OUTLINE OF THE HYDROGEOLOGY OF THE PERTH REGION

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ABSTRACT

Groundwater is important to the city of Perth for public water supply, irrigation of parks and gardens and horticulture and about one in four houses has its own bore for garden watering. The superficial aquifer receives stormwater drainage and is easily contaminated from accidental spills or waste disposal. It supports perennial wetlands, and has been drained in areas of urban development with shallow water tables. The confined aquifers are used mainly for public water supply and are used conjunctively with the unconfined groundwater and surface water. The Gnangara Mound, which is the main resource in the superficial aquifer and also recharges the confined aquifers, is protected from urban development and is covered by native woodland or pine forest. Groundwater in the crystalline rocks of the Darling Range is limited to low yielding bores and wells for gardens or orchards.

1 INTRODUCTION

The presence of groundwater is a characteristic of Perth and its surroundings. Groundwater is visible in the many wetlands that dot the coastal plain (Fig.1); it is readily available for water supply to gardens and parks; it supplies a greater proportion of the reticulated supply; it is a receiving body for urban drainage and it provides a medium for the dilution and dispersion of waste water and contaminants. Groundwater is present at a shallow depth, but generally does not pose a hazard to engineering structures.

Shallow water table lakes are a natural feature of the coastal plain. They regulate evaporation by changing in area over time in response to varied rainfall and hence control discharge and water levels in the unconfined groundwater flow system.

The sandy soils allow direct recharge to the shallow unconfined aquifer which is available for water supply throughout most of the coastal plain below Perth. Similarly, the underlying confined aquifers can be utilised over a wide area. The city is fortunately situated for groundwater supply purposes. Recharge areas are located just outside the urban area where land use, and hence water quality, can be controlled (Western Australia Legislative Assembly, 1994).

Areas of the city with shallow water tables are easily drained, while the dune systems in the coastal strip provide local infiltration sumps for storm water. Although the unconfined aquifers are easily polluted from waste water and leachate, they also provide a mechanism to dilute and remove contaminants.

The Gnangara Mound just north of the city is one of the most hydrogeologically significant areas in the Perth Basin as it recharges both the unconfined and the confined aquifers. This is typical of the basin in that recharge is concentrated in the centre of the basin, and only minor recharge takes place along the eastern margin. Consequently the groundwater is fresh in the centre of the coastal plain and brackish along the eastern margin. Groundwater discharges around the Swan River, which is brackish or saline in its upper reaches.

Urbanisation has led to changes in the hydrology, generally increasing recharge to the superficial aquifer and resulting in rising water levels. However, in the confined aquifers groundwater levels are falling in response to increasing abstraction. Dewatering for shallow structures is easily accomplished by spearpoint systems, although the Tamala Limestone is very transmissive and dewatering can provide a challenge.

The city has access to a number of aquifers: parks and gardens can be irrigated from the shallow aquifer, and potable water can be drawn from deeper aquifers where the water quality can be protected. The convenient distribution of the confined aquifers, at least north of the Swan River, allows conjunctive use with surface water from reservoirs in the Darling Range.

There are three main aquifers (Table 1), the unconfined superficial formations and the confined Leederville and Yarragadee aquifers. Locally the Mirrabooka aquifer is also used for public supply. A comprehensive account of the hydrogeology and groundwater resources of the Perth Region is given by Davidson (1995). Appleyard (next volume) addresses the issues of groundwater contamination.

The Perth Region is reliant on groundwater for water supply. In 2002-03 groundwater formed about three quarters of total water use. Groundwater is predominantly used in the northern Perth area, but only a few southern suburbs are totally reliant on surface water and groundwater can be supplied to most parts of the Metropolitan area. Groundwater from the Gnangara Mound has also been pumped 600 km to the Goldfields via Mundaring Weir.

The geothermal gradient in the Perth Region ranges from around 2 degrees per hundred metres in sands to around 5 degrees per hundred metres in shale. The temperature is about 21 degrees at the water table and it rises to around 40 degrees in the Yarragadee aquifer below the city (Davidson, 1995). Geothermal heat is extracted from the Yarragadee for heating swimming pools.

