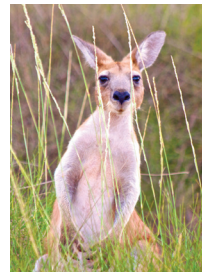




Government of **Western Australia**
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Groundwater resources of the Lesueur carbon storage project area (SW Hub)

April 2013

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Biography

Philip Commander has been involved with groundwater investigations in the Perth Basin, particularly in the Mandurah-Bunbury area, for much of his 38-year career with the Geological Survey and the Department of Water. He retired as Principal Hydrogeologist in 2009 and is currently Adjunct Assistant Professor at The University of Western Australia.

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Summary

The Harvey Ridge structural subdivision is one of the least prospective areas for groundwater in the Perth Basin, because of the low elevation, clay soils and unfavourable structure which result in high salinity. Fresh groundwater is generally only available from the superficial aquifer in the centre and west of the coastal plain, and locally along the Darling Scarp. Groundwater use is generally restricted to shallow bores in the superficial aquifer and the upper part of the underlying Leederville aquifer. Most of the groundwater in the underlying confined aquifers is brackish or saline, with hypersaline groundwater at depth in the Cattamarra, Eneabba and Lesueur aquifers considered to be stagnant and isolated from meteoric groundwater flow.

Introduction

The SW Hub project area is within the Harvey Ridge structural subdivision of the Perth Basin. The Perth Basin is a sedimentary basin filled with sedimentary rocks, mainly sands and clays, laid down between the Permian and Cretaceous geological periods (300 to 100 million years ago), and is separated from the Archaean granitic rocks to the east by the Darling Fault. It extends from Geraldton in the north to Augusta in the south. The sandstones in the basin form major confined aquifers, containing groundwater, which are used for domestic, stock, irrigation, industry and town water supply. The Harvey Ridge is one of the least prospective areas in the basin for groundwater for a number of reasons; low elevation, clay soils and unfavourable structure combine to restrict groundwater recharge and lead to high groundwater salinity. The superficial (unconfined) aquifer, which is a maximum of 30 metres thick, is the most important aquifer in the region, but usage is mostly in the central and west of the coastal plain as the superficial formations in the east are clayey and the salinity high.

The hydrogeology of the superficial aquifer is known from over a hundred shallow investigation bores, but there are comparatively few bores in the confined aquifers because of the poor prospects for low salinity groundwater. The principal sources of information are the Geological Survey of WA (GSWA) Harvey and Binningup Lines of exploratory water bores drilled in the early 1980s.

Superficial aquifer

The superficial formations cover the Swan Coastal Plain, extending from the Darling Scarp, where they overlie granitic rocks, to the coast. They include a number of formations which range in age from late Pliocene (1.5 million years) at the Darling Scarp to mid to late Pleistocene and Holocene (less than 10 000 years) at the coast, representing mainly beach, alluvial and aeolian (windblown) deposits.

In general, the sediments are mostly clay in the east, and mostly sands and limestone in the centre and west. Small areas of sand and gravel are present along the more elevated foothills of the Darling Scarp. Together, the superficial formations form the superficial aquifer, though the included Guildford Clay does not transmit or store groundwater readily.

The Yoganup Formation occurs along the Darling Scarp, and is composed of sand gravel and clay. It contains economic deposits of mineral sands. The Guildford Clay (previously also known as the Guildford Formation) occupies the flat eastern part of the coastal plain, the Pinjarra Plain. It is up to 30 metres thick and is predominantly clay, with minor sand beds.

The Bassendean Sand (previously referred to as the sand member of the Guildford Formation) and underlying Ascot Formation (also previously referred to as the Jandakot beds) is also around 30 metres thick, comprising quartz sand overlying finer grained shelly, partly calcareous and peaty sand. The Tamala Limestone forms the high stable Spearwood Dunes composed of limestone and sand. The formation is up to 90 metres thick, but only the lowermost 25 metres is below the water table. Lake deposits occur in the vicinity of the coastal lakes, consisting of limestone, shelly calcareous clay and marl. The Safety Bay Sand forms the unconsolidated Quindalup Dunes, along the coast.

Recharge to the superficial aquifer takes place locally to sandy deposits along the foot of the Darling Scarp from runoff and from rainfall where there are sandy sediments.

