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Hydrogeology of the Dongara Borehole Line

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1 Introduction

1.1 Background

Hydrogeological investigation in Western Australia was originally conducted by the Geological Survey of Western Australia (GSWA). Exploratory borehole lines in the Perth Basin were drilled from Karridale in the south-west to Dongara in the north. The Dongara Borehole Line drilling concluded hydrogeological investigation conducted by the GSWA, which began in 1961.

Groundwater exploration for town water supplies at Allanooka and Irwin View has provided data north of the Irwin River (Figure 1). Shallow groundwater investigations include the Greenough Shallow and Leeman Shallow Drilling programs, which investigated the stratigraphy of the superficial formations on the Swan Coastal Plain. Investigation for the town water supply at Morawa proceeded farther south, near the Arrowsmith River. The closest deep exploratory borehole line to the Dongara Line is the Eneabba Line, which is 50 km to the south of Dongara.

State groundwater resource investigation, monitoring and management is now managed by the Department of Water. Groundwater resources are being utilised by irrigated horticulture, mineral sands mining and iron ore processing to the east and the oil and gas industry. Requests for use by these industries are growing with increasing population and a high demand for resources in the area.

The Dongara Borehole Line was drilled in 1995 to improve the understanding of the structure and lithology of the aquifers, and to monitor potentiometric head changes in aquifers within the northern Perth Basin. This report summarises the hydrogeology of the Dongara Borehole Line and presents information about groundwater resources in the northern Perth Basin.

1.2 Location

Four of the Dongara Line bores are situated along the Yandanooka West Road (Figure 1), south-east of the coastal town of Dongara, which is approximately 300 km north of Perth. The borehole nearest to Dongara is accessible from the Brand Highway, and is situated approximately 15 km southeast of Dongara. The borehole line extends for 50 km to the east.

1.3 Climate

The region experiences hot dry summers and cool wet winters. The mean annual daily temperature is 26°C and the average annual rainfall decreases from 465 mm at the coast to 335 mm inland. Rain falls mostly in the cooler months, from May through to August, and evaporation rates exceed rainfall in summer. Summer thunderstorms and remnant tropical cyclones can cause isolated heavy rain resulting in local flooding.

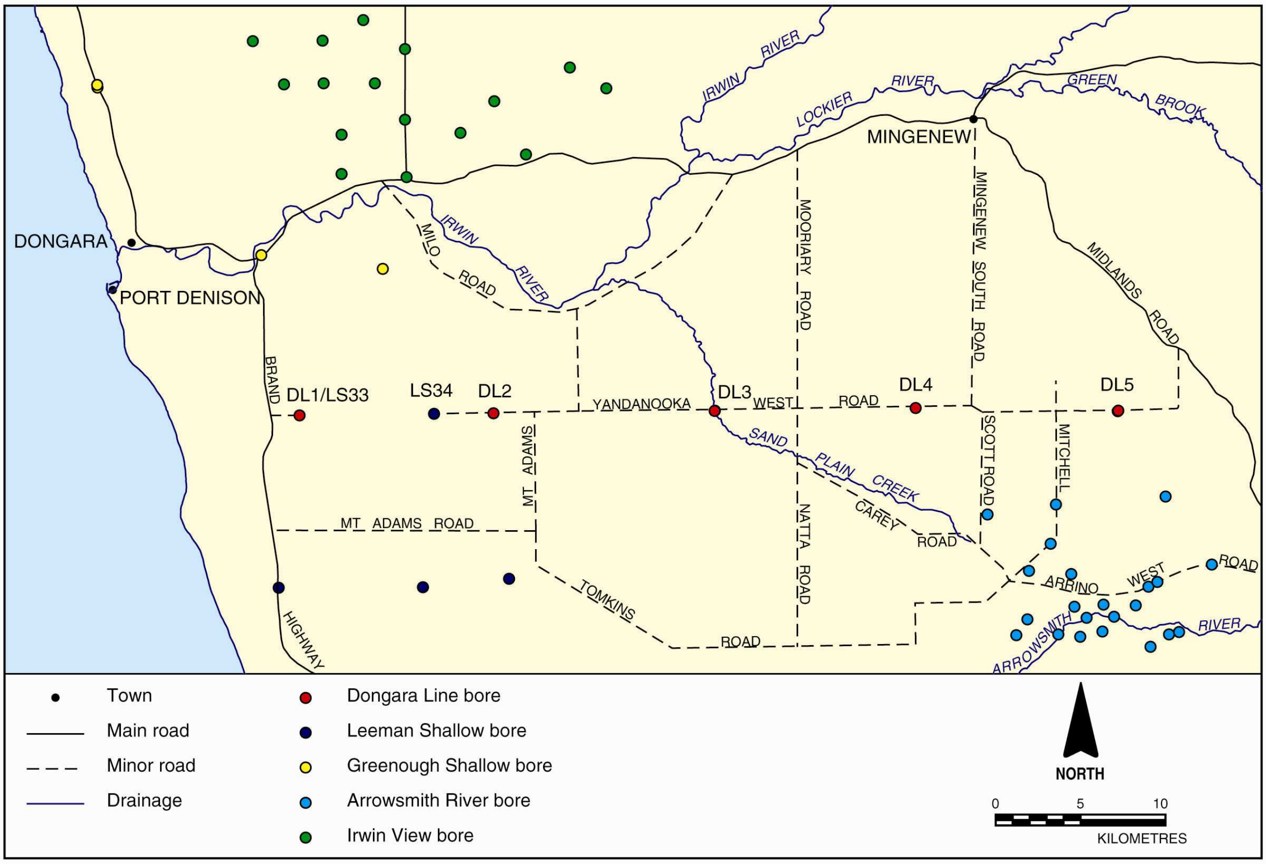

Figure 1. Location map

1.4 Physiography

The Dongara Line crosses three physiographic regions, consisting of an undissected, upland area, a gently undulating and dissected region having variable geomorphic units, and the coastal plain (Figure 2).

