr>
<tr>
<td></td>
<td>G61330074 HS43A</td>
<td>7.2 m, slight decline</td>
<td>806–831, stable</td>
</tr>
<tr>
<td></td>
<td>G61330075 HS43B</td>
<td>8.0 m, slight decline</td>
<td>181–192, stable</td>
</tr>
<tr>
<td></td>
<td>G61330076 HS44A</td>
<td>12.0 m, slight decline</td>
<td>1040–1083, stable</td>
</tr>
<tr>
<td></td>
<td>G61330077 HS44B</td>
<td>12.6 m, (since 1991 no data)</td>
<td>187–298</td>
</tr>
<tr>
<td></td>
<td>G61330079 HS45A</td>
<td>15.2 m, slight decline</td>
<td>940–1094, stable</td>
</tr>
<tr>
<td></td>
<td>G61330080 HS45B</td>
<td>16.0 m, stable</td>
<td>141 (Sep. 1991)</td>
</tr>
<tr>
<td></td>
<td>G61330081 HS47C</td>
<td>0.2 m, stable</td>
<td>22825–24805, stable</td>
</tr>
<tr>
<td></td>
<td>G61330082 HS47D</td>
<td>0.2 m, stable</td>
<td>735–737, stable</td>
</tr>
<tr>
<td></td>
<td>G61330083 HS48A</td>
<td>2.8 m, slight decline</td>
<td>1326–1336, stable</td>
</tr>
<tr>
<td></td>
<td>G61330084 HS48B</td>
<td>2.8 m, slight decline</td>
<td>1062–1111, stable</td>
</tr>
<tr>
<td></td>
<td>G61330085 HS48C</td>
<td>2.8 m, slight decline</td>
<td>550–575</td>
</tr>
<tr>
<td></td>
<td>G61330086 HS48D</td>
<td>2.8 m, slight decline</td>
<td>1221–1326, stable</td>
</tr>
<tr>
<td></td>
<td>G61330087 HS49A</td>
<td>5.0 m, falling</td>
<td>1419–1436, stable</td>
</tr>
<tr>
<td></td>
<td>G61330088 HS49B</td>
<td>5.25 m, slight decline</td>
<td>236–498</td>
</tr>
<tr>
<td></td>
<td>G61330089 HS50A</td>
<td>8.0 m, slight decline</td>
<td>984–1061, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61330090 HS50B</td>
<td>8.0 m, slight decline</td>
<td>224–870, slight rise</td>
</tr>
<tr>
<td></td>
<td>G61330091 HS53A</td>
<td>1.8 m, slight decline</td>
<td>2172–2480, stable</td>
</tr>
<tr>
<td></td>
<td>G61330092 HS53B</td>
<td>1.8 m, slight decline</td>
<td>2420–2744</td>
</tr>
<tr>
<td></td>
<td>G61330093 HS53C</td>
<td>1.8 m, slight decline</td>
<td>2200–3510</td>
</tr>
<tr>
<td></td>
<td>G61330094 HS54A</td>
<td>6.2 m, slight decline</td>
<td>742–782, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61330095 HS54B</td>
<td>6.3 m, slight decline</td>
<td>210–224, stable</td>
</tr>
<tr>
<td></td>
<td>G61330096 HS55A</td>
<td>1.0 m, slight decline</td>
<td>4230–4351</td>
</tr>
<tr>
<td></td>
<td>G61330097 HS55B</td>
<td>1.0 m, slight decline</td>
<td>371–776, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61330098 HS58A</td>
<td>-0.3 m, stable</td>
<td>588–803</td>
</tr>
<tr>
<td></td>
<td>G61330099 HS58B</td>
<td>0 m, slight rise</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>G61330100 HS39A</td>
<td>0.8 m, slight decline</td>
<td>4906–5252</td>
</tr>
</tbody>
</table>
Groundwater monitoring inventory (cont.)

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Well (SRWRISS No.)</th>
<th>Potentiometric surface or range (m AHD)</th>
<th>Salinity (TDS) (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>superficial</td>
<td>G61330101 HS59B</td>
<td>0.9 m, slight decline</td>
<td>242-530, slight rise</td>
</tr>
<tr>
<td></td>
<td>G61430008 HS36A</td>
<td>3.8 m, slight decline</td>
<td>1287-1370</td>
</tr>
<tr>
<td></td>
<td>G61430009 HS56B</td>
<td>4.0 m, slight decline</td>
<td>463-515, stable</td>
</tr>
<tr>
<td>Leederville</td>
<td>None</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cattamarra</td>
<td>None</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Groundwater licensing policy

General policy

- **MUR-1** Priority Beneficial Uses in Murray Groundwater Area are:
  1. Environment
  2. Community Use, and
  3. Private Use.

- **MUR-2** Groundwater shall be allocated from the superficial aquifer in preference to the confined aquifers if the required resource is available, environmentally acceptable, of suitable quality, and if the project is economically practical.

- **MUR-3** Applications for abstraction greater than 100,000 kL/year from the superficial aquifer should be referred for assessment and approval to the Allocation and Use Efficiency (South) Section of the Allocation Branch.

- **MUR-4** Licensees proposing to draw groundwater from the Leederville aquifer are instructed that subsequent to an encounter with the green clay, screening below this identifiable marker will deem them to be drawing from the 'lower' Leederville aquifer, and allocation will be licensed accordingly.

- **MUR-5** All new licence applications or applications to significantly increase current licences drawing from the Leederville aquifer should be referred for review and assessment to the Allocation and Use Efficiency (South) Section of the Allocation Branch.

- **MUR-6** Pending further investigation, no new licences are to be issued which allocate groundwater from the Cattamarra aquifer. Consideration will be given to abstraction from the Cattamarra aquifer if applicants prove the sustainability of the aquifer to the satisfaction of the Water and Rivers Commission.

- **MUR-7** Groundwater abstraction from the superficial aquifer of less than 1500 kL/year for stock and domestic purposes shall be exempt from licensing.

- **MUR-8** Wells screened within the confined aquifers, below the bottom of the superficial aquifer, must be pressure cement grouted.

- **MUR-9** Proponents of a proposal to abstract equal to or greater than 500 000 kL/year are required to submit to the Water and Rivers Commission a hydrogeological report assessing the possible local and regional impacts of the proposed abstraction on the hydrology, environment and other groundwater users in support of a groundwater well licence application. The report is to be prepared by a competent groundwater professional and is to be completed at the applicant's expense.

- **MUR-10** Groundwater allocations equal to or greater than 500 000 kL/year require the metering of groundwater abstraction as a condition of licence. This volume is to be reported annually to the Water and Rivers Commission.

- **MUR-11** Groundwater should be used efficiently, utilising best practise techniques and irrigation methods.

- **MUR-12** Applications for a groundwater well licence within 1 km of a System 6 Reserve or EPP Coastal Plain Lake identified within Appendix 2 of the Murray Groundwater Area Allocation Plan shall be referred to the Allocation and Use Efficiency (South) Section of the Allocation Branch.
## Coolup subarea (cont.)