However, the main recharge to the superficial aquifer takes place directly from rainfall in the centre of the coastal plain to the Bassendean Sand, forming the Yanget Mound (north) and the Mialla Mound to the south, separated by the Harvey River Diversion Drain. Groundwater flow from the mounds is mostly westwards, but also with a component to the east discharging to the Harvey and Brunswick Rivers.

The height of the water table in the Yanget and Mialla Mounds is sufficient to generate groundwater flow from the superficial aquifer into the underlying Leederville aquifer.

Locally along the Darling Scarp, where the Leederville Formation is absent, the Cattamarra aquifer is also recharged by leakage from the superficial aquifer.

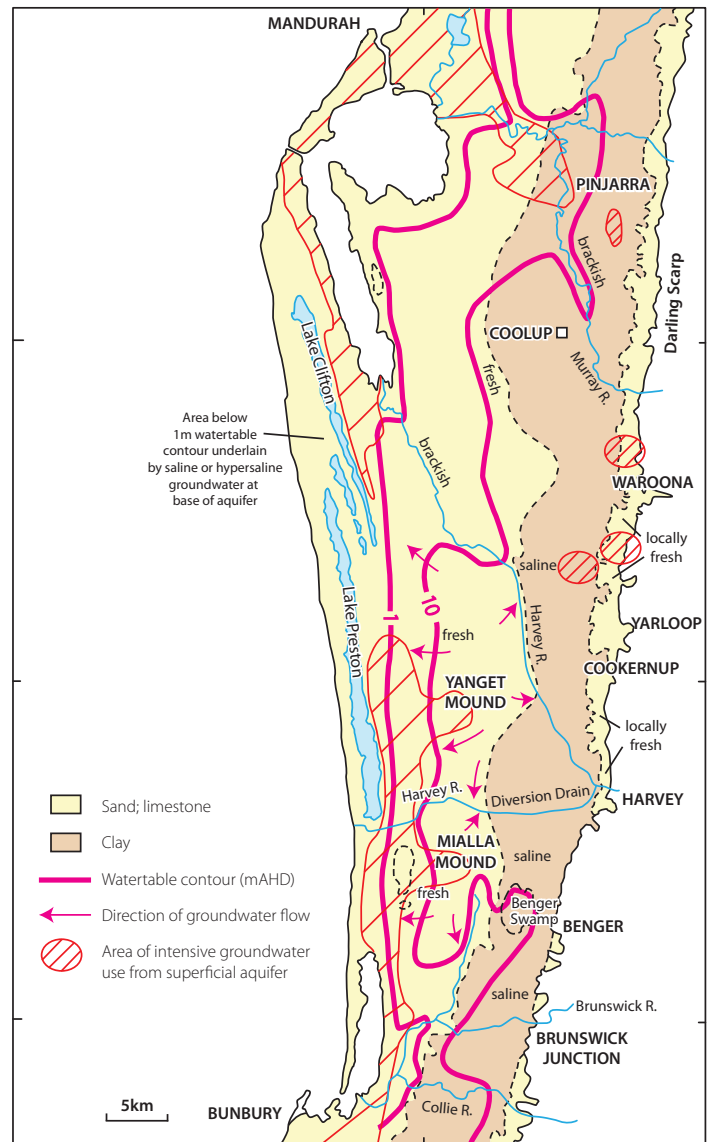
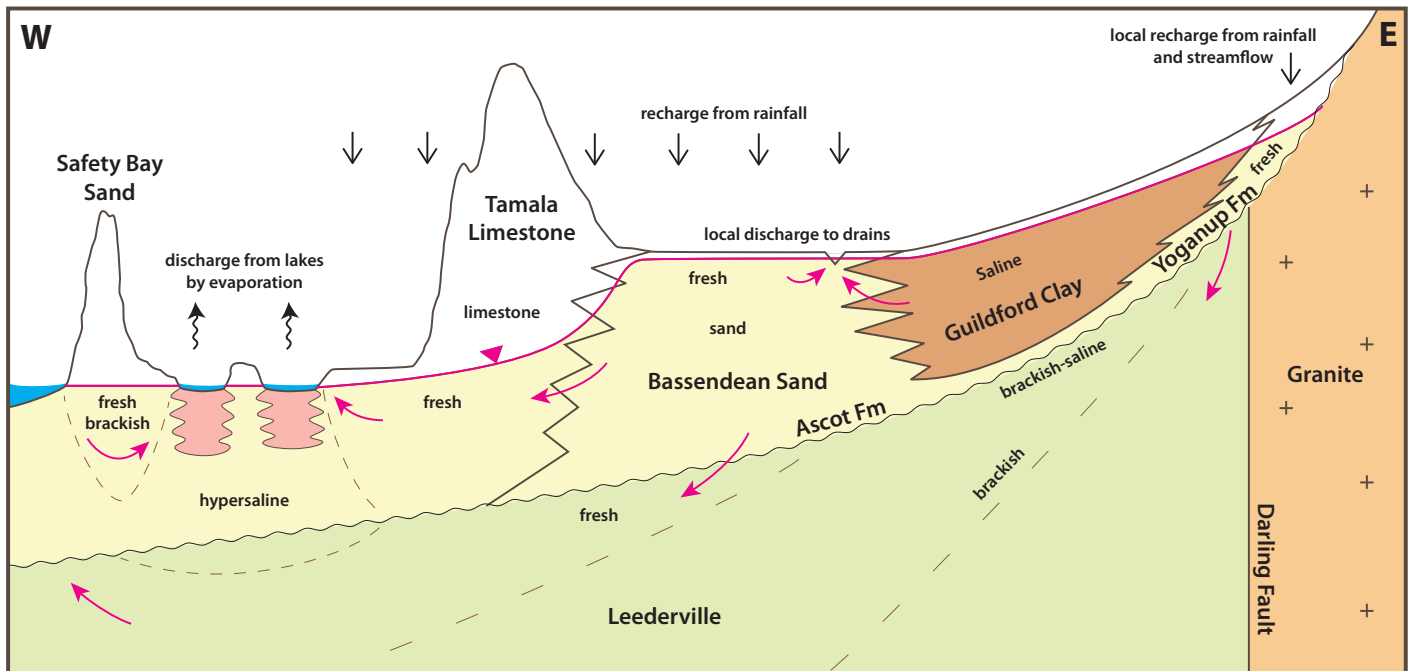