The Gingin Scarp marks the eastern limit of marine erosion, and separates the Swan Coastal Plain and the Arrowsmith Region. The Dandaragan Scarp separates the Arrowsmith Region and Dandaragan Plateau, and is an erosional feature marked by the outcrop of the Otorowiri Siltstone beneath a laterite capping.

In the Lockier Region, east of the Dongara Line, clayey soils derived from Permian sediments are exposed in a low-lying area. The region is drained by the Lockier River and the upper part of the Irwin River. Deep gullies have incised into dispersive clays. This erosion follows land clearing and increases in saline runoff from inland.

The Dandaragan Plateau has an elevation up to 300 m AHD and is capped by laterite overlying Cretaceous sediments and sand plains. It is relatively flat with older alluvial channels infilled with eolian sediments and dissected by the Arrowsmith River to the south. The region bears physiographic resemblance to the Victoria Plateau, north of the Irwin River, although the soil types differ.

The Arrowsmith Region is a laterite-capped plateau that is dissected by active drainage to forms a gently undulating land surface. The Irwin River and Arrowsmith River cross the region and Sand Plain Creek, a tributary of the Irwin River, intersects the Dongara Line.

The Swan Coastal Plain is covered by Quaternary formations including alluvial fans, eolian calcarenite and the Quindalup and Spearwood Dune Systems. Farther inland, the Eneabba Plain is a low-lying portion of the coastal plain, consisting of Early Pleistocene to Late Tertiary shoreline, lagoonal and dune deposits, which have been modified to present day alluvial, lacustrine and eolian sequences (Mory, 1995). The Swan Coastal Plain is bounded to the east by the Gingin Scarp.

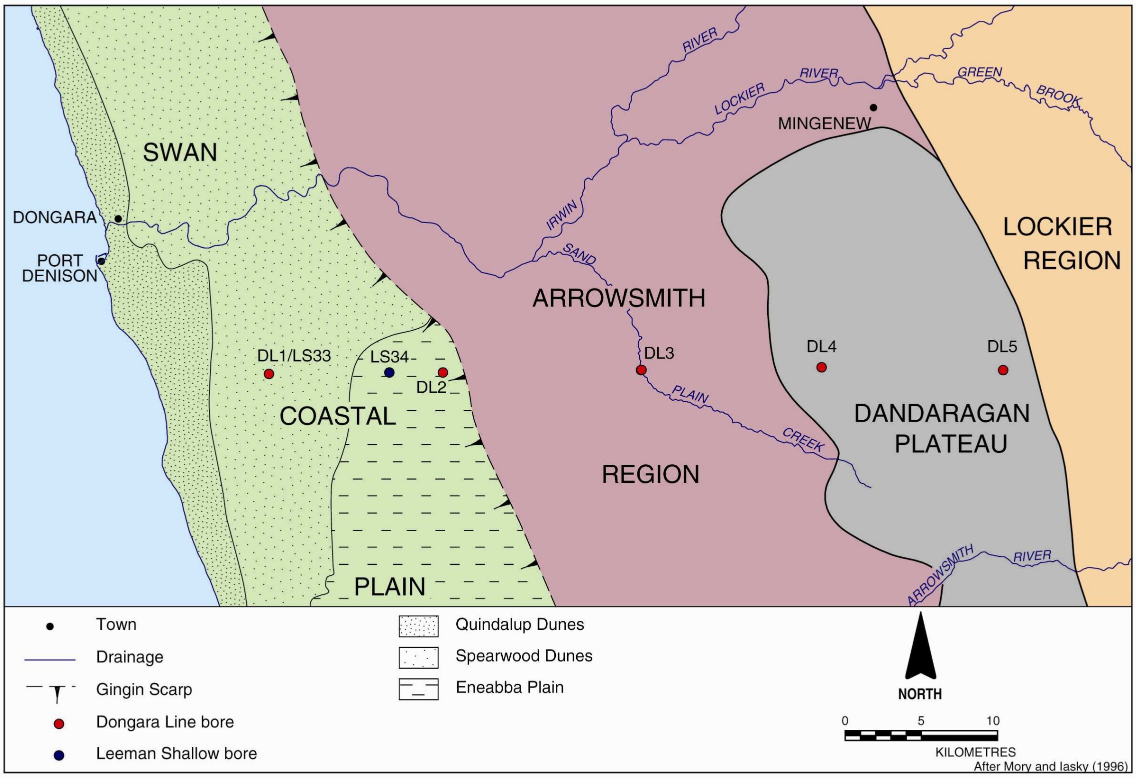

Figure 2. Physiography

1.5 Land use

Most land east of the Brand Highway has been cleared for agricultural use, whereas the coastal areas are still naturally vegetated. Remnant native vegetation also occurs in some riparian zones and in flood-prone areas. Pasture and cereal crops are common in the area, and rely on winter rainfall for growth. To the north, in the Irwin River Valley, horticulture, orchards, tree plantations and viticulture are becoming increasingly popular, though limited by groundwater availability and quality.

Gas is produced from underground reserves south of the Dongara Line in the Mondarra gasfield, and north in the Dongara gasfield. Mineral sands, laterite for gravel and limestone deposits are mined in the region.

1.6 Groundwater use

The Dongara Line is located in the Arrowsmith Groundwater Area. This area is proclaimed under the *Rights in Water and Irrigation Act* (1914), thus most groundwater use is licensed. Allocation limits have been set by the Department of Water and licensed use must not exceed these limits, which have been calculated based on current hydrogeological understanding.