### Groundwater licensing policy (cont.)

<table>
<thead>
<tr>
<th>General policy</th>
<th>Specific policy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MUR-13</strong> All groundwater well licence applications for horticultural development within the Murray Groundwater Area concerning developments with the potential to cause nutrient enrichment of groundwater/surface water must, subsequent to the completion of a Horticultural Development Application Form, be referred to the Department of Environmental Protection.</td>
<td></td>
</tr>
<tr>
<td><strong>MUR-14</strong> If deemed necessary by the Water and Rivers Commission, groundwater well licence applications may be referred to the Department of Environmental Protection for the assessment of the potential impact upon the Peel–Harvey estuarine system.</td>
<td></td>
</tr>
<tr>
<td><strong>MUR-15</strong> Project approval is required from the local authority and other relevant government agencies prior to the issue of a groundwater well licence.</td>
<td></td>
</tr>
<tr>
<td><strong>MUR-16</strong> Applications associated with a landuse change to intensive agriculture (as defined in SPP No. 2) within the Peel–Harvey catchment are to be referred to Agriculture WA for their assessment of the landuse suitability.</td>
<td></td>
</tr>
<tr>
<td><strong>MURsp1</strong> Given the allocation of 1 000 000 kL to the lower Leederville aquifer over the 4 km zone extending west of the Darling Fault (see Section 9.3), the maximum groundwater quantity available for allocation to the lower Leederville aquifer west of the delineated zone is therefore 2 700 000 kL.</td>
<td></td>
</tr>
</tbody>
</table>

### Recommendations

- Groundwater shall be allocated from the superficial aquifer in preference to the confined aquifers; however, if the required resource is not available from the superficial aquifer, then abstraction from within the Leederville aquifer will be considered, as pumping from the aquifer will induce recharge and enable future abstraction from the aquifer to approach the groundwater availability estimated.
- Applications for small increases to existing licenses drawing from the Cattamarra aquifer, for viable existing uses, will be considered on their merits.
- Additional monitoring wells are required within the Leederville aquifer, to more accurately determine the hydrogeology, and to further assess the groundwater resources of the aquifer.
13.2 Nambeelup subarea

<table>
<thead>
<tr>
<th>Nambeelup subarea description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
</tr>
<tr>
<td>Geomorphic regions</td>
</tr>
<tr>
<td>Shire</td>
</tr>
</tbody>
</table>

**Hydrogeology**

**superficial aquifer**
- The average saturated thickness of the sediments in this area are approximately 10 m.
- The aquifer consists mainly of clay and sandy sediments.
- The watertable is generally very shallow and numerous drains have been constructed through the area.
- Well yields in this area are expected to be low.

**Leederville aquifer**
- The Leederville aquifer exists throughout the subarea. In the west, the Rockingham aquifer occupies an erosional channel in the Leederville aquifer.
- The existence of a green clay marker, of approximate thickness of 5–10 m, separates the aquifer into two principal aquifer zones, described as the ‘upper’ and ‘lower’ Leederville aquifers. This aquifer division has been employed for management purposes.
- The green clay marker is assumed to outcrop the Leederville aquifer horizon in a southeasterly direction, effectively separating the aquifer into the ‘upper’ Leederville located to the west, and the ‘lower’ Leederville located within a belt to the east.
- The top of the Leederville aquifer may be encountered at depths of about 10 to 50 m.
- The salinity of the Leederville aquifer ranges from fresh to brackish.
- Upward leakage may occur in the western part of the subarea to the superficial aquifer and the Rockingham Sand aquifer.

**Cattamarra aquifer**
- The Cattamarra aquifer exists throughout the subarea.
- The top of the Cattamarra aquifer may be encountered at depths of about 30 to 200 m. The depth increases in a westerly direction.
- The Cattamarra aquifer exhibits unconfined aquifer conditions in the east, where the South Perth Shale is absent and the overlying sediments are thin.
- Recharge to the aquifer occurs where downward heads prevail. Elsewhere, the groundwater is pressurised and its potentiometric surface may be higher than the superficial aquifer watertable. Artesian flow may occur in low-lying areas.

**Groundwater resources**

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Superficial (kL/year x 10^6)</th>
<th>Leederville (kL/year x 10^6)</th>
<th>Cattamarra (kL/year x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper</td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>Groundwater quality</td>
<td>fresh / brackish</td>
<td>fresh / brackish</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Total allocation limit</td>
<td>11.8</td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Current private allocations</td>
<td>0.9</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Current scheme allocations</td>
<td>0</td>
<td>0</td>
<td>0.7</td>
</tr>
<tr>
<td>Future scheme allocations</td>
<td>4.6</td>
<td>4.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Unallocated resources</td>
<td>6.3</td>
<td>1.8</td>
<td>1.1</td>
</tr>
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</table>
Nambeelup subarea (cont.)

Groundwater use

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial aquifer</td>
<td>Used primarily for plant production, horticulture production and domestic</td>
</tr>
<tr>
<td></td>
<td>supply.</td>
</tr>
<tr>
<td>Leederville aquifer</td>
<td>Used primarily for public water supply, horticulture production and animal</td>
</tr>
<tr>
<td></td>
<td>production.</td>
</tr>
<tr>
<td>Cattamarra aquifer</td>
<td>Not utilised.</td>
</tr>
</tbody>
</table>

Constraints

- The Environmental Protection (Peel–Harvey Estuarine System) Policy will place constraints on the acceptable land uses, to prevent eutrophication of the estuarine system.
- There will be constrained usage within and adjacent to System 6 reserves and EPP Coastal Plain Lakes.
- The proposed Dandalup Water Reserve may place constraints on acceptable land uses, to protect the groundwater resources from contamination.