Figure 1: Superficial aquifer - hydrogeology and groundwater use

The superficial aquifer discharges to Lakes Preston and Clifton. These lakes are groundwater sinks in which evaporation concentrates the salts in the discharging groundwater. Over time, the salinity is increasing, and the salinity of groundwater below the lakes is hypersaline, as much as twice the salinity of seawater. The average water level in the lakes is below sea level.

There are small areas of low salinity groundwater in the superficial aquifer along the more elevated parts of the foothills, at Harvey and to the north. In general, the groundwater is brackish in the east of the coastal plain, and saline near Benger Swamp, where there are no foothills.



10m 1km Water table

VE X 100

Figure 2: Superficial aquifer - diagrammatic cross section

Low salinity groundwater, less than 500 mg/L occurs in the Bassendeau Sand on the Yanget and Mialla Mounds, rising slightly westwards in the Tamala Limestone. This low salinity groundwater discharges to the coastal lakes over a wedge of hypersaline groundwater at the base of the aquifer.

The superficial aquifer is widely used for stock and domestic purposes, except in areas of high salinity, associated with the Guildford Clay. The aquifer is used extensively for irrigation of vegetables and lucerne along the Old Coast road/Forrest Highway in the Myalup area. There has been minor use for mineral sands close to the Darling Scarp.

Leederville aquifer

The Cretaceous Leederville Formation underlies the superficial formations across almost the entire area, being absent only in a small area east of Pinjarra and at Bunbury, and underlying Osborne formation in the Miami-Dawesville area. Whereas the Leederville Formation contains thick sandstone beds in the Metropolitan area and Bunbury, in the Harvey Ridge the formation is comparatively shaly, and there are few good aquifer horizons.

In the Mandurah area, the three members present in the Metropolitan area, the Pinjar, Wanneroo and Mariginiup member are recognised, however this distinction is not easy to recognise in the Harvey Ridge. A prominent green clay marks the boundary between the Mariginiup and Wanneroo members, but this has not been identified south of Lake Clifton investigation bore C6 on Johnston Road. The strata dip generally to the west, but this is locally reversed over the crest of the underlying Harvey Ridge structure.

The channel sand, or the Rockingham Sand east of Mandurah, referred to in previous publications, is now considered to be a sandy facies of the Wanneroo Member. The underlying South Perth Shale and Gage Sandstone are not recognised south of Mandurah. The Leederville Formation in the Harvey Ridge area is mainly shale with thin interbedded sands, likely to correlate with the Mariginiup Member (Lower Leederville aquifer).