Groundwater in the region is in high demand by mineral and agricultural industries. Mineral ore processing uses 0.2 GL, which is 40% of the current allocation for the entire groundwater area. Large allocations are also in reserve for public water supply (about 30%) and the remaining allocations are for irrigation of pasture and crops, including mango trees, olive trees, orchards, vegetables, and for aquaculture.

Future development in the area will require groundwater for public water supply, increased mining activity including petroleum, gas, iron ore and mineral sands, and for larger irrigation requirements.

2 Investigation

2.1 Previous work

Most deep exploratory drilling in the area has been undertaken for oil and gas exploration following oil shows in BMR10 and 10A, which were drilled by the Bureau of Mineral Resources from 1959 to 1960. Petroleum exploration and production in the area is continuing. The economic geology, including groundwater resource potential, is summarised in Mory (1995).

Groundwater exploration in the area was centred on development of town water supplies for Geraldton and Dongara, and included drilling of the Allanooka, Irwin View and Mount Hill bores (Allen, 1980). Barnett (1970) describes the results of exploratory drilling that was carried out in the Arrowsmith area for the Morawa town water supply.

Systematic exploratory drilling conducted by GSWA continued in the northern Perth Basin, when the Eneabba Borehole Line was drilled between 1972 and 1974 (Commander, 1978, 1981). This drilling provided 28 new bores, ranging in depth from 70 to 800 m. The project was undertaken for hydrogeological exploration and all bores were cased for future water level observation.

Investigations into the shallow coastal aquifers began with the Greenough Shallow drilling project north of the Dongara Line (Koomberi, 1994). This exploration continued to the south with the Leeman Shallow drilling between Leeman and Dongara (Nidagal, 1994). The Leeman Shallow bore site LS33 is co-located with DL1, and LS34 also lies within the Dongara Line. Data from these bores have been included in this assessment.

The Dongara Line traverses the Mondarra gasfield, and there are a number of deep exploration and production wells nearby, including West White Point. Seismic exploration has provided information on the deep structure in the oil and gas exploration fields. Structure of the northern Perth Basin is summarised in Mory and Iasky (1996).

2.2 Purpose and scope

The drilling of the Dongara Borehole Line was conducted by GSWA as part of continuing groundwater resource assessment in the northern Perth Basin. This investigation provides lithological, palynological, geophysical and hydrogeological data in an area lying between the Eneabba Line and the Irwin View project. Groundwater monitoring wells have been installed in the superficial, Yarragadee and Parmelia aquifers.

2.3 Drilling and bore construction

The Dongara Borehole Line consists of five sites, at each of which a deep and a shallow bore have been constructed. Site DL1 is co-located with the Leeman Shallow bore LS33, on private property accessible from the Brand Highway. Sites LS34, DL2 to DL5 are on Yandanooka West Road reserve (Figure 1). All Dongara Line sites are on or adjacent to land cleared for pasture and crops. Drilling, bore construction and sampling details for all sites are summarised in the GSWA bore completion report for the Dongara Line (Groves, 1995).

Preparation for the drilling of Dongara Line commenced in 1990 with the construction of water supply bores (suffix “W”) at sites DL1 to DL3 and DL5, using the Department of Mines Jacro 350 drilling rig. The water supply bores range in depth from 20 to 125 m. The water supply bores were drilled to a maximum of 50 m below the watertable and cased with 114 mm outer diameter (OD) steel casing. The bores were screened with 6 m lengths of 114 mm OD stainless steel, 0.5 mm continuous aperture wire-wound well screen.

Deep drilling was commenced in 1995 by the Bunbury Boring Company, using a Bourne 2000 drilling rig. The deep bores (suffix “A”) were all drilled in 1995, and range in depth from 399 to 501 m bgl. Both the shallow water supply bores and the deep bores were drilled using mud-rotary technique.

The ground surface for the deep bores was stabilised using a 320 mm inner diameter (ID) steel surface conductor pipe. DL4A was abandoned after the surface conductor pipe casing parted during installation and a second deep bore, DL4B, was drilled. Mild-steel welded casing of 154 mm ID was used to case the bore DL1A from surface to the top of the screen assembly, and was pressure-cemented in place.

The screen assembly was telescoped inside the main casing, and sealed in place using an inflatable packer. The screen assembly consists of a packer, 102.3 mm ID stainless steel riser pipe, 100 mm ID stainless steel screen, and a 102 mm ID stainless steel sump. Stainless steel wire-wound well screen with 1 mm continuous aperture was used for the deep bore and 0.5 mm aperture for the shallow bore.

The bores were completed and painted blue at the surface and a cement block installed surrounding the headworks. Identification labels were welded onto the headworks and a lockable cap put on the bore. As artesian flow was encountered at DL1A, a packer was placed above the screened interval and artesian headworks, including a main valve, six inch (152 mm) gate and a head plate with a one inch (25 mm) nipple on top, were used to seal the borehole.

2.4 Sampling and logging

Sludge samples for all DL bores were taken and logged at 3 m intervals, and these are stored in the GSWA core library. A wire-line core was recovered from LS33A and

LS34A in the superficial formations (Nidagal, 1994) with data from these bores included in this hydrogeological assessment.

Shallow bores were geophysically logged using a Gearhart Owen GO3 for gamma, short- and long-normal resistivity. Deep bores were logged geophysically using a Century PC3 for natural gamma, short- and long-normal resistivity, point resistivity, self-potential and temperature.

Strata samples were selected by the site hydrogeologist and processed to determine spore-pollen zonation (Backhouse, 1995a–e). Water samples were collected from each bore at the completion of airlifting, and basic cation and anion chemical analyses were conducted by Australian Environmental Laboratories.