Groundwater monitoring inventory

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Well Number</th>
<th>Potential surface or range (m AHD)</th>
<th>Salinity (TDS) (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial</td>
<td>G61410058</td>
<td>1.5 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>T640</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G61410070</td>
<td>6.0 m, stable</td>
<td>1025 (May 1987)</td>
</tr>
<tr>
<td></td>
<td>T590</td>
<td></td>
<td>204-902</td>
</tr>
<tr>
<td></td>
<td>G61410079</td>
<td>16.0 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>T650</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G61410090</td>
<td>14.6 m, slight decline</td>
<td>214 (Feb 1981)</td>
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<tr>
<td></td>
<td>T550</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G61410106</td>
<td>19.5 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>T600</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G61410112</td>
<td>16.5 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>T660</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>G61410127</td>
<td>21.3 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>T610</td>
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<td></td>
</tr>
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<td></td>
<td>G61410136</td>
<td>25.7 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>T670</td>
<td></td>
<td></td>
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<td></td>
<td>G61410149</td>
<td>33.1 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>T620</td>
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<td></td>
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<tr>
<td></td>
<td>G61419520</td>
<td>4.2 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>NDSS 3/92</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>G61419521</td>
<td>4.2 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>NDSS 4/92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leederville</td>
<td>G61415009</td>
<td>7.7 m, falling</td>
<td>2453–2629</td>
</tr>
<tr>
<td></td>
<td>AM65</td>
<td></td>
<td>787–2558</td>
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<tr>
<td></td>
<td>G61415010</td>
<td>3.4 m, stable</td>
<td>610 (Dec 1982)</td>
</tr>
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<td></td>
<td>AM65A</td>
<td></td>
<td>634 (Mar 1991)</td>
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<td></td>
<td>G61415027</td>
<td>10.0 m, falling</td>
<td>470–476</td>
</tr>
<tr>
<td></td>
<td>AM66</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G61415028</td>
<td>16.5 m, slight decline</td>
<td>2260 (Sep 84)</td>
</tr>
<tr>
<td></td>
<td>AM66A</td>
<td></td>
<td>322–472</td>
</tr>
<tr>
<td></td>
<td>G61415061</td>
<td>18.9 m, falling</td>
<td>244 (Oct 1985)</td>
</tr>
<tr>
<td></td>
<td>AM70A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cattamarra</td>
<td>G61415011</td>
<td>7.7 m, falling</td>
<td>2260 (Sep 84)</td>
</tr>
<tr>
<td></td>
<td>AM65B</td>
<td></td>
<td>322–472</td>
</tr>
<tr>
<td></td>
<td>G61415016</td>
<td>8.6 m, falling</td>
<td>244 (Oct 1985)</td>
</tr>
<tr>
<td></td>
<td>AM68</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G61415059</td>
<td>24.5 m, falling</td>
<td>244 (Oct 1985)</td>
</tr>
<tr>
<td></td>
<td>AM69</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G61415060</td>
<td>19.0 m, falling</td>
<td>244 (Oct 1985)</td>
</tr>
<tr>
<td></td>
<td>AM70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Groundwater licensing policy

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<thead>
<tr>
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</tr>
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<tbody>
<tr>
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</tr>
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</tr>
<tr>
<td><strong>MUR-16</strong> Applications associated with a landuse change to intensive agriculture (as defined in SPP No. 2) within the Peel–Harvey catchment area are to be referred to Agriculture WA for their assessment of the landuse suitability.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specific policy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MURsp1</strong> Given the allocation of 1 000 000 kL to the lower Leederville aquifer over the 4 km zone extending west of the Darling Fault (see Section 9.3), the maximum groundwater quantity available for allocation to the lower Leederville aquifer west of the delineated zone is therefore 200 000 kL.</td>
</tr>
<tr>
<td><strong>MURsp2</strong> The monitoring of NDSS bores currently carried out by the Water Corporation, should be transferred to the Water and Rivers Commission. It is proposed that their monitoring become the responsibility of the Commission, and that they be included within the Commission’s ‘Country Groundwater Monitoring Program’.</td>
</tr>
</tbody>
</table>
**Recommendations**

- Groundwater shall be allocated from the superficial aquifer in preference to the confined aquifers; however, if the required resource is not available from the superficial aquifer, then abstraction from within the Leederville aquifer will be considered, as pumping from the aquifer will induce recharge and enable future abstraction from the aquifer to approach the groundwater availability estimated.
- Abstractions from the Leederville aquifer should be allocated to both the 'upper' and 'lower' aquifers to distribute the draw throughout the full thickness of the aquifer.
- Additional monitoring wells are required within the Leederville aquifer, to more accurately determine the hydrogeology, and to assess further the groundwater resources of the aquifer.
13.3 Pinjarra subarea

<table>
<thead>
<tr>
<th>Pinjarra subarea description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area</strong></td>
</tr>
<tr>
<td><strong>Geomorphic regions</strong></td>
</tr>
<tr>
<td><strong>Shire</strong></td>
</tr>
</tbody>
</table>

### Hydrogeology

#### Superficial aquifer
- The average saturated thickness of the sediments in this area are approximately 20 m.
- The aquifer thickness progressively increases from east to west.
- The soil is predominantly clayey.
- The watertable is generally very shallow and numerous drains have been constructed throughout the area.
- Well yields in this area are expected to be low.

#### Leederville aquifer
- The Leederville aquifer exists throughout the subarea.
- The top of the Leederville aquifer may be encountered at a depth of about 20 m.
- The existence of a green clay marker, of approximate thickness of 5–10 m, separates the aquifer into two principal aquifer zones, described as the 'upper' and 'lower' Leederville aquifers. This aquifer division has been employed for management purposes.
- The green clay marker is assumed to outcrop the Leederville aquifer horizon in the northwestern corner of the subarea, however, the subarea essentially consists of the 'lower' Leederville aquifer.
- Recharge occurs to the Leederville aquifer in the eastern part of the Coastal Plain, where downward hydraulic heads prevail.
- The salinity of the Leederville aquifer ranges from fresh to brackish.

#### Cattamarra aquifer
- The Cattamarra aquifer exists throughout the subarea.
- The top of the Cattamarra aquifer may be encountered at depths of about 35–150 m. The depth increases in a westerly direction.
- The Cattamarra aquifer exhibits unconfined aquifer conditions in the east, where the South Perth Shale is absent and the overlying sediments are thin or absent.
- Recharge to the aquifer occurs in the east where downward hydraulic heads prevail.

### Groundwater resources

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Superficial (kL/year×10^6)</th>
<th>Leederville (kL/year×10^6)</th>
<th>Cattamarra (kL/year×10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fresh / brackish</td>
<td>Fresh / brackish</td>
<td>Fresh / brackish</td>
</tr>
<tr>
<td><strong>Groundwater quality</strong></td>
<td></td>
<td>Upper</td>
<td>Lower</td>
</tr>
<tr>
<td><strong>Total allocation limit</strong></td>
<td>1.5</td>
<td>0.1</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Current private allocations</strong></td>
<td>0.1</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Current scheme allocations</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Future scheme allocations</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Unallocated resources</strong></td>
<td>1.4</td>
<td>0.1</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Note: * An existing groundwater user has a licence agreement that enables temporary extension of the licensed allocation to a maximum of 4 000 000 kL/year from the Cattamarra aquifer, when surface water sources are inadequate.
Pinjarra subarea (cont.)