Most groundwater is sodium chloride type, reflecting the composition of rainwater derived from seaspray, and groundwater salinity is relatively high owing to the high concentration of saltfall near the coast. Both oxidation and reduction processes take place within the unconfined aquifers; reduction of sulphate to hydrogen sulphide is common in the superficial aquifer particularly in the Bassendean Sand, and oxidation of pyrite with consequent acidity also occurs (Appleyard, next volume).

The hydrogeology of the Metropolitan Region has been comprehensively described and mapped by Davidson (1995) building on earlier work by Allen (1976, 1979). Commander and others (1991) provide a brief outline of the context within the Perth Basin, while Appleyard and others (1999) addressed issues of urban development.

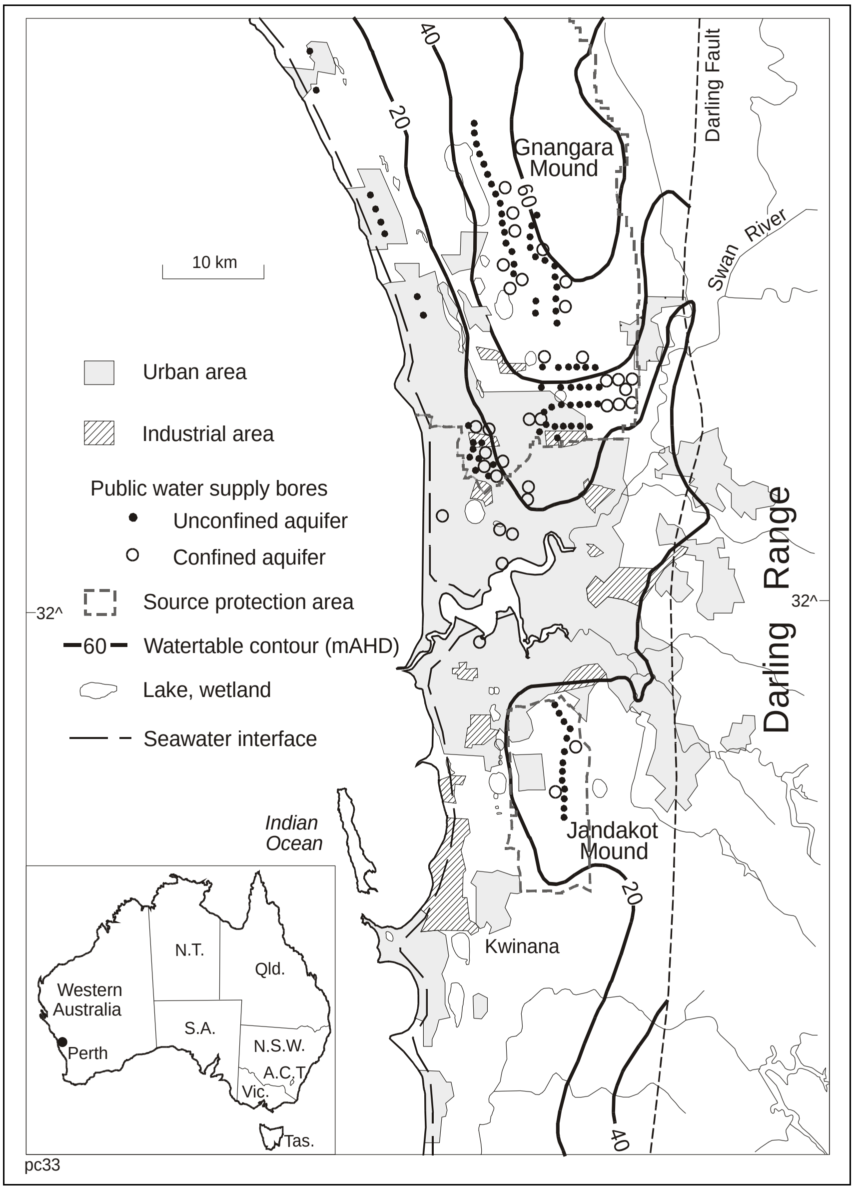
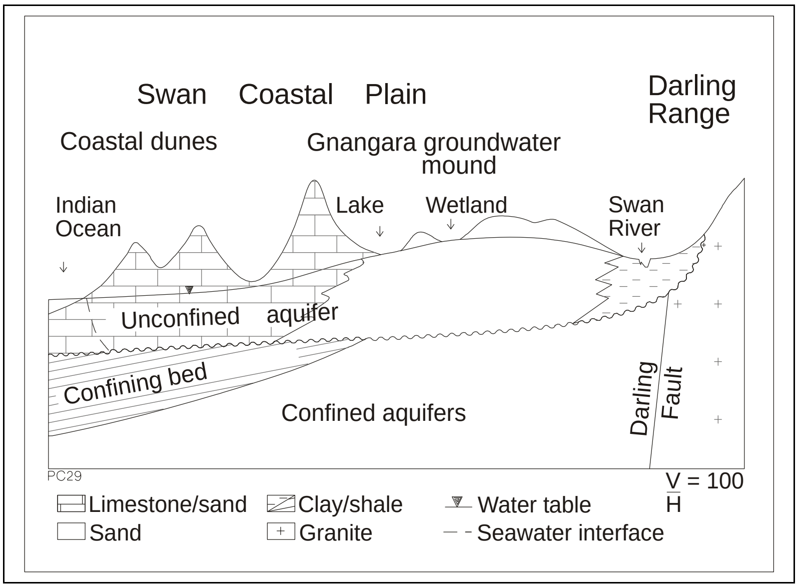