The natural surface and top of casing of each bore have been levelled to the Australian Height Datum (AHD). Water levels were measured in the bores following bore completion, and again several months after drilling. Since 1997, water levels have been monitored either annually or biannually, although no measurements were taken between 1998 and 2001. Annual water-level measurement has continued from 2001 until present in most DL bores.

Table 1. Bore completion data

Bore No.	*AMG East*	*AMG North*	*Date completed*	*Surface elevation (m AHD)*	*Casing top (m AHD)*	*Total depth (m bgl)*	*Observation interval (m bgl)*	*Static water level on 10/10/95 (m btoc)*	*Potentiometric head (m AHD)*	*Salinity (mg/L TDS calc.)*	*Airlift yield (m^3/day)*	*Aquifer*	*Status*
DL1A	308400	6752100	29/06/1995	15.87	16.91	501	406-412	+2.135	19.05	3650	510	Yarragadee	Monitoring
DL1W	308400	6752100	9/08/1990	16.12	16.75	64	43-49	15.43	1.32	10600	345.6	Yarragadee	Monitoring
LS34A	316400	6752100	9/08/1990	31.981	32.58	100.14	80.5-86.5	n/a	31.06	570	n/a	Yarragadee	Monitoring
LS34B	316400	6752100	10/08/1990	31.93	32.62	20.54	13.9-19.9	n/a	30.95	460	n/a	superficial	Monitoring
DL2A	320000	6752250	23/07/1995	84.63	85.48	501	421-427	39.35 (8/95)	46.13	1720	690	Yarragadee	Monitoring
DL2W	320000	6752250	3/08/1990	84.66	85.61	102	63-69	34.00 (8/95)	51.16	420	207	Yarragadee	Monitoring
DL3A	333200	6752500	24/08/1995	128.45	129.21	481	429-435	54.4	74.81	860	350	Yarragadee	Monitoring
DL3W	333200	6752500	31/07/1990	128.23	129.13	125.2	103-109	49.52	79.61	540	239	Yarragadee	Monitoring
DL4A	344800	6752700	25/08/1995	n/a	n/a	35	cased	n/a	n/a	n/a	n/a	n/a	Back filled / abandoned
DL4B	344800	6752700	19/09/1995	257.48	258.30	501	459-465	180.31	77.99	1560	195	Yarragadee	Monitoring
DL5A	357000	6752500	15/09/1995	298.85	299.50	399	363-369	209.75	89.75	1710	241	Yarragadee	Monitoring
DL5W	357000	6752500	26/07/1990	298.73	299.69	125.3	102-108	77.59	221.1	310	107	Parmelia	Monitoring

n/a – data not available.

3 Geology

3.1 Setting

The Dongara Line is located within the northern Perth Basin, in a half graben, and bounded to the east by the Darling Fault. Sediments in the basin are intensely block faulted and deposition dates back to the Silurian when the Darling Fault was initiated. Faulting occurred in the Late Permian and continued until the Neocomian, when significant deposits of mostly fluvial and lacustrine sediments were deposited (Cockbain, 1990).

The borehole line crosses several structural subdivisions (Figure 3), including the Dongara Terrace, Beharra Springs Terrace and Allanooka High (Mory and Iasky, 1996). Vertical fault displacement is up to 15 km on the Urella Fault. Most major faults strike north-northwest and dip to the west, while transfer faults such as the Allanooka Fault strike west to northwest and dip to the south. The Mountain Bridge Fault, the Beharra Springs Fault and the Urella Fault separate the major subdivisions.