Groundwater use

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Well (SWRISS No.)</th>
<th>Potentiometric surface or range (m AHD)</th>
<th>Salinity (TDS) (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>superficial</td>
<td>G61430001 HS40A</td>
<td>15.4 m, stable</td>
<td>2546–2651, rising</td>
</tr>
<tr>
<td></td>
<td>G61430002 HS40B</td>
<td>24.0 m, slight decline</td>
<td>266–271, stable</td>
</tr>
<tr>
<td></td>
<td>G61430003 HS46A</td>
<td>19.5 m, slight decline</td>
<td>357–355, stable</td>
</tr>
<tr>
<td></td>
<td>G61430004 HS46B</td>
<td>21.4 m, slight decline</td>
<td>477–616</td>
</tr>
<tr>
<td></td>
<td>G61430005 HS51A</td>
<td>5.3 m, slight decline</td>
<td>532–534, stable</td>
</tr>
<tr>
<td></td>
<td>G61430006 HS52A</td>
<td>27.3 m, slight decline</td>
<td>520–596, rising</td>
</tr>
<tr>
<td></td>
<td>G61430007 HS52B</td>
<td>28.0 m, stable</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td>G61430010 HS57A</td>
<td>20.2 m, slight decline</td>
<td>697–680, stable</td>
</tr>
<tr>
<td></td>
<td>G61430011 HS57B</td>
<td>4.8 m, slight decline</td>
<td>353–613, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61430013 HS60A</td>
<td>7.0 m, slight decline</td>
<td>1063–984, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61430014 HS60B</td>
<td>8.0 m, slight decline</td>
<td>540–326</td>
</tr>
<tr>
<td></td>
<td>G61430015 HS61A</td>
<td>23.1 m, slight decline</td>
<td>no data</td>
</tr>
<tr>
<td>Leederville</td>
<td>None</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cattamarra</td>
<td>None</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Groundwater licensing policy

- **MUR-1** Priority Beneficial Uses in Murray Groundwater Area are:
  1. Environment
  2. Community Use, and
  3. Private Use.

- **MUR-2** Groundwater shall be allocated from the superficial aquifer in preference to the confined aquifers if the required resource is available, environmentally acceptable, of suitable quality, and if the project is economically practical.

- **MUR-3** Applications for abstraction greater than 100,000 kL/year from the superficial aquifer should be referred for assessment and approval to the Allocation and Use Efficiency (South) Section of the Allocation Branch.

- **MUR-4** Licensees proposing to draw groundwater from the Leederville aquifer are instructed that subsequent to an encounter with the green clay, screening below this identifiable marker will deem them to be drawing from the 'lower' Leederville aquifer, and allocation will be licensed accordingly.

- **MUR-5** All new licence applications or applications to significantly increase current licences drawing from the Leederville aquifer should be referred for review and assessment to the Allocation and Use Efficiency (South) Section of the Allocation Branch.
### Groundwater licensing policy (cont.)

#### General policy
- **MUR-6** Pending further investigation, no new licences are to be issued which allocate groundwater from the Catamarra aquifer. Consideration will be given to abstraction from the Catamarra aquifer if applicants prove the sustainability of the aquifer to the satisfaction of the Water and Rivers Commission.
- **MUR-7** Groundwater abstraction from the superficial aquifer of less than 1500 kL/year for stock and domestic purposes shall be exempt from licensing.
- **MUR-8** Wells screened within the confined aquifers, below the bottom of the superficial aquifer, must be pressure cement grouted.
- **MUR-9** Proposers of a proposal to abstract equal to or greater than 500 000 kL/year are required to submit to the Water and Rivers Commission a hydrogeological report assessing the possible local and regional impacts of the proposed abstraction on the hydrology, environment and other groundwater users in support of a groundwater well licence application. The report is to be prepared by a competent groundwater professional and is to be completed at the applicant's expense.
- **MUR-10** Groundwater allocations equal to or greater than 500 000 kL/year require the metering of groundwater abstraction as a condition of licence. This volume is to be reported annually to the Water and Rivers Commission.
- **MUR-11** Groundwater should be used efficiently, utilising best practise techniques and irrigation methods.
- **MUR-12** Applications for a groundwater well licence within 1 km of a System 6 Reserve or EPP Coastal Plain Lake identified within Appendix 2 of the Murray Groundwater Area Allocation Plan shall be referred to the Allocation and Use Efficiency (South) Section of the Allocation Branch.
- **MUR-13** All groundwater well licence applications for horticultural development within the Murray Groundwater Area concerning developments with the potential to cause nutrient enrichment of groundwater/surface water must, subsequent to the completion of a Horticultural Development Application Form, be referred to the Department of Environmental Protection.
- **MUR-14** If deemed necessary by the Water and Rivers Commission, groundwater well licence applications may be referred to the Department of Environmental Protection for the assessment of the potential impact upon the Peel–Harvey estuarine system.
- **MUR-15** Project approval is required from the local authority and other relevant government agencies prior to the issue of a groundwater well licence.
- **MUR-16** Applications associated with a landuse change to intensive agriculture (as defined in SPP No. 2) within the Peel–Harvey catchment are to be referred to Agriculture WA for their assessment of the landuse suitability.

#### Specific policy
- **MURsp1** Given the allocation of 1 000 000 kL to the lower Leederville aquifer over the 4 km zone extending west of the Darling Fault (see Section 9.3), the maximum groundwater quantity available for allocation to the lower Leederville aquifer west of the delineated zone is therefore 1 300 000 kL.
- **MURsp2** Licensee's proposing to draw from the Leederville aquifer are advised that within the Pinjarra subarea, the green clay may not be encountered during drilling. Minimal groundwater is available from the upper aquifer, and therefore wells should be screened in the lower aquifer.
Pinjarra subarea (cont.)

**Recommendations**

- Groundwater shall be allocated from the superficial aquifer in preference to the confined aquifer; however, if the required resource is not available from the superficial aquifer, then abstraction from within the Leederville aquifer will be considered, as pumping from the aquifer will induce recharge and enable future abstraction from the aquifer to approach the groundwater availability estimated.

- A moratorium should be imposed preventing further abstraction from the Cattamarra aquifer. This moratorium is subject to the implementation of future allocation policies derived from proposed investigations into the sustainable yield of the Cattamarra aquifer.

- Additional monitoring wells are required screened into the Leederville and Cattamarra aquifers, to more accurately determine the hydrogeology, and to assess further the groundwater resources of the aquifers.

- The Commission should consult with Alcoa as to the analysis and results of Alcoa’s numerical modelling of the aquifer systems currently being performed. The modelling is designed to determine the sustainable yield if the Cattamarra aquifer at the Pinjarra refinery, and to assess the local and regional effects of abstraction from the Cattamarra aquifer.

- Following analysis of preliminary results of Alcoa’s numerical modelling, and assessment of groundwater monitoring data, Alcoa, in conjunction with the Commission, shall assess the requirements for additional hydrogeological data and groundwater monitoring at the Pinjarra refinery site. This consultation may result in a requirement for the construction of additional monitoring bores.
13.4 Waroona subarea

### Waroona subarea description

**Area**
23,402 ha

**Geomorphic region**
Swan Coastal Plain, Darling Plateau

**Shire**
Waroona

### Hydrogeology

**Superficial aquifer**
- The average saturated thickness of the sediments in this area are approximately 20 m.
- The aquifer thickness progressively increases from east to west.
- The aquifer consists mainly of clay and sandy sediments.
- The watertable is generally very shallow and numerous drains have been constructed throughout the area.
- Well yields in this area are expected to be low.