Recharge to the Leederville aquifer can only take place by leakage from the superficial aquifer, generally where the Guildford Clay is absent. Recharge takes place locally in elevated areas along the Darling Scarp, and from beneath the water table mounds in the central part of the coastal plain. Recharge is also affected by the dip of the strata, determining where sand beds may be truncated at the basal unconformity of the superficial formations.

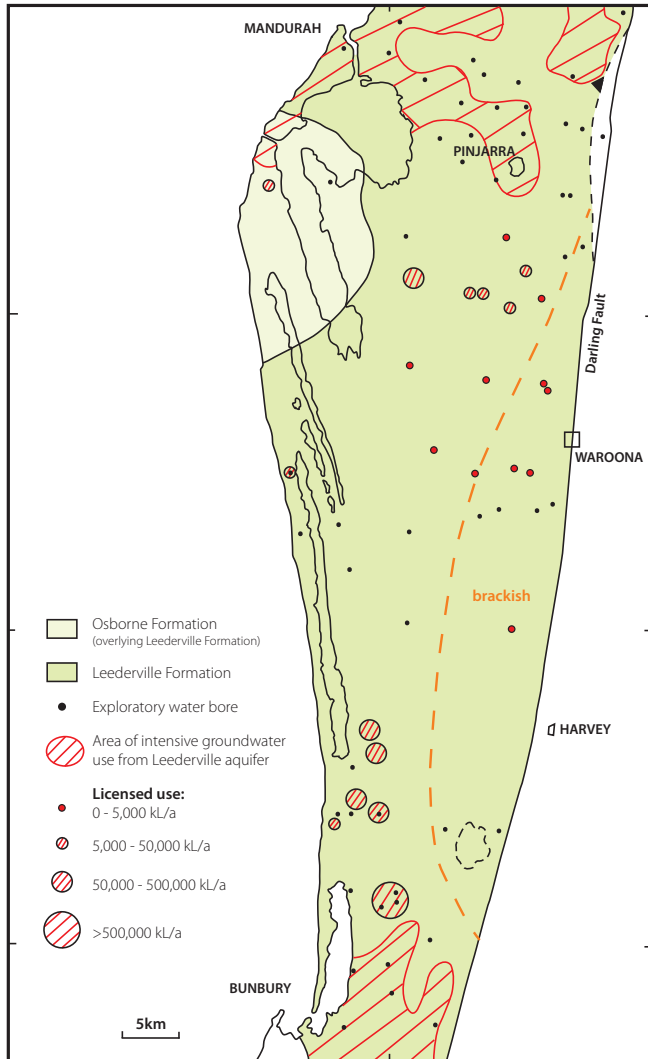


Figure 3: Leederville aquifer

Groundwater from the Leederville aquifer discharges upwards to the Superficial aquifer along the coast (as at Preston Beach where there is artesian flow).

Groundwater salinity is quite variable, both spatially and with depth. Generally, the groundwater is brackish in the east of the coastal plain in the Harvey Ridge area, with comparatively thin horizons of fresh water in the centre and west where recharge conditions are more favourable. Low salinity groundwater can only occur where there is potential to recharge from the overlying superficial aquifer, and where the groundwater in that aquifer is fresh.

The Leederville aquifer is used extensively for water supply in the Mandurah/ Pinjarra area, and south of Kemerton/Australind where the groundwater is low salinity. There is little use in the Harvey Ridge area because of the high salinity. The aquifer supplies Preston Beach, and there are a few irrigation licences in the Myalup and Coolup areas, and some licensed domestic supplies (mainly 1500 kL/a), and there has been use for mining at Cookernup. However, these supplies are marginal to brackish.

There has been little exploration in the Leederville aquifer because of the high salinity, but current investigation drilling by the Department of Water will better define the prospects.

Yarragadee aquifer

The Late Jurassic Yarragadee Formation is absent on the Harvey Ridge, having been removed by erosion at the time of continental rifting and breakup about 130 million years ago. The southern Yarragadee aquifer extends only as far north as Australind, whereas the northern Yarragadee aquifer does not extend farther south than North Dandalup. The southern Yarragadee aquifer is used for Australind, Eaton and Bunbury public water supply.

Low salinity groundwater in the Cattamarra aquifer at Kemerton is considered to originate by groundwater flow from the southern Yarragadee aquifer. In the Metropolitan area, the term Yarragadee aquifer includes the Cattamarra Coal Measures, as there is a degree of hydraulic connection between them.