Figure 1: Location map of the Perth Region showing extent of urban area and groundwater features.

2 GROUNDWATER USE

The presence of groundwater-fed wetlands and springs around the river made the region attractive for permanent settlement. With the arrival of Europeans, shallow wells were dug for water supply, but by the 1880s problems with contamination from cess pits led to outbreaks of typhoid and there was an incentive to exploit artesian water. In the 1890s and early 1900s a number of artesian bores were drilled, into both the Leederville and Yarragadee aquifers, although Fremantle was supplied with water from galleries dug along the water table in the limestone beneath the prison (Osborne, this volume).

After a hiatus in water bore drilling as major water supply, dams were constructed in the Darling Range and additional artesian bores were drilled for public supply in the 1950s and early 1960s. In the mid 1960s the superficial formations were explored at Gnangara and developed for public water supply in the 1970s. Also in the 1970s the Metropolitan Water Authority drilled the Artesian Monitoring Bore Network (Davidson, 1995), which enabled increasing use of the confined aquifers for public supply.



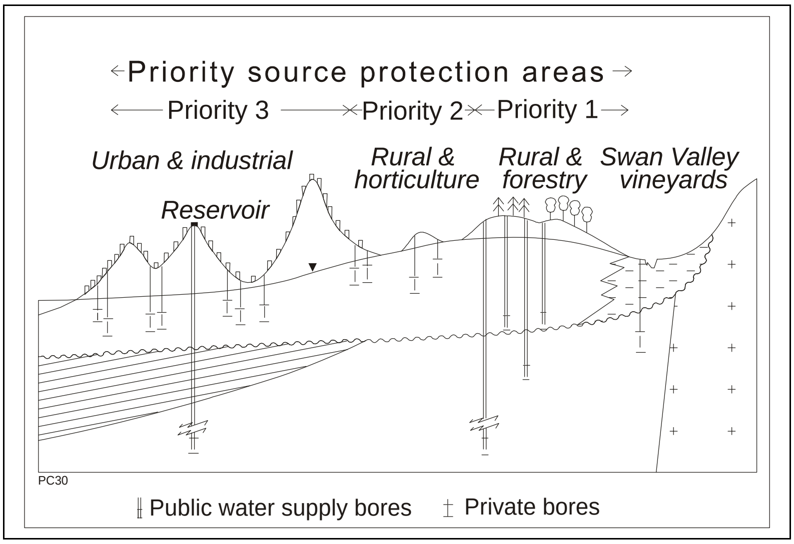


Figure 2: Schematic sections showing a) hydrogeology, b) groundwater utilisation and groundwater protection areas.

The groundwater component of the public water supply was expanded after the 1977 drought, when a total sprinkler ban had to be imposed. Expansion of the groundwater supply in the late 1990s enabled restrictions on sprinkler use to be limited to two days a week in spite of the record low runoff to the dams in 2001. To further increase supply capacity, and allow reservoir levels to recover, three Yarragadee bores were drilled in the Gwelup-Scarborough area in 2001-02.