**Leederville aquifer**
- The Leederville aquifer exists throughout the subarea.
- The top of the Leederville aquifer may be encountered at a depth of about 20 m.
- The existence of a green clay marker, of approximate thickness of 5–10 m, separates the aquifer into two principal aquifer zones, described as the ‘upper’ and ‘lower’ Leederville aquifers. This aquifer division has been employed for management purposes.
- The green clay marker is assumed to outcrop the Leederville aquifer horizon in the northwestern corner of the subarea, however, the subarea essentially consists of the ‘lower’ Leederville aquifer.
- The salinity of the Leederville aquifer ranges from fresh to brackish.
- Downward leakage to the Cattamarra aquifer is expected to be negligible.

**Cattamarra aquifer**
- The Cattamarra aquifer exists throughout the subarea.
- The top of the Cattamarra aquifer may be encountered at depths of about 50 to 200 m. The depth increases in a westerly direction.
- Recharge to the aquifer is negligible due to the high proportion of siltstone and shale in the overlying Leederville aquifer.
- The Cattamarra aquifer is likely to be saline through most of the area.
- The confining South Perth Shale does not appear to be present in this area.

### Groundwater resources

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Superficial (kL/year×10^6)</th>
<th>Leederville (kL/year×10^6)</th>
<th>Cattamarra (kL/year×10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper</td>
<td>Lower</td>
</tr>
<tr>
<td>Groundwater quality</td>
<td>fresh / brackish</td>
<td>fresh / brackish</td>
<td>fresh / brackish</td>
</tr>
<tr>
<td>Total allocation limit</td>
<td>6.6</td>
<td>0</td>
<td>7.5</td>
</tr>
<tr>
<td>Current private allocations</td>
<td>1.4</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Current scheme allocations</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Future scheme allocations</td>
<td>0</td>
<td>0</td>
<td>7.4</td>
</tr>
<tr>
<td>Unallocated resources</td>
<td>5.2</td>
<td>0</td>
<td>4.4</td>
</tr>
</tbody>
</table>
### Groundwater use

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Use Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial aquifer</td>
<td>Used primarily for horticulture production and domestic supply.</td>
</tr>
<tr>
<td>Leederville aquifer</td>
<td>Used primarily for horticulture production.</td>
</tr>
<tr>
<td>Cattamarra aquifer</td>
<td>Not utilised.</td>
</tr>
<tr>
<td>Constraints</td>
<td>The Environmental Protection (Peel–Harvey Estuarine System) Policy will place constraints on the acceptable land uses, to prevent eutrophication of the estuarine system.</td>
</tr>
<tr>
<td></td>
<td>There will be constrained usage within and adjacent to System 6 reserves and EPP Coastal Plain Lakes.</td>
</tr>
</tbody>
</table>

### Groundwater monitoring inventory

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Well (SWRISS No.)</th>
<th>Potentiometric surface or range (m AHD)</th>
<th>Salinity (TDS) (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial</td>
<td>G61330026 HS19A</td>
<td>12.5 m, slight decline</td>
<td>463–494, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61330027 HS19B</td>
<td>12.5 m, slight decline</td>
<td>119–187, slight rise</td>
</tr>
<tr>
<td></td>
<td>G61330028 HS20A</td>
<td>11.0 m, stable</td>
<td>2843–2860, stable</td>
</tr>
<tr>
<td></td>
<td>G61330029 HS20B</td>
<td>11.8 m, stable</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>G61330030 HS21A</td>
<td>13.2 m, slight decline</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td>G61330031 HS21B</td>
<td>13.1 m, slight decline</td>
<td>1660–17820?</td>
</tr>
<tr>
<td></td>
<td>G61330032 HS22A</td>
<td>38.7 m, slight decline</td>
<td>126–154</td>
</tr>
<tr>
<td></td>
<td>G61330033 HS22B</td>
<td>38.6 m, slight decline</td>
<td>133–140</td>
</tr>
<tr>
<td></td>
<td>G61330034 HS23A</td>
<td>8.1 m, slight decline</td>
<td>874–847, stable</td>
</tr>
<tr>
<td></td>
<td>G61330035 HS23B</td>
<td>8.75 m, stable</td>
<td>108–121, stable</td>
</tr>
<tr>
<td></td>
<td>G61330036 HS24A</td>
<td>9.5 m, slight decline</td>
<td>2156–2117, slight rise</td>
</tr>
<tr>
<td></td>
<td>G61330037 HS24B</td>
<td>9.5 m, falling</td>
<td>4625–4812</td>
</tr>
<tr>
<td></td>
<td>G61330038 HS25A</td>
<td>14.0 m, 4 m range, falling</td>
<td>2002–1985, stable</td>
</tr>
<tr>
<td></td>
<td>G61330039 HS25B</td>
<td>14.8 m, 4 m range, falling</td>
<td>2282–3091, slight rise</td>
</tr>
<tr>
<td></td>
<td>G61330040 HS26A</td>
<td>30.2 m, slight decline</td>
<td>623–706, slight rise</td>
</tr>
<tr>
<td></td>
<td>G61330041 HS26B</td>
<td>34.0 m, slight decline</td>
<td>124–153, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61330042 HS27A</td>
<td>7.5 m, slight decline</td>
<td>2095, stable</td>
</tr>
<tr>
<td></td>
<td>G61330043 HS27B</td>
<td>7.5 m, slight decline</td>
<td>418–2260, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61330044 HS28B</td>
<td>12.0 m, slight decline</td>
<td>2002–2079, stable</td>
</tr>
<tr>
<td></td>
<td>G61330045 HS28C</td>
<td>13.5 m, slight decline</td>
<td>106–161, stable</td>
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<tr>
<td></td>
<td>G61330046 HS29A</td>
<td>16.0 m, slight decline</td>
<td>2865–2821, stable</td>
</tr>
<tr>
<td></td>
<td>G61330047 HS29B</td>
<td>17.1 m, slight decline</td>
<td>63–110, slight decline</td>
</tr>
<tr>
<td></td>
<td>G61330048 HS30A</td>
<td>23.4 m, slight decline</td>
<td>1210–1127, slight decline</td>
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<tr>
<td></td>
<td>G61330049 HS30B</td>
<td>26.0 m, falling</td>
<td>727–993, slight decline</td>
</tr>
<tr>
<td>Leederville</td>
<td>G61330136 HL3A1</td>
<td>13.1 m, slight decline</td>
<td>2260–2464, stable</td>
</tr>
<tr>
<td></td>
<td>G61330142 HL4AB</td>
<td>25.4 m, slight decline</td>
<td>1391–1306, slight rise</td>
</tr>
<tr>
<td>Cattamarra</td>
<td>G61330137 HL3A2</td>
<td>13.1 m, slight decline</td>
<td>6130–6580?</td>
</tr>
<tr>
<td></td>
<td>G61330140 HL4A1</td>
<td>16.2 m, stable</td>
<td>no data</td>
</tr>
</tbody>
</table>
### Groundwater licensing policy