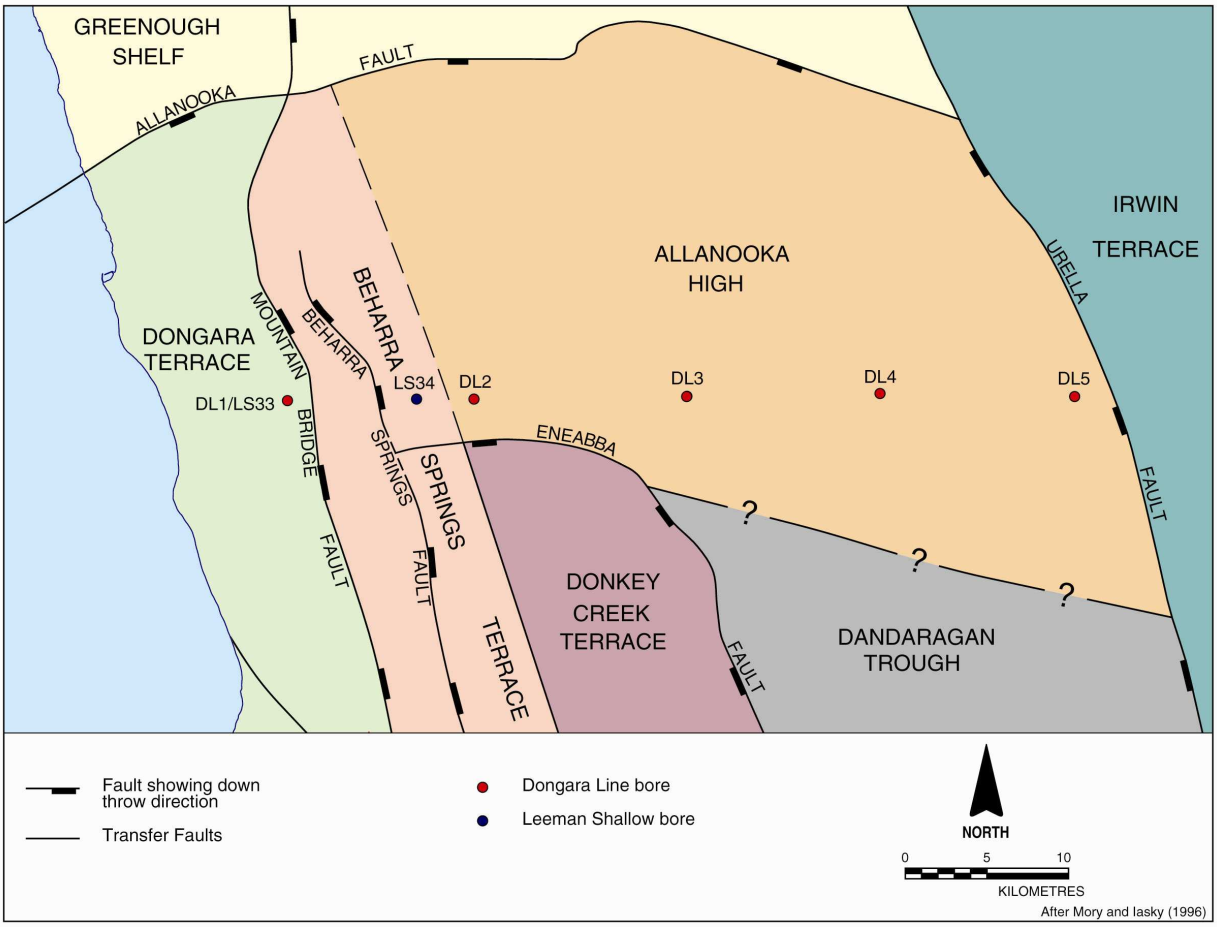

Figure 3. Structure

3.2 Stratigraphy

The formations intersected by the Dongara Line range in age from Quaternary to Jurassic (Table 2). The strata are up to 5 km thick from surface to basement, thinning to the west and unconformably overlying undifferentiated Proterozoic rocks (Mory, 1995). The Yarragadee Formation and overlying Parmelia Formation have been assigned to the Jurassic and Cretaceous respectively. A laterite veneer covers the Mesozoic formations east of the Gingin Scarp, and on the coastal plain, they are unconformably overlain by Quaternary superficial formations.

The superficial formations intersected were up to 100 m thick, although some coastal dune areas are likely to exceed this figure. They unconformably overlie the Yarragadee Formation, west of the Gingin Scarp, comprising limestone, sand and clay of Pleistocene to Holocene age.

Table 2. Stratigraphic succession

Period	Age	Formation	Maximum thickness (metres)	Lithology	Resource potential
Quaternary	L. Pleistocene	Tamala Limestone	25	limestone, sand	coastal aquifer
	Pleistocene	Guildford Formation	21	sand, clay	aquifer
Tertiary	Pliocene	Yoganup Formation	6	iron cemented clayey sand, sand	minor aquifer
			unconformity		
Cretaceous	Neocomian	Parmelia Formation	199	sand, clay	aquifer
		Otorowiri Siltstone	34	siltstone, shale, clay,	aquiclude
			unconformity		
Jurassic	Tithonian–Berriasian	Yarragadee Formation	> 500	sandstone, siltstone, shale	regional aquifer

3.2.1 Yarragadee Formation

The Yarragadee Formation occurs extensively throughout the northern Perth Basin and was intersected in all Dongara Line deep bores (Figure 2). The Yarragadee Formation is at the surface in bore DL3, subcrops beneath the superficial formations in DL1 and DL2, and subcrops beneath the Parmelia Formation in DL4 and DL5. The formation was not fully penetrated in the Dongara Line, as it is believed to be up to 2500 m thick on the Allanooka High (Playford et al., 1976). The formation outcrops in places along the Irwin River, including Depot Hill, where it is a well-cemented sandstone, though in most areas it is concealed by laterite, alluvium and colluvium.