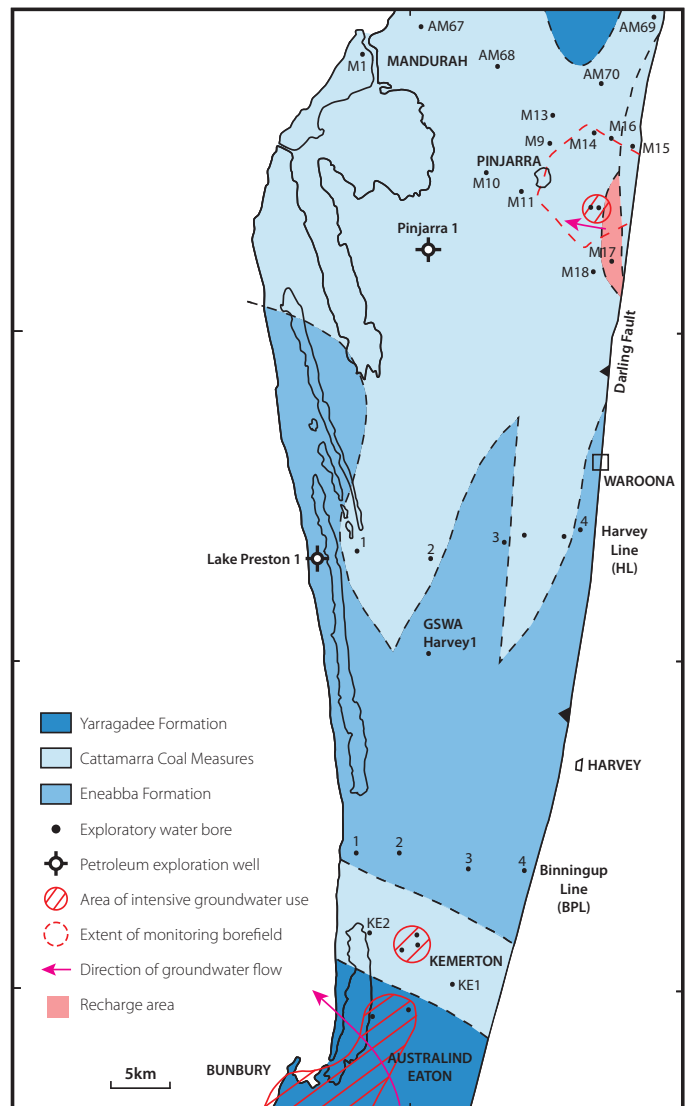


Figure 4: Eneabba, Cattamarra and Yarragadee aquifers

Cattamarra aquifer

The Early Jurassic Cattamarra Coal Measures is present below the Leederville Formation in the Kemerton area and to the south, and to the north of Waroona. The formation overlies the Eneabba Formation in HL1, and there is a relatively thin sequence in HL2 and between HL3 and HL4. In older literature, the term 'Cockleshell Gully Formation' is used to include both the Cattamarra Coal Measures and Eneabba Formation.

The Cattamarra Coal Measures consists of grey shale interbedded with weakly consolidated sandstone, and minor coal measures. The sands beds can be as much as 50 metres thick, and are good aquifers, as at the alumina refinery east of Pinjarra.

Recharge to the formation is very restricted. East of Pinjarra, and to the north along the Darling Scarp, small areas occur immediately below the superficial aquifer allowing recharge, but elsewhere the Cattamarra aquifer is blanketed by the shales in the Leederville Formation. Because the Cattamarra aquifer is faulted, interrupting hydraulic continuity, groundwater occurs in local flow systems, and low salinity groundwater is localised to areas where the structure is favourable for recharge and groundwater flow.

Groundwater salinity in the top of the formation in HL1 is less than 3000 mg/L reflecting leakage from the overlying Leederville aquifer. Elsewhere in the Harvey ridge area, the groundwater salinity exceeds 3000 mg/L, reaching over 30,000 mg/L at the base of Harvey Line 1.

Groundwater from the Cattamarra aquifer is used only at the Pinjarra alumina refinery, and at Kemerton. At Pinjarra, the low salinity groundwater in the Cattamarra aquifer occurs in a restricted basin recharged through the superficial aquifer, whereas the low salinity groundwater at Kemerton (around 1000mg/L) is considered to originate from the southern Yarragadee.