| General policy | *MUR-1* Priority Beneficial Uses in Murray Groundwater Area are:  
|               | (1) Environment  
|               | (2) Community Use, and  
|               | (3) Private Use.  
|               | *MUR-2* Groundwater shall be allocated from the superficial aquifer in preference to the confined aquifers if the required resource is available, environmentally acceptable, of suitable quality, and if the project is economically practical.  
|               | *MUR-3* Applications for abstraction greater than 100,000 kL/year from the superficial aquifer should be referred for assessment and approval to the Allocation and Use Efficiency (South) Section of the Allocation Branch.  
|               | *MUR-4* Licensees proposing to draw groundwater from the Leederville aquifer are instructed that subsequent to an encounter with the green clay, screening below this identifiable marker will deem them to be drawing from the 'lower' Leederville aquifer, and allocation will be licensed accordingly.  
|               | *MUR-5* All new licence applications or applications to significantly increase current licences drawing from the Leederville aquifer should be referred for review and assessment to the Allocation and Use Efficiency (South) Section of the Allocation Branch.  
|               | *MUR-6* Pending further investigation, no new licences are to be issued which allocate groundwater from the Cattamarra aquifer. Consideration will be given to abstraction from the Cattamarra aquifer if applicants prove the sustainability of the aquifer to the satisfaction of the Water and Rivers Commission.  
|               | *MUR-7* Groundwater abstraction from the superficial aquifer of less than 1500 kL/year for stock and domestic purposes shall be exempt from licensing.  
|               | *MUR-8* Wells screened within the confined aquifers, below the bottom of the superficial aquifer, must be pressure cement grouted.  
|               | *MUR-9* Proponents of a proposal to abstract equal to or greater than 500,000 kL/year are required to submit to the Water and Rivers Commission a hydrogeological report assessing the possible local and regional impacts of the proposed abstraction on the hydrology, environment and other groundwater users in support of a groundwater well licence application. The report is to be prepared by a competent groundwater professional and is to be completed at the applicant's expense.  
|               | *MUR-10* Groundwater allocations equal to or greater than 500,000 kL/year require the metering of groundwater abstraction as a condition of licence. This volume is to be reported annually to the Water and Rivers Commission.  
|               | *MUR-11* Groundwater should be used efficiently, utilising best practise techniques and irrigation methods.  
|               | *MUR-12* Applications for a groundwater well licence within 1 km of a System 6 Reserve or EPP Coastal Plain Lake identified within Appendix 2 of the Murray Groundwater Area Allocation Plan shall be referred to the Allocation and Use Efficiency (South) Section of the Allocation Branch.  
|               | *MUR-13* All groundwater well licence applications for horticultural development within the Murray Groundwater Area concerning developments with the potential to cause nutrient enrichment of groundwater/surface water must, subsequent to the completion of a Horticultural Development Application Form, be referred to the Department of Environmental Protection.  
|               | *MUR-14* If deemed necessary by the Water and Rivers Commission, groundwater well licence applications may be referred to the Department of Environmental Protection for the assessment of the potential impact upon the Peel–Harvey estuarine system.  |
### Groundwater licensing policy (cont.)

<table>
<thead>
<tr>
<th>General policy (cont.)</th>
<th>Specific policy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MUR-15</strong> Project approval is required from the local authority and other relevant government agencies prior to the issue of a groundwater well licence.</td>
<td></td>
</tr>
<tr>
<td><strong>MUR-16</strong> Applications associated with a landuse change to intensive agriculture (as defined in SPP No. 2) within the Peel–Harvey catchment are to be referred to Agriculture WA for their assessment of the landuse suitability.</td>
<td></td>
</tr>
<tr>
<td><strong>MURsp1</strong> Given the allocation of 1 000 000 kL to the lower Leederville aquifer over the 4 km zone extending west of the Darling Fault (see Section 9.3), the maximum groundwater quantity available for allocation to the lower Leederville aquifer west of the delineated zone is therefore 6 400 000 kL.</td>
<td></td>
</tr>
<tr>
<td><strong>MURsp2</strong> Licensee’s proposing to draw from the Leederville aquifer are advised that within the Pinjarra subarea, the green clay may not be encountered during drilling. Minimal groundwater is available from the upper aquifer, and therefore all abstraction will be licensed from the lower aquifer.</td>
<td></td>
</tr>
</tbody>
</table>

### Recommendations

*Groundwater shall be allocated from the superficial aquifer in preference to the confined aquifers; however, if the required resource is not available from the superficial aquifer, then abstraction from within the Leederville aquifer will be considered, as pumping from the aquifer will induce recharge and enable future abstraction from the aquifer to approach the groundwater availability estimated.*
14. Conclusions

14.1 Monitoring

Monitoring wells

Most of the monitoring wells of the MGA were drilled by the Geological Survey of Western Australia to provide geological and hydrogeological information. The Water and Rivers Commission have taken over the monitoring and maintenance of these wells. Monitoring data collected from these wells are stored in the SWRIS database.

Limitations of current program

The current level of monitoring is considered to be inadequate primarily due to the lack of monitoring wells in certain areas and the lack of groundwater salinity monitoring.

Water levels in most monitoring wells are generally recorded twice yearly, during summer and winter when water levels are at their lowest and highest, respectively. However, although this frequency of water-level monitoring may be adequate, salinity data are sparse and generally limited to that recorded at the time of drilling.
There is a large network of wells monitoring the superficial aquifer of the MGA and these are located primarily in the central and southern part of the groundwater area. However, there are relatively few wells monitoring the Leederville and Cattamarra aquifers, particularly in the centre of the groundwater area, where both the Leederville and Cattamarra aquifers are heavily utilised.

Private wells

Currently within the Murray Groundwater Area, there are four licensees who hold licences permitting groundwater abstraction exceeding 500,000 kL/year. The Water and Rivers Commission aims to ensure that these licensees adhere to the terms, limitations and conditions as stipulated within their respective licences, which request the submission of regular aquifer performance reviews.

Proposed monitoring program

The proposed monitoring program utilises the existing wells to record any changes to water levels and water quality in the aquifers. Any subsequently drilled monitoring wells should follow the proposed monitoring program, unless otherwise stated.

The proposed monitoring frequency for each aquifer is displayed below. The monitoring of production and monitoring wells of town water supply schemes and private wells should be conducted by the licensee as per the groundwater licence conditions.
Table 6. Proposed monitoring frequency

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Water levels</th>
<th>Field conductivity</th>
<th>Water quality analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>superficial</td>
<td>biannual</td>
<td>-</td>
<td>5 yearly</td>
</tr>
<tr>
<td>Leederville</td>
<td>biannual</td>
<td>-</td>
<td>5 yearly</td>
</tr>
<tr>
<td>Yarragadee</td>
<td>biannual</td>
<td>-</td>
<td>5 yearly</td>
</tr>
</tbody>
</table>

The main change to the monitoring program is an increase in water-quality sampling. This is justified by the increasing level of abstraction from the aquifers and the lack of current data. Wells monitored twice yearly should be monitored in March and September, when the water levels are at their lowest and highest levels respectively.