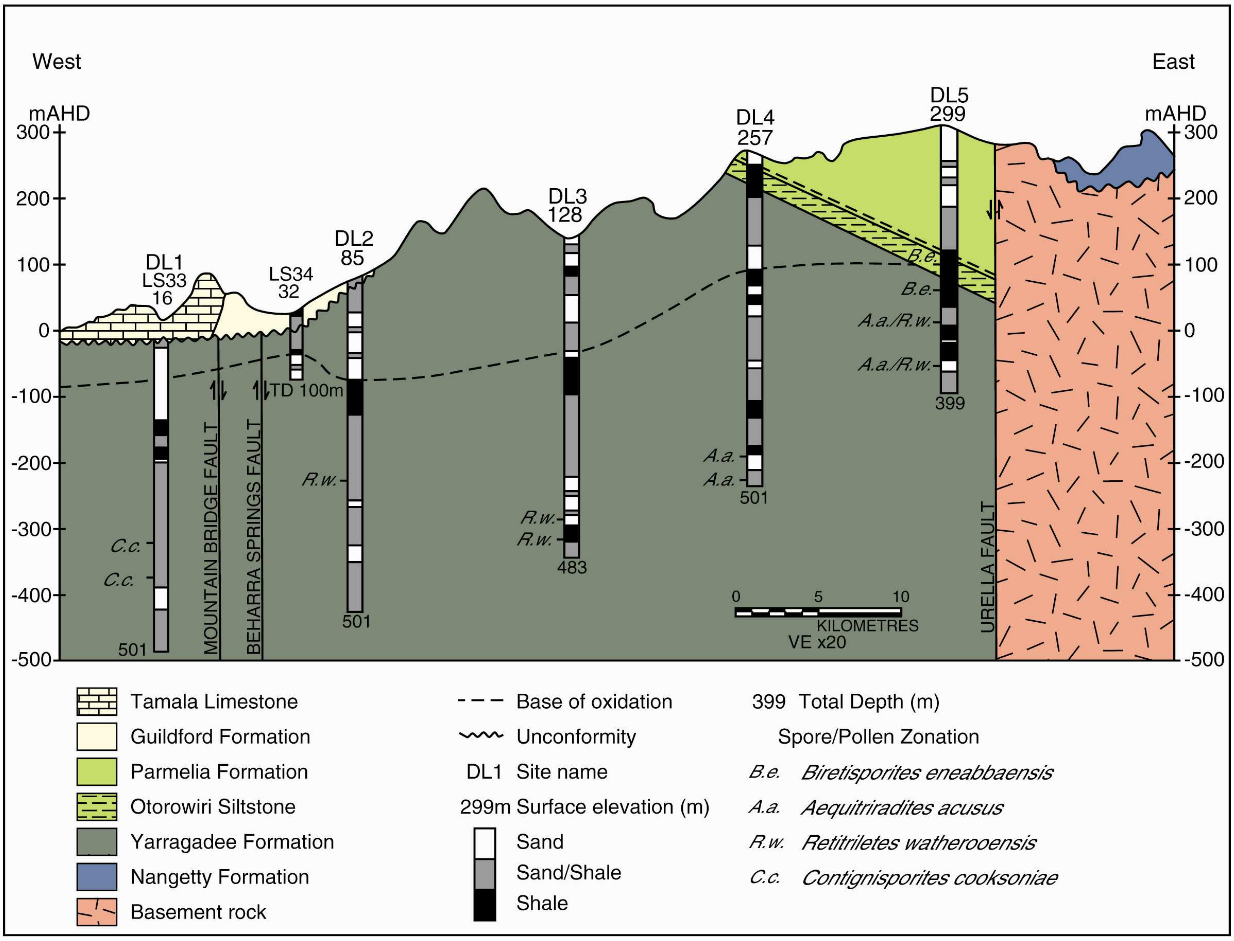

Figure 4. Geology

The Yarragadee Formation comprises interbedded sand, sandstone, siltstone and shale. Sand content in the formation decreases with depth, and sand beds vary in thickness from less than 5 m to greater than 20 m. Grain size ranges from pebble to fine grained, and consists of quartz, with common feldspar, minor pyrite and carbonaceous material. The feldspar has been weathered to kaolinite near the surface. Clays are greyish white with some lamination, and they contain pyritic material. The shale and siltstone are generally darker in colour, containing carbonaceous material and trace pyrite. The formation in the Arrowsmith Region is capped by laterite and all layers above and near the watertable are stained or cemented with iron oxides. The zone of oxidation extends up to 130 m beneath the Neocomian unconformity and the formation appears unoxidised beneath the watertable, and where the Yarragadee is overlain by the Parmelia Formation.

The oldest strata intersected in DL1A and LS33A were identified as the *Contignisporites cooksoniae* zone, which is of Bathonian to Callovian age. The formation becomes progressively younger to the east, indicating the Jurassic strata are dipping to the east, probably at an angle similar to that represented by the Otorowiri Siltstone Member of the Parmelia Formation, which is intersected in DL4B and DL5A (see Figure 4). The *Retitriletes watherooensis* zone was identified in DL2A and DL3A and the *Aequitriradites acusus* zone in bore DL4B. Both zones are Tithonian age. These palynological zones are typical of the Yarragadee Formation, which is dated from the Middle Jurassic to Early Cretaceous.

3.2.2 Parmelia Formation

The Parmelia Formation consists of strata previously assigned to the South Perth Formation and the Upper Yarragadee Formation (Barnett, 1970; Commander, 1978 and 1981). The Parmelia Formation was identified in bores DL4A and DL5A and is present at the surface at these sites. The Parmelia Formation conformably overlies the Yarragadee Formation east of the Dandaragan Scarp.

The formation can be divided into two conformable facies: the overlying, more-shaly, silty Carnac Member and the underlying, sandier Parmelia Sand Member (Crostella and Backhouse, 2000). These two members have not been differentiated in the Dongara Line.

The upper member of the formation is grey and comprises interbedded sand, clay and silt. Sand beds are on average 30 m thick and the unit becomes progressively more clayey with depth, grading into the Otorowiri Siltstone. The sand is fine to very coarse grained, with common gravel and pebbles. Grains consist of quartz and feldspar and minor ‘smoky’ quartz, iron-oxide coated grains and traces of opaline silica and pyrite. White to pinkish-white kaolinite is present in the upper parts of the formation because of feldspar weathering, however the member is oxidised to the top of the Otorowiri Siltstone Member. Cherty quartz pebbles are more common near the base of the Parmelia Formation where it overlies the Otorowiri Siltstone Member.

Otorowiri Siltstone Member

The Otorowiri Siltstone Member is a distinct unit within the Parmelia Formation, easily identifiable by its shaly texture and consistent gamma-ray signature. The formation outcrops beneath laterite capping on the upper part of the Dandaragan Scarp, and it was intersected in both DL4B and DL5A (Figure 4). The maximum penetrated thickness of the Otorowiri Member is 34 m, in DL 5A. It is conformably overlain by the sandier, upper member of the Parmelia Formation and dips eastward into a gently, south-plunging synclinal structure.

The Otorowiri Siltstone Member consists of dark-grey to greenish-grey, micaceous siltstone and mudstone with minor medium- to coarse-grained sand. The gamma-ray log is smooth and consistent at 100 API units for the entire member, indicating homogeneous strata. The siltstone is moderately consolidated and weakly laminated. Palynology samples from DL4B and DL5A identify the *Biretisporites eneabaenisis* zone, which is Berriasian age, and indicates the Parmelia Formation (Backhouse, 1995e).

3.2.3 Superficial formations

The superficial formations occur along the coast and extend up to 20 km inland to the Gingin Scarp, just east of site DL2 (Figure 2). A comprehensive description of the superficial formations present in the area is given in Nidagal (1994).