Gardens in Perth need to be watered through the summer from October to April and about one in four houses on the coastal plain has a bore in the superficial aquifer for garden use. A large increase in the number of private bores occurred in response to the total sprinkler ban in 1977-8. Public open spaces managed by local authorities are also supplied from bores in either the superficial or Leederville aquifers.

Groundwater from the superficial aquifer is used for horticulture, principally from the Tamala Limestone, as the overlying Spearwood soils are most suitable. Heavy soils in the Swan Valley, principally used for vineyards, are irrigated from the Leederville aquifer (Allen, 1981). Groundwater is used by a variety of industries, mainly concentrated in the Kwinana area. Groundwater contamination issues associated with these industries are discussed by Appleyard (nex volume).

Areas of Bassendean Sand with shallow water tables have been drained by a network of open drains which discharge into the Swan and Canning Rivers. Drainage of wetlands has also been carried out within the Tamala Limestone, draining to Herdsman Lake, and thence to the ocean through a tunnel (Osborne, next volume).

Storm water runoff is directed into sumps and compensating basins which infiltrate directly to the shallow aquifer. Roof runoff and paved areas on private property are also drained into soak wells. Septic tanks were used in inner suburban areas developed following the war, though a program of infill sewerage, with the stated aim of reducing nutrient discharge to the Swan River is now underway (Appleyard, next volume).

3 GROUNDWATER MANAGEMENT

The Corridor Plan (Western Australia Legislative Assembly, 1994) effectively constrains the urban development of Perth and provides protection in the form of rural use or forestry to the main groundwater recharge areas of the Gnangara and Jandakot Mounds.

Groundwater quality in public drinking water sources is controlled by three categories of Priority Source Protection Areas (Fig. 2B). The objective of P1 is to ensure no degradation of water quality used for public supply (e.g. State forest in the Gnangara Mound). P2 is to ensure no increased risk to groundwater quality by regulating existing land uses (eg rural land uses on Jandakot Mound). In P3 areas, water supply needs coexist with other land uses including light industry and commercial (eg the Gwelup borefield, in which some bores have had to be closed down already due to contamination and may eventually have to be relinquished).

For the purpose of allocating groundwater for consumption, the Perth Region is divided into groundwater areas and sub-areas. All abstraction is licensed, except for garden bores which are currently exempt from licensing in the Perth Groundwater area (the urban area), although they cannot be used during daytime. The confined aquifers are generally reserved for public water supply or watering public open space within the region, except in the Swan Valley where the Leederville aquifer is used extensively for irrigation of vineyards. A licence is also required for dewatering, although a very short term requirement with limited impact may be exempted.

The wetlands on the coastal plain are constraints on the development of groundwater. Environmental water requirements in the form of water levels have been set to conserve wetlands habitats and phreatophytic vegetation. Banksia deaths in the vicinity of pumping bores have demonstrated the groundwater dependence in late summer of species not normally considered to be phreatophytic.

Water levels throughout the coastal plain are monitored by a network of bores and up to date water level information can be obtained from Water and Rivers Commission. The complex interplay of land use and abstraction in both the confined and unconfined aquifers is accounted for in the PRAMS (Perth Regional Aquifer Modelling System) groundwater flow model (Yu and others, 2002), which is designed to simulate abstraction from the confined and unconfined aquifers, calibrated against as much as 30 years of water level measurements.

Artificial recharge has been trialed only on a local scale, into settling ponds in the superficial aquifer and into bores in the Leederville aquifer, but there is a great potential for future reuse or storage of waste or storm water, or for conjunctive use of hills water.