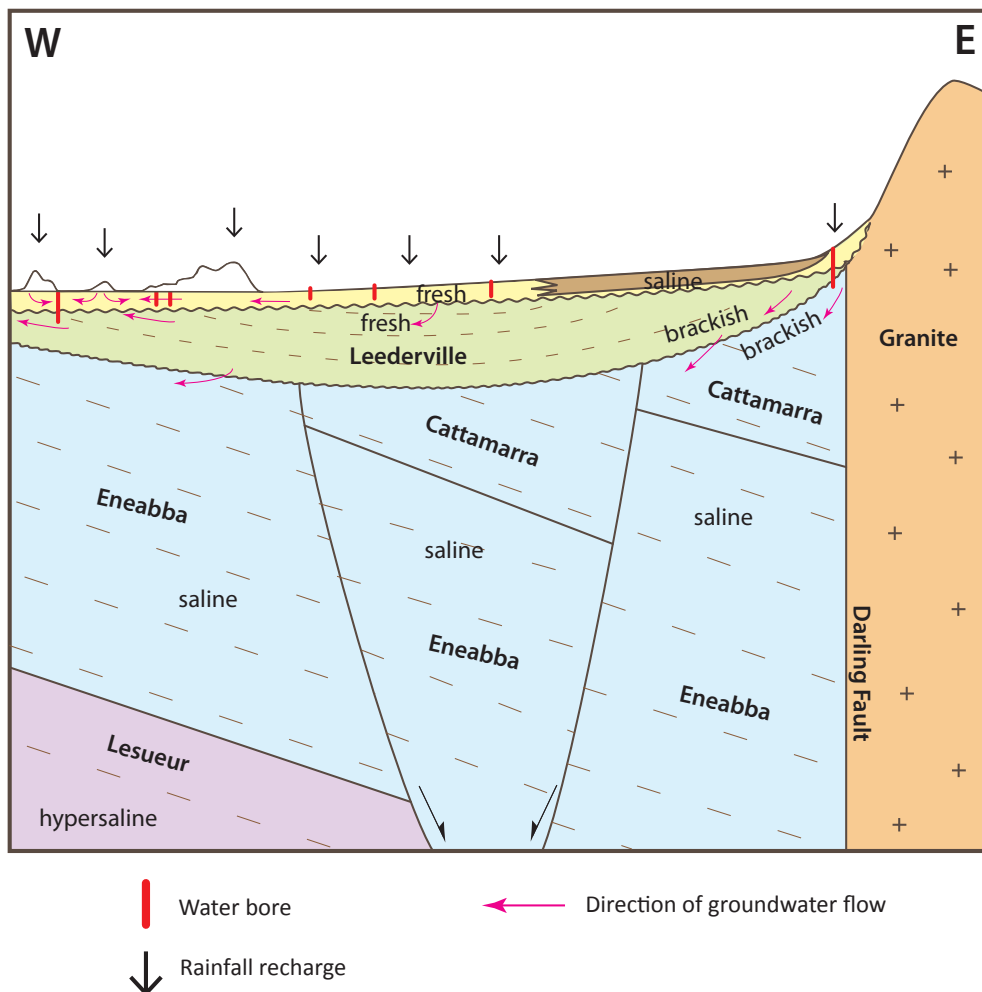
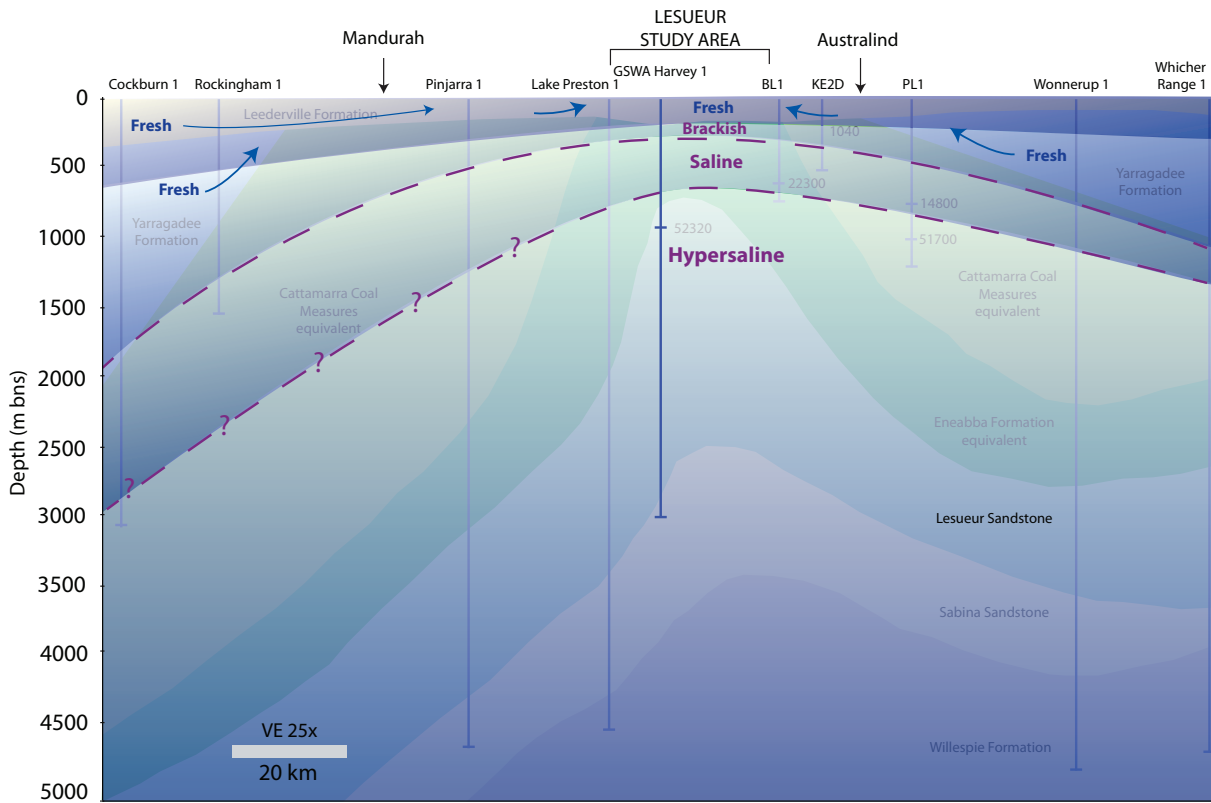