The Tamala Limestone is present along the coast, adjacent to the Guildford Formation farther inland. The Yoganup Formation occurs at the base of the superficial formations, near the Gingin Scarp. Core loss during drilling of the Leeman Shallow bores LS33A and LS34A indicates that the coastal superficial formations are cavernous.

Yoganup Formation

The Yoganup Formation was intersected in LS34A, which is situated between sites DL1 and DL2. The formation consisted entirely of moderately hard, iron-cemented, orange-brown, subangular to subrounded, fine- to medium-grained sand, and trace clay. The formation is overlain by the Guildford Formation and is defined by its previously known stratigraphic position, as it is difficult to distinguish from the underlying Yarragadee Formation (Nidagal, 1994).

Guildford Formation

The Guildford Formation lies at the base of the Gingin Scarp and extends west, where it is contiguous with the Tamala Limestone. This formation unconformably overlies the Yarragadee Formation or the Yoganup Formation where present. Interfingering sand and clay facies are present in the Guildford Formation, and these are overlain by a thin layer of Bassendean Sand in the Dongara Line. The Guildford Formation pinches out to the west, where the Tamala Limestone overlies the Mesozoic formations.

The Guildford Formation, which was intersected in bore LS34A, consists of a cream to orange-yellow sand to clayey-sand with subangular to subrounded, fine- to very fine-grained quartz grains. Trace heavy minerals, clay and pink feldspars are present and the base of formation has a moderately-hard layer of iron cemented fine- to medium-grained sand.

Tamala Limestone

The Tamala Limestone unconformably overlies the Jurassic sediments and interfingers with the Guildford Formation at its eastern extent. The Tamala Limestone was intersected in bore LS33A and DL1A and is present on the central and western parts of the Swan Coastal Plain. The limestone is creamy white to pale orange in colour, powdery to hard and contains solution cavities with secondary calcite precipitation. Fine-grained quartz sand has often infilled the solution cavities within the limestone. Solution channels, karst features and cave systems are developed throughout the limestone, indicated by core loss in LS33A.

4 Hydrogeology

The Dongara Line intersects the Parmelia aquifer, Yarragadee aquifer and the superficial aquifer. The Otorowiri Siltstone is an aquiclude between the Parmelia aquifer and Yarragadee aquifer. The superficial aquifer is unconfined and comprises the superficial formations. The Yarragadee aquifer exists across the entire Dongara Line, unconfined in the Arrowsmith Region and confined by the superficial aquifer to the west and Otorowiri Siltstone to the east. The Parmelia aquifer is unconfined on the Dandaragan Plateau, perched above the Yarragadee aquifer just east of the Dandaragan Scarp. Fresh groundwater springs from the Parmelia aquifer along the Dandaragan Scarp, either from seepage through or over the Otorowiri Siltstone.

The area is traversed by two rivers running parallel to the Dongara Line. The Irwin River to the north is a losing stream in its upper reaches to the Yarragadee aquifer and a gaining stream in the lower reaches from the Yarragadee aquifer. Sand Plain Creek crosses the Dongara Line at DL3, discharging during rainfall events into the Irwin River and into underlying sediments. The Arrowsmith River to the south gains water discharging from the Parmelia aquifer on the Dandaragan Plateau, and loses water into the Yarragadee aquifer. The river does not discharge to sea, but into underground caves at the unconformity between the superficial and Yarragadee aquifers.

4.1 Superficial aquifer

The superficial aquifer extends from the coast to the Gingin Scarp. The average saturated thickness is 20 m, though it increases to up to 40 m at LS34 near the Gingin Scarp. The superficial aquifer is completely oxidised, with the zone of oxidation residing beneath in the Yarragadee aquifer.

The watertable slopes steeply westwards at the base of the Gingin Scarp and flattens to 0.8 m AHD in bore DL1W on the Swan Coastal Plain. This occurs where the Tamala Limestone is present. The hydraulic gradient increases in the Guildford sands at LS34 where the watertable is at around 30 mAHD. The depth to watertable ranges from 2 to 15 m in observation bores and exceeds this under the coastal dunes. The hydrograph for LS34B indicates that groundwater levels have remained stable in the superficial aquifer since 1998.

Recharge to the superficial aquifer is from direct rainfall precipitation on the Swan Coastal Plain and surface water recharge from the Arrowsmith River. There is also potential for upward leakage from the Yarragadee aquifer near to the coast and lateral discharge from the Yarragadee aquifer in the Arrowsmith region (Figure 5). A throughflow rate of 37 000 m^3/day into the superficial aquifer at the 20 m watertable contour was estimated using data from the Leeman Shallow bores in the area (Nidagal, 1994). The superficial aquifer discharges at the coast, where the watertable is close to sea level.

Groundwater is fresh in LS34 with a measured total dissolved solids (TDS) concentration of 460 mg/L. Groundwater salinity increases towards the coast, possibly due to mixing with seawater, and upward leakage from the Yarragadee aquifer. Nidagal (1994) mapped the saltwater interface several hundred metres west of DL1.