Data collected from the wells should be as accurate as practicable to assist in correctly assessing the aquifer performance. Accurate data are more important when wells are not monitored regularly.

Before a well is sampled for conductivity or water quality, it should be airlifted and three casing volumes should be displaced. This method will reduce any stratification of the water in the well and will enable more accurate data to be produced.

Regional officers of the Commission should regularly review monitoring data and consult with the Allocation and Use Efficiency (South) Section concerning any irregularities found within the data. Following review from regional officers, the monitoring data and reports should be referred to the Allocation and Use Efficiency (South) Section for further review, and for any alterations that may be deemed necessary to the monitoring program.
Additional monitoring wells required

Additional exploratory drilling should be carried out in the northern part of the MGA to provide hydrogeological information and monitoring facilities in the superficial and Leederville aquifers. This could be conducted by the relevant agencies to investigate the feasibility of the proposed water supply schemes.

It is also recommended that additional exploratory drilling be carried out in the central part of the MGA to provide hydrogeological data and monitoring facilities in the Leederville and Cattamarra aquifers. This is considered essential as detailed hydrogeological information on these aquifers within this area is scarce.

Alcoa constantly review their groundwater monitoring program, and following consideration of the aquifer performance reviews and subsequent numerical groundwater modelling, a revised monitoring program will be formulated between Alcoa and the Water and Rivers Commission. Alcoa have also agreed to provide monitoring data to the Commission in digital form for inclusion in the Commission's SWRIS database. This consultation may result in a requirement for the construction of additional monitoring bores.
14.2 Aquifer performance

Superficial aquifer

There are numerous wells screened in the superficial aquifer of the MGA. Groundwater levels in all wells have varied seasonally, with seasonal variations ranging from around 1 m to as much as 4 m. In general, the seasonal watertable ranges are 1–2 m, with the greatest range of 2–4 m occurring adjacent to the Darling Scarp (Figure 16). The smallest range (0.2–0.8 m) is recorded in the Bassendean Sands fringing the Peel Inlet and Harvey Estuary.

The groundwater levels across the MGA have been plotted to indicate the difference in summer and winter water levels between the years 1990 and 1996 (Figure 19). The water-level contours indicate that water levels remained relatively steady through the western fringe and central margins of the groundwater area, with variations of less than 0.4 m. A large portion of the central and eastern parts of the groundwater area exhibited groundwater level declines between the summers of 1990 and 1996. This may be attributed to reduced rainfall recharge associated with the below average rainfall years for the three year period concluding 1995. Larger reductions in water levels (~0.8 m) were observed within the central-eastern regions of the MGA, and may be attributed to the very low rainfall during the winter of 1989.
Winter water levels have not declined and have, in fact, increased through the central margins of the area. Rainfall in 1996 exceeded that in 1990, and 1996 water levels therefore exceeded the winter levels of 1990 because of the greater recharge derived from the higher rainfall. The winter difference plots indicate the rapid recovery of the aquifer following a modest rainfall. Following the below average rainfall of 1995, 1996 summer water levels were low compared with those of 1990. However, following the steady rainfall during winter 1996, the aquifer was well recharged and water levels recovered accordingly.

The superficial monitoring well hydrographs indicate that within the Nambeelup and Coolup subareas, groundwater levels have remained relatively constant since the commencement of monitoring in 1998. Groundwater levels within the central and eastern parts of the Coolup subarea experienced slight declines during 1994, 1995, and the summer of 1996, reflecting in each case the consecutive below-average rainfall of the preceding years. Water levels recovered in response to the sound rainfall of 1996, and the further ample rainfall year in 1997 will see water levels approaching the established long-term average levels.

The salinity within the superficial aquifer increases in the direction of groundwater flow, and monitoring wells have recorded salinities greater than 5000 mg/L TDS near the Peel Inlet and salinities around 500 mg/L adjacent to the Darling Scarp.
Leederville aquifer

During the last five years the water levels have declined by approximately 2 m in well AM70A and by approximately 1.5 m in AM68A (west of AM70). The potentiometric heads of wells AM65 and AM56A, situated to the north of the Nambeelup subarea, have experienced lesser declines since 1990, with well AM65 remaining relatively constant since 1989. The hydrographs also indicate a seasonal variation in water levels, the magnitude being more evident in well AM56A.

Potentiometric heads in confined wells (screened in the Leederville aquifer) in the south of the groundwater area vary seasonally as indicated by the hydrograph of well HL4B. There appears to be a slight decline in the groundwater levels in well HL4B in the early part of 1995. The reason for this decline is unknown as abstraction from the Leederville aquifer in the area is small. However, this water level behaviour reflects that within the superficial wells of the area, and it is deduced that the aquifers are hydraulically connected in this region.

To assess the aquifer's performance accurately, additional drilling of wells monitoring the Leederville aquifer is required throughout the MGA.

Groundwater salinities of around 2300 mg/L TDS and 1350 mg/L respectively have been recorded in wells HL3A1 and HL4B. To the north of the groundwater area, salinity data from wells of the Artesian Monitoring Series indicate that salinity increases from east to west at the base of the
aquifer, from approximately 500 mg/L TDS (well AM70A) close to the Darling Scarp to around 3000 mg/L (well AM65) adjacent to the Serpentine River.

Cattamarra aquifer

Hydrographs of artesian wells screened in the Cattamarra aquifer indicate a decline in the potentiometric surface in the north of the groundwater area. During the last five years the hydrostatic heads have declined by approximately 3 m in wells AM69 and AM70, and by approximately 2 m in AM68. It is highly likely that this depressurisation of the aquifer is due to the large groundwater abstraction from the Cattamarra aquifer near Pinjarra. Groundwater levels in artesian wells (screened in the Cattamarra aquifer) in the south of the groundwater area are relatively steady as indicated in well HL3A2.

From the monitoring wells available, groundwater salinity of the aquifer is generally brackish to saline. Wells AM68 and AM70, located close to the Darling Scarp in the recharge area of the aquifer, have salinities indicating fresh water. However, wells HL3A2 and HL4A1 to the south of the Waroona subarea are saline, with salinities exceeding 6000 mg/L TDS.

14.3 Groundwater availability

The annual groundwater availability of the superficial, Leederville and Cattamarra aquifers is summarised in Table 12. The availabilities represent the total allocation limits as detailed within
the subarea factsheets. The table indicates that the superficial aquifer of the MGA is a substantial resource. The groundwater resources of the Leederville are modest, and those of the Cattamarra aquifer are considered to be small, and these therefore need to be managed in an equitable and sustainable manner as allocations approach the availability limits.