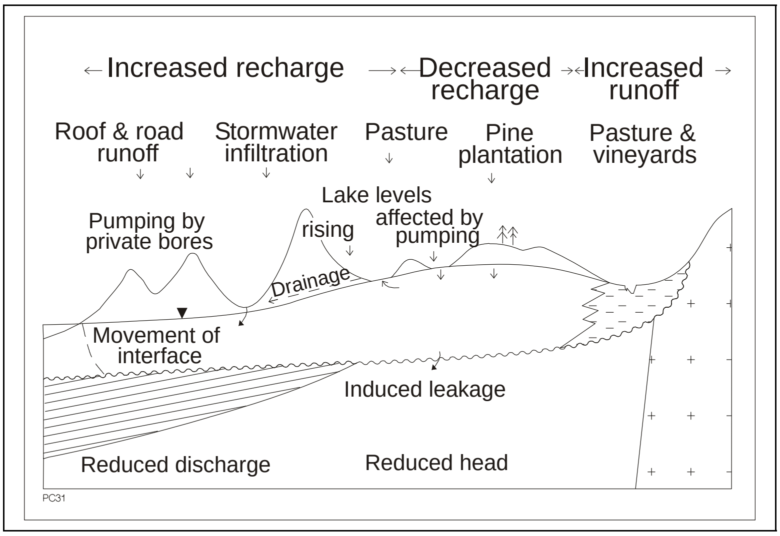
Bores in the zone of saltwater interface in the superficial aquifer around the Swan Estuary and along the coast extending inland about 1 km may need to be pumped carefully to maintain low salinity. This is particularly the case in the Mosman Park peninsula, but elsewhere fresh groundwater can usually be obtained close to the shoreline.

4 WATER LEVEL CHANGES

Groundwater maintains numerous wetlands within the Bassendean Dunes and linear chains of lakes within the Spearwood Dunes. These wetlands represent the full storage in the aquifer and expand and contract with climate changes.

Water table levels have been shown to respond to long term rainfall changes (Yesertener, 2002), falling in the decades up to 1914, rising to around 1969 and falling thereafter. The greatest variation is about 4 m on the crest of the Gnangara Mound.

Land use is a major factor in water table level changes (Fig.3). Increased groundwater recharge from urbanisation, due to storm water, roof runoff, less tree cover and imported water, has led to rising water levels, with flooding of dune depressions (Appleyard, 2001). Removal of native trees and pines has resulted in rapid water level rises which have required drainage. In the inner suburbs, the trend is for urban infill with increasing roof and pavement area from which runoff is directed into onsite soakwells. Pine plantations have had the effect of reducing water levels as they mature.



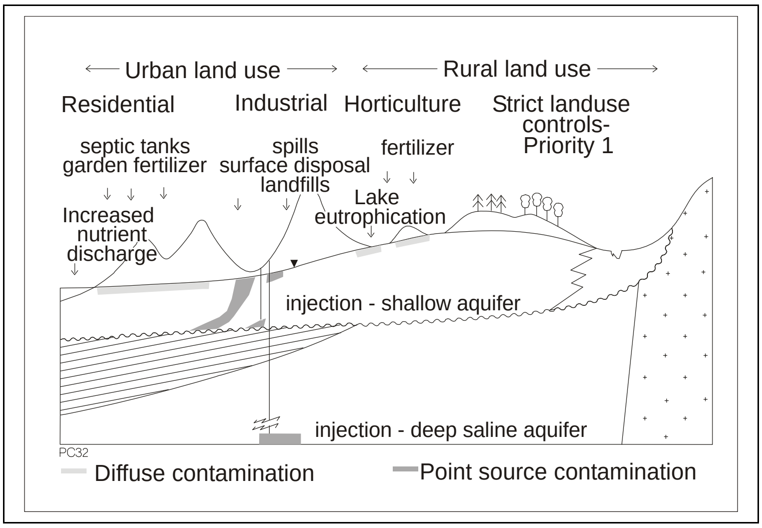


Figure 3: Schematic sections showing a) change in water balance, b) changes in water quality.

Urban development in the last 30 years has taken place in areas that formerly had higher water table levels. Local authority building regulations require a minimum separation of foundations from the maximum water table level and new development in areas of high water table are required to control maximum water levels at the level of the Average Annual Maximum Water Level (Leybourne, 2001). This presents a difficulty in determining the appropriate level, especially in areas with no long term monitoring data. The water table is mapped in the Perth Groundwater Atlas (Water and Rivers Commission, 1997), however this was designed to predict depth to water table for purposes of installing bores, and the information, derived from a variety of sources, is not accurate enough to predict depth to groundwater within the level of accuracy generally needed for such purposes.

Storm water drainage from roads in much of the western part of the city is into recharge sumps in dune swales. In the high watertable eastern areas, a network of drains has been constructed discharging into the Swan River. A chain of wetlands within the Spearwood Dunes is drained to Herdsman Lake and thence to the ocean by a tunnel through the Tamala Limestone (Osborne, next volume). The Northbridge area of Perth was formerly swamp and was drained through Claisebrook to the river at East Perth early in the development of the city.