Figure 5: Diagrammatic cross-section to illustrate structure of the confined aquifers

North - South cross-section showing groundwater salinity in the confined aquifers



Note: The strata interfaces in the petroleum wells are based on Crostella and Backhouse (2000); while those at the water wells are based on the relevant GSWA reports. Interpretation of interfaces at GSWA Harvey 1 is based on Arthur Mory (DMP) pers comm. This geological section is based on a simple interpolation of interfaces between the wells that are not along a straight line. Hence, there is a large uncertainty in the depths of interfaces between the wells. The DMP is currently reviewing these interpretations.

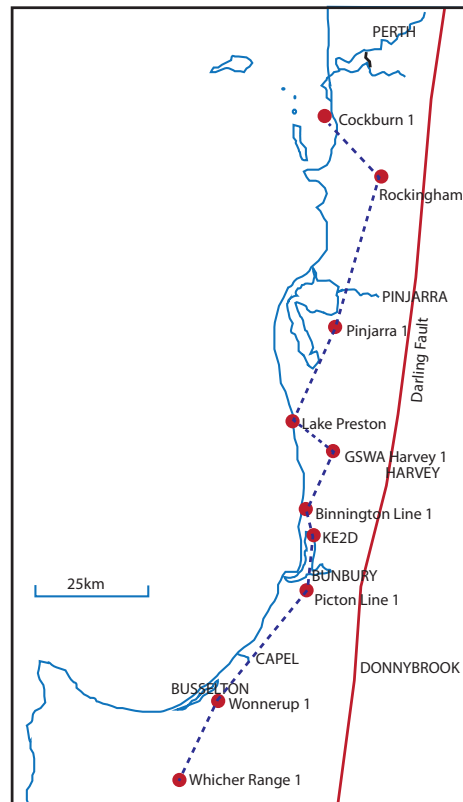
- 52320 Salinity of groundwater sample (mg/L TDS)
- Direction of groundwater flow
- Fresh** < 1000 mg/L
- Brackish** 1000 - 3000 mg/L
- Saline** 3000 - 35000 mg/L
- Hypersaline** >35000 mg/L
- Note: Seawater salinity is 35000 m/L

Figure 6: North - South cross section showing groundwater salinity in the confined aquifers

Eneabba aquifer

The Early Jurassic Eneabba Formation underlies the Cattamarra Coal Measures, and directly underlies the Leederville Formation, where the Cattamarra Coal Measures are absent. It occurs in the Harvey and Binningup Lines but has not been identified as a separate unit in petroleum exploration wells south of the Binningup Line.