**Table 12. Groundwater availability in the Murray Groundwater Area**

<table>
<thead>
<tr>
<th>Subarea</th>
<th>Superficial (kL/year×10^6)</th>
<th>Leederville (kL/year×10^6)</th>
<th>Cattamarra (kL/year×10^6)</th>
<th>Groundwater salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper</td>
<td>Lower</td>
<td></td>
</tr>
<tr>
<td>Coolup</td>
<td>20.2</td>
<td>3.5</td>
<td>4.5</td>
<td>small</td>
</tr>
<tr>
<td>Nambeelup</td>
<td>11.8</td>
<td>6.0</td>
<td>3.0</td>
<td>small</td>
</tr>
<tr>
<td>Pinjarra</td>
<td>1.5</td>
<td>0.1</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Waroona</td>
<td>6.6</td>
<td>Not found</td>
<td>7.5</td>
<td>small</td>
</tr>
<tr>
<td>Total</td>
<td>40.1</td>
<td>9.6</td>
<td>17.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>

**14.4 Groundwater allocation**

The groundwater resources of the MGA are utilised for public and domestic water supply and for mining, agricultural, recreational and environmental concerns. The groundwater resources that have been allocated from the superficial, Leederville and Cattamarra aquifers are summarised in **Table 13**. These total allocations were derived having incorporated current private and scheme allocations, and future scheme allocations.

This table indicates that the Leederville and Cattamarra aquifers are heavily utilised, given the magnitude of these resources. Considerable resources remain in the superficial aquifer and future abstraction should be encouraged from this aquifer.
<table>
<thead>
<tr>
<th>Subarea</th>
<th>Superficial (kL/year×10^5)</th>
<th>Leederville (kL/year×10^5)</th>
<th>Cattamarra (kL/year×10^5)</th>
<th>Groundwater Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper</td>
<td>Lower</td>
<td></td>
</tr>
<tr>
<td>Coolup</td>
<td>0.6</td>
<td>1.4</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Nambeelup</td>
<td>5.5</td>
<td>4.2</td>
<td>1.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Pinjarra</td>
<td>0.1</td>
<td>0.0</td>
<td>0.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Waroona</td>
<td>1.4</td>
<td>N/A</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>7.6</td>
<td>5.6</td>
<td>3.0</td>
<td>4.3</td>
</tr>
</tbody>
</table>

### 14.5 Allocation Policies

Management of groundwater use is necessary to protect the groundwater resources and ensure that community water supply requirements are met. In an area where groundwater resources are limited, the licensing of wells/bores allows effective management of groundwater usage.

Groundwater well licences may contain specific conditions relating to well construction, the amount of groundwater that may be pumped each year, the maximum pumping rate, the purposes for which the groundwater may be used etc.

The licensing conditions may also affect the activities that may be conducted on the land in the area. In Special Rural/Rural Residential Zones, the groundwater licences are issued with allocations not exceeding 1500 kL/year.
Superficial aquifer

The licensing of bores/wells in the superficial aquifer is required throughout the Murray Groundwater Area. The only exception are bores/wells which are utilised for domestic purposes (including household and garden).

In areas where the watertable is shallow, the most efficient method of abstracting water may be from an excavation. Significant quantities of groundwater may be pumped this way, relatively cheaply, even from areas where the soil contains significant quantities of clay. Yields from conventional wells may be low in areas where the soil contains a large proportion of clay.

The groundwater resources of the superficial aquifer are more substantial than those of the Leederville and Cattamarra aquifers and future abstraction is encouraged from this aquifer. This may be beneficial in reducing the amount of groundwater discharging into the drains in the Peel–Harvey Catchment area. A moratorium on clearing and drainage is currently in place to alleviate the flow of nutrient-laden water via drains to the Peel–Harvey estuarine system.

Leederville aquifer

All bores/wells in the Leederville aquifer must be licensed. Because a green clay horizon divides the Leederville aquifer into two zones, the aquifer is represented as having an ‘upper’ and a ‘lower’ zone. The split also serves to distribute the draw evenly throughout the thickness of the aquifer.
Significant groundwater is available from the ‘lower’ Leederville aquifer, and abstraction from this aquifer zone is encouraged. Groundwater within the ‘upper’ Leederville aquifer, available predominantly from the Collup and Nambeelup subareas, also has the potential for further abstraction.

Applications for increases to existing licences, and new licence applications should be referred to the Allocation and Use Efficiency (South) Section of the Allocation Branch for appraisal.

Wells drilled into the Leederville aquifer are required to be pressure cement grouted from the overlying superficial formations, preventing intermixing of varying quality groundwater and providing increased well stability.

To minimise the potential for nearby abstractions to adversely affect well productivity, regional officers should consult with and advise prospective licensees of existing production wells close to the proposed well location. Well depths should be investigated and, further to this, applicants may be advised to screen their wells at intervals different from those of adjacent wells.

**Cattamarra aquifer**

The Cattamarra aquifer is heavily utilised in the MGA. All bores/wells in the Cattamarra aquifer must be licensed.
The resources of the Cattamarra aquifer are considered to be small and they need to be managed in a sustainable manner. As a result of this allocation plan, a policy is in place that allows no new licences to be issued for abstraction from the Cattamarra aquifer. Applications for increases to existing licences should be referred to the Allocation and Use Efficiency (South) Section of the Allocation Branch for appraisal.

An existing groundwater user has a licence agreement which allows for temporary extension of the licensed allocation of 2 500 000 kL/year to a maximum allocation of 4 000 000 kL/year, during periods of unseasonably low rainfall where Barrett and Oakley Brooks surface-water storages are not replenished. Average abstraction has over the past 20 years has, however, been 1 700 000 kL/year.

14.6 Meters

In adherence with the Board of the Water and River Commission’s metering policy, all licensed groundwater allocations exceeding 500 000 kL/year are to be metered.

14.7 Alterations to the Water Resources Licensing Database

Owing to the division of the Leederville aquifer into two distinct zones, it is required that the Water Resources Licensing Database for all subareas within the Murray Groundwater Area be appropriately amended.
New licences issued to draw from the Leederville aquifer, should be assigned to either the ‘upper’ of the ‘lower’ aquifer zone as described within this allocation plan. Licences which may have several wells drawing from both aquifer zones, should be split into two separate licences for the upper and lower zones.

14.8 Licensee obligations

If a licensee is to draw from the Leederville or Cattamarra aquifers, all well logs must be forwarded to the Water and Rivers Commission. This will enable the Commission to expand its current knowledge of the hydrogeology of the aquifer systems, and will contribute to future policy implementation. The Commission anticipates full licensee participation concerning this matter.

14.9 Additional work required

Currently, insufficient data exist to accurately estimate the groundwater resources available for allocation from the Leederville and Cattamarra aquifers in the MGA. Additional work is required to be carried out by the Commission, which may include an in-fill drilling investigation and computer modelling, to identify all of the recharge areas of the aquifers.

In addition, no detailed study has been carried out to accurately determine the additional recharge to the Leederville aquifer that is likely to be induced by pumping. This would need to be confirmed in view of the falling water levels that have been recorded in the area.
Alcoa are, however, currently undertaking numerical groundwater flow modelling of the superficial, Leederville and Cattamarra aquifer systems at Pinjarra to assess the sustainable yield from the Cattamarra aquifer. Groundwater fluxes between the superficial, Leederville and Cattamarra aquifers will be assessed for different borefield abstraction schemes as part of investigations.
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