The potential for subsidence due to pumping the confined aquifers was noted by Davidson (1995). A drawdown of 20 metres in the confined aquifers might be expected to cause 20 mm of elastic compression, but since the Cretaceous and Jurassic strata have been uplifted and eroded, it is likely that they are fully consolidated and any compression will be elastic.

Davidson (1995) commented that accelerated development of sinkholes in the Tamala Limestone could result from changes to the hydraulic environment, but the relationship between collapses and groundwater is not certain. Davidson (1995) also noted that piping and erosion occurs around springs in the banks of the Swan River principally on the outside of meanders upstream from East Perth.

5 AQUIFER DESCRIPTIONS

5.1 SUPERFICIAL AQUIFER

The superficial formations (Commander, this volume) collectively form an unconfined aquifer, though there is local confinement below the Guildford Clay. The saturated thickness ranges from about 70 metres on the crest of the Gnangara Mound to a minimum of about 25 m. The water table is shallow beneath much of the central and eastern parts of the coastal plain (Pinjarra Plain), but is as much as 50 m deep below the Spearwood Dunes.

Groundwater recharge is from winter rainfall and is highest in the central and western parts of the coastal plain where the superficial formations are sandy and where runoff is minimal. Rates of recharge to groundwater range from 12 –22 % of annual rainfall for native banksia woodland to 40 –60% below cleared agricultural land.

Seasonal water table fluctuations range from less than 0.5 m in the Tamala Limestone, 1-1.5 m in the Bassendean Sand and 3 m in the Guildford Clay, reflecting transmissivity of the sediments. Representative and comparative hydrographs are given in Davidson (1995).

Table 1: Hydrostratigraphy.

Formation	**Hydrogeology**
Superficial formations	Regional unconfined aquifer
Rockingham Sand	Local confined aquifer
Mullaloo Sandstone	Local confined aquifer
Kings Park Formation	Confining bed
Como Sandstone	Local confined aquifer
Mirrabooka Member/Poison Hill Greensand	Local confined aquifer
Osborne Formation –Kardinya Shale	Confining bed
Leederville Formation-Wanneroo Member	Regional confined aquifer
South Perth Shale	Confining bed
Yarragadee Formation	Regional confined aquifer
Cattamarra Coal Measures	Local confined aquifer

The water table configuration is characterised by two major groundwater mounds either side of the Swan River (Fig.1), the Gnangara Mound to the north and the Jandakot Mound to the south. Groundwater flow is outward from the two mounds. Only minor recharge takes place at the base of the Darling Scarp, where the soils are generally clayey. Groundwater flow rates typically range from 50 – 150 m/a in the Bassendean and Gnangara Sands, and may be twice as much in the Tamala Limestone (Davidson, 1995). Hydraulic conductivities average 15 m/d in the sands to a range of 100-1000 m/d in the Tamala Limestone (Davidson,1995).

A major discontinuity in the water table occurs at the contact between sand and limestone within, or at the eastern edge of, the Tamala Limestone. In the Yanchep caves, this can be observed as a seepage face in the sand below the limestone, which is dissolved at the contact. Elsewhere, a steep drop in water table is inferred. Caution should be exercised in using the water levels in the Groundwater Atlas (Water and Rivers Commission, 1997) in this zone.

The superficial aquifer discharges to wetlands, to Ellen Brook and the Canning River on the Pinjarra Plain, to the Swan River and to the ocean. Most wetlands on the coastal plain are throughflow lakes, which have a plume of higher salinity groundwater on the downstream side. Lakes Cooloongup and Walyungup are salt lakes into which groundwater discharges and contributes salts to the underlying body of hypersaline groundwater.

Discharge from the aquifer takes place above a saltwater interface which is present around the Swan Estuary and along the coast (Cargeeg and others, 1987).

The groundwater salinity is lowest (less than 250 mg/L) in the Gnangara and Jandakot Mounds and typically rises to 600–800 mg/L along the coast (Davidson, 1995). Pockets of high salinity occur in groundwater discharge areas (Maddington, Serpentine Flats). Lakes Coogee, Cooloongup and Walyungup are saline.