The Eneabba Formation consists of interbedded weakly cemented sands and shales. The formation is characterised by multicoloured red- brown, yellow, and grey shales, and was previously known as the Multicoloured Member of the Cockleshell Gully Formation. The formation in the easternmost bores of the Harvey and Binningup Line is particularly shaley.



A thickness of about 600 m was intersected in HL2 and the formation probably has a maximum thickness of around 1000 m. Groundwater salinity increases with depth. In the Binningup Line bores, the salinity is only less than 5000 mg/L in the western BPL 1 and 2, which is likely to reflect recharge by leakage from the overlying Leederville aquifer, or flow from the southern Yarragadee aquifer to the south. In the east at BPL 3 and 4 the salinity exceeds 20,000 mg/L consistent with the more shaley lithology, and there being little potential for recharge from the high salinity groundwater in both the Superficial and Leederville aquifers around Benger Swamp. Similar conditions exist along the Harvey Line. The Eneabba Formation is not used for groundwater supply on account of the high salinity and depth, and in the east, sands are poorly developed.

Lesueur aquifer

The Late Triassic Lesueur Sandstone extends over the whole area at depths generally exceeding 700 metres, and has only been intersected in deep petroleum exploration wells and the GSWA Harvey 1 geosequestration data well.

The Lesueur Sandstone is subdivided into the basal Wonnerup Member which consists of poorly sorted medium to coarse grained sandstone with interstitial kaolin, and the upper Yalgorup Member (previously also known as the Myalup Member) containing finer sands and dark grey siltstone beds. The formation is about 1200m thick in Lake Preston 1. The underlying Triassic Sabina Sandstone, which is 561 m thick in Lake Preston 1, and consists of fine to medium grained sandstone, can also be considered part of the Lesueur aquifer.

The reported presence of interstitial kaolin, and the depth of burial indicate low hydraulic conductivity. Bore yields from the Wonnerup member at Augusta are relatively low, due to the consolidation of the sandstone.

Wireline logs through the formation indicate that the groundwater is saline or hypersaline. In GSWA Harvey 1 the salinity is estimated to be 60,000 mg/L in the Wonnerup Member and around 50000 mg/L in the Yalgorup Member. One fluid sample was taken from the Yalgorup member at 856 m, which gave a salinity of 52,320 mg/L. The log derived water salinity at this depth is about 53,000 mg/L, giving good agreement between estimated and measured formation water salinity. In Pinjarra No 1 the bore completion report suggested that the wireline log indicated low salinity formation water, however, there is no sampling, and this must be regarded as incorrect.

The nearest parts of the Lesueur aquifer containing low salinity groundwater are locally at Augusta and at Jurien, where the formation comes near the surface, but these localised flow systems are not considered to be well connected with the formation at depth in the central parts of the Perth Basin.

Groundwater flow systems

There has been no age dating of groundwater systems in the area, but comparisons can be made with other areas of the Perth Basin where dating has been carried out on low salinity groundwaters. Meteoric water, originating as rainfall, circulates in the superficial aquifer, with flow paths of the fresh water likely to be of the order of hundreds of years. Similarly, meteoric water circulates in the Leederville aquifer, but over timescales likely to be of thousands to tens of thousands of years. To the south of the area, at Bunbury, groundwater in the Yarragadee aquifer has been dated to around 40 000 years.

The Lesueur aquifer is everywhere overlain by the Eneabba Formation therefore there is little opportunity for recharge of lower salinity water. Like the Eneabba and Cattamarra Coal Measures, the saline groundwater can be considered to be stagnant or flowing extremely slowly, isolated from the meteoric water cycle. Further, groundwater in the Lesueur Sandstone is likely to be highly compartmentalised by faulting, further reducing the hydraulic connectivity and opportunity for groundwater flow.

It is likely that the saline groundwater in the confined aquifers has originated as sequestered seawater which could have entered the aquifers in the late Pliocene (around 2 million years ago) when the Darling Scarp was a coastline, or more likely as early as marine transgressions in the early Cretaceous (130 million years ago), following uplift and erosion, and prior to deposition of the Leederville Formation. The evolution of the hypersaline groundwater could be through the process of ultrafiltration over a long period whereby hydrostatic pressure allows water molecules to pass through shales, leaving the larger salt molecules behind.

Reports describing the hydrogeology of the area

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GSWA publications can be accessed from Geoscience information, maps and reports at www.dmp.wa.gov.au

Unpublished GSWA Hydrogeology Reports are held by the Department of Water



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