The superficial aquifer is used for public water supply from borefields in the Gnangara Sand on the Gnangara and Jandakot Mounds and from the Tamala Limestone in the northern coastal suburbs. The aquifer is used for watering parks and recreation grounds, for irrigation of horticultural crops (particularly from Tamala Limestone on Spearwood soils) and by garden bores throughout the coastal plain.

Groundwater from the superficial aquifers is treated for public supply to remove dissolved gases, dissolved iron and suspended matter.

Low salinity groundwater occurs as a lens above saline or hypersaline groundwater at Rottnest Island (Playford and Leech, 1977). The island water supply is partly drawn from low yielding shallow bores, which have to be carefully managed to maintain low salinity. Part of the Rottnest Island supply is also obtained by desalination of brackish groundwater.

5.2 ROCKINGHAM SAND

The Rockingham Sand is incised into the Leederville aquifer between Rockingham and Mandurah. Groundwater discharges into it from the Leederville aquifer and the overlying superficial aquifer and discharges at a salt water interface. Groundwater in the base of the aquifer is saline and fresh groundwater occurs only in the upper 40 m, except east of Mandurah where all the groundwater is saline.

5.3 MULLALOO SANDSTONE (KINGS PARK FORMATION)

The Mullaloo Sandstone is in hydraulic connection with the superficial aquifer and is confined beneath by shales in the underlying Kings Park Formation. Groundwater is fresh at City Beach IF 01 bore (drilled close to the beach) to a depth of 40 m (Cargeeg and others, 1987), suggesting that fresh water extends well offshore.

The Mullalloo Sandstone has only been utilised for water supply along the Swan River from Burswood to South Perth, where the overlying superficial formations are predominantly clay. It is not well mapped and may consist of disconnected stringers of sand within the shale.

5.4 MIRRABOOKA AQUIFER

The Mirrabooka aquifer (Davidson, 1995) consists of the Poison Hill and Molecap Greensands and the Mirrabooka Member of the Osborne Formation. The aquifer occurs below the superficial formations north of the Swan River as far as Wanneroo and extends north eastwards along Ellen Brook.

The aquifer is in hydraulic contact with the superficial aquifer, being recharged in the north and discharging to the superficial aquifer near the Swan River and coast.

Groundwater salinity ranges from 130-350 mg/L (Davidson, 1995). Groundwater from the aquifer is drawn for public supply from the Mirrabooka wellfield.

5.5 LEEDERVILLE AQUIFER

The Wanneroo Member of the Leederville Formation is the main part of the Leederville aquifer. It occurs throughout the basin in the Perth Region, except in the south east near the Darling Fault and in areas where it has been removed and replaced by the Kings Park Formation. It overlies either the Mariginiup Member or the South Perth Shale, except on the crest of the Pinjar Anticline, where it directly overlies the Yarragadee or Parmelia Formations. Locally, the Henley Sandstone Member of the Osborne Formation is in hydraulic contact with the Leederville Formation and is considered part of the Leederville aquifer

Recharge takes place through the superficial aquifer on the Gnangara Mound, in the south east (west of Armadale Byford) and on the eastern part of the coastal plain south of the Serpentine River.

Groundwater flows into the region from Gingin in the north east and flows to the Swan River and coast, apparently discharging upwards along the margin of the Kings Park Formation and Rockingham Sand and upwards to the superficial aquifer near the coast in areas where the Osborne Formation is absent.

Groundwater in the Leederville aquifer has been dated by carbon 14 (Thorpe and Davidson, 1991) and is generally less than 30 000 years old.

Groundwater salinity is less than 500 mg/L north of the Swan River and in patches near the Darling Scarp to the south east. The salinity exceeds 1000 mg/L around the contact with the Kings Park Formation; in the eastern Swan Valley, the Kwinana Rockingham area, Serpentine, and in the Maddington area, where it is greater than 3000 mg/L.

The Leederville Formation (sometimes called the ‘shallow artesian aquifer’) is a major aquifer used for public water supply mostly north of the Swan River, for irrigation of vineyards in the Swan Valley and for watering public open space. Groundwater from the Leederville aquifer is treated for public supply, particularly to remove dissolved iron.

5.6 YARRAGADEE AQUIFER

The Yarragadee Aquifer, which includes the overlying and hydraulically connected Gage Sandstone, extends south to North Dandalup but is absent along the Darling Fault south of Armadale and in the Mandurah-Rockingham area, where the Cattamarra Coal Measures (included by Davidson, 1995, in the Yarragadee aquifer) subcrops beneath the Leederville. The Gage Formation has a maximum thickness of 350 m, while the Yarragadee Formation may be as much as 1500 m thick, but only the uppermost 500 m or so has been penetrated by water bores.

Groundwater flow is from the north, with the addition of recharge in a comparatively small area in the north of the Gnangara Mound by leakage through the Wanneroo Member of the Leederville Formation. This recharge is low salinity, less than 500 mg/L, and flows southwards to cross the coast between City Beach and Whitfords. Groundwater elsewhere in the aquifer is brackish, reaching over 300 mg/L in the Swan Valley.

Groundwater discharges at least several kilometres offshore; the potentiometric head of 20-30 m at the coastline indicating fresh water extends a significant distance from the coast.

Groundwater from the Yarragadee Formation has been carbon dated, and flow rate of about 1 m per year is inferred for flow from the northern Gnangara Mound to City Beach where it is over 40 000 years old (Thorpe and Davidson, 1991).

The Yarragadee Aquifer is used only for public water supply, mainly north of the Swan River. Bores in Attadale and Melville supply brackish water which is mixed with better quality Hills or Jandakot water. Geothermal heat is also extracted from the groundwater to heat swimming pools at Melville and Claremont.

Groundwater from the Yarragadee aquifer generally does not require treatment for public supply and is reticulated directly into reservoirs to cool and mix with hills water or treated groundwater.

5.7 CATTAMARRA COAL MEASURES

The Cattamarra Coal Measures was included in the Yarragadee aquifer by Davidson (1995). However it forms a local fault-bounded flow system close to the Darling Fault south of Armadale. It is recharged through the overlying superficial aquifer and possibly through the Leederville aquifer. Groundwater salinity is less than 500 mg/L.

Groundwater is used locally for irrigation and to the south for the Pinjarra alumina refinery. The deeper sandstones at Serpentine appear to have a direct connection with the superficial aquifer, as bores installed for public water supply could not be used owing to excessive drawdown in the superficial aquifer affecting private supplies.

A bore into the Cattamarra Coal Measures at Kwinana, where the groundwater salinity exceeds 10 000 mg/L, has been used for waste disposal (Appleyard, next volume).

5.8 DARLING RANGE (YILGARN CRATON)

In the Darling Range (Fig.1), groundwater occurs in alluvial and colluvial sediments, in the weathered zone and to a lesser extent in the fractured crystalline bedrock. The sediments are predominantly clay and low yields are available from soaks in the valleys. Groundwater supplies can be obtained from the base of the weathered zone, in the saprolite grit, generally at depths of up to 25 m, but bore yields are generally less than 100 kL/d. Groundwater is not widely available from fractured bedrock. Experience from the water supply tunnels shows that water-bearing fractures in granitic rocks are very widely spaced.

Groundwater in the Darling Range ranges from fresh to brackish, becoming increasing saline to the east. Groundwater salinity also increases from south to north, consistent with the decrease in annual rainfall.

Springs occur below the laterite cap and are the cause of unstable ground on slopes in the Darling Range. Gozzard (1986) has mapped areas of solifluction in which he notes that seepage is common. Wyrwoll (this volume) comments on the role of groundwater in the formation of landslips.

The hydrogeology of the Darling Range has not been described in detail. Yonge (1964) reported on a study for fruit growers in Kalamunda, Karagullen and Pickering Brook. He found that the most productive bores (yields <400 kL/d) were located in the bottoms of broad valleys, where pressure water occurs below 6-12 m of clay. He also indicated that there was probably a greater thickness of weathering on the valley flanks, compared with the centres of the valleys where the weathered profile may have been stripped to bedrock, and that a water-bearing sand layer below the clay was probably weathered in situ granite.

Yonge (1964) described the presence of horizontal exfoliation joints and suggested anecdotal evidence of groundwater moving in conduits, possibly weathered fracture zones. He quoted yields less than 100 kL/d.

Groundwater is used on a small scale from bores and wells for gardens and limited irrigation of orchards inland from the scarp. To the north of Perth, groundwater from fractured rocks of the Chittering Metamorphic Belt is utilised for the Bindoon water supply. Low salinity groundwater from springs or soaks is bottled and marketed as spring water.

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