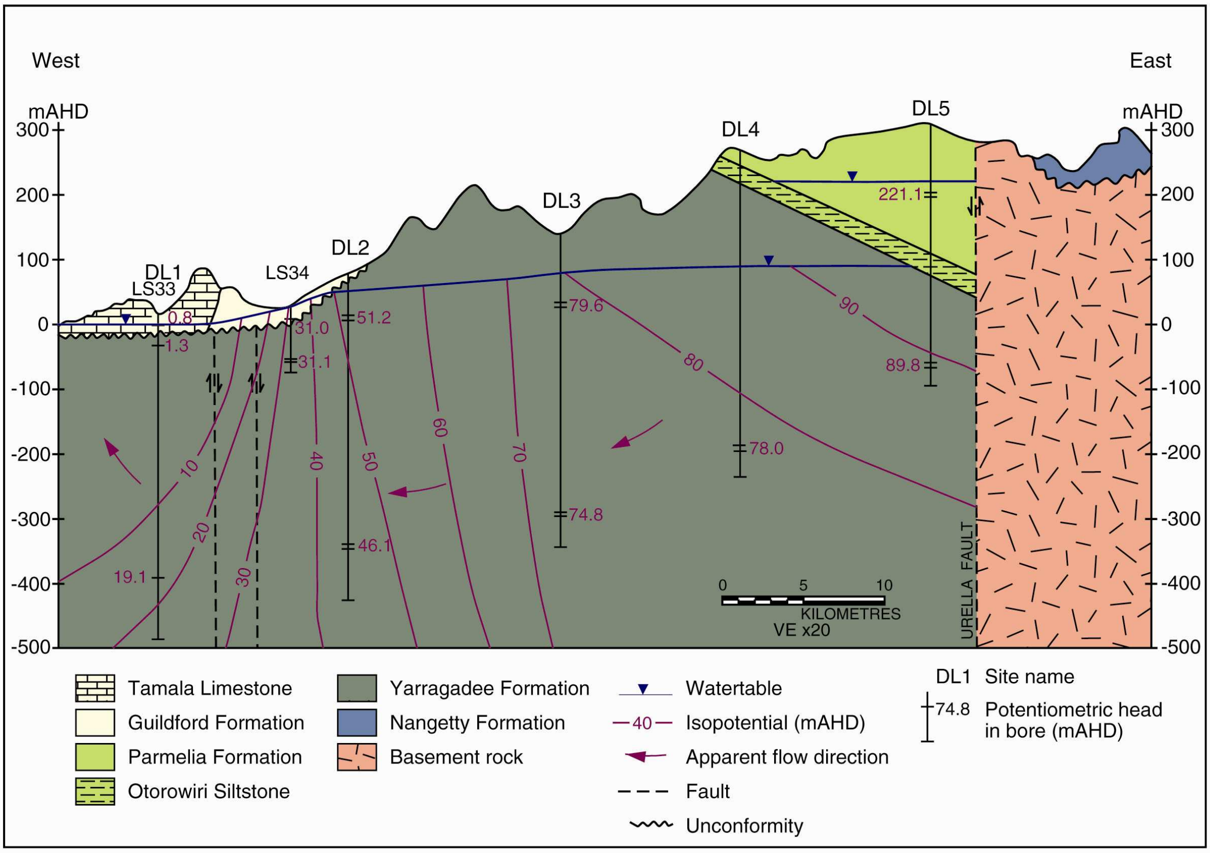

Figure 5. Isopotentials and apparent groundwater flow

4.2 Parmelia aquifer

The Parmelia aquifer is an unconfined, and in places perched aquifer, which sits above the Otorowiri Siltstone Member. The aquifer is near surface beneath laterite west of the Dandaragan Scarp, and bounded by crystalline basement at the Urella Fault in the east. The aquifer is completely oxidised to the top surface of the Otorowiri Siltstone.

The Parmelia aquifer is screened in DL5W, where there is a downward head of 132 m between the Parmelia aquifer and the underlying Yarragadee aquifer, which is screened in DL5A. The saturated thickness of the Parmelia aquifer increases from zero, in places near the Dandaragan Scarp, to in excess of 150 m to the east (Figure 5).

The Dandaragan Plateau north of the Arrowsmith River is a topographic high, and as a result, the Parmelia aquifer in this area can receive rainfall recharge only.

Potentiometric heads in bores in the region indicate a southerly flow direction, with groundwater discharging near the Arrowsmith River where it crosses the Dandaragan Plateau.

Natural spring flow and seepage from the Parmelia aquifer occurs near the outcrop of Otorowiri Siltstone along the Dandaragan Scarp. The springs are surrounded by lush vegetation, and provide drinking water for animals in the summer months. The potentiometric head has risen 3 m since 1998 in DL5W as a result of land clearing. The rising watertable is likely to have enhanced seepage rates from the aquifer.

Groundwater in the Parmelia aquifer is fresh with a salinity of 310 mg/L in DL5W. The low salinity is a result of direct rainfall recharge into the aquifer and an absence of runoff from areas having saline soils and streambeds.

4.3 Otorowiri Siltstone

The Otorowiri Siltstone is the basal unit of the Parmelia Formation and comprises shale, siltstone and clay. The member coincides with the Dandaragan Scarp and acts as an aquiclude between the Parmelia and Yarragadee aquifers. Natural springs mark discharge from the Parmelia aquifer where the watertable height is above the siltstone. It is partly oxidised close to surface in DL4B, where there is groundwater seepage through the siltstone.

4.4 Yarragadee aquifer

The Yarragadee aquifer is overlain by thin surficial deposits of alluvium, colluvium and laterite. The aquifer is unconfined throughout the Arrowsmith Region becoming confined in the west by the superficial formations and east by the Parmelia aquifer. The Yarragadee aquifer extends beyond the coastline and is bounded by the Urella Fault to the east. The aquifer is oxidised above the watertable in all bores and deeper in places where surface to groundwater recharge is occurring.

The watertable depth in the unconfined Yarragadee aquifer extends to 200 m below ground level, discharging into the lower Irwin River. East of the Dandaragan Scarp, the aquifer is confined beneath the Otorowiri Siltstone Member, where the potentiometric head is 25 m above the base of the Otorowiri Siltstone. The aquifer was not fully penetrated in this drilling investigation, though other exploration indicates that the thickness exceeds 2000 m.

The potentiometric head falls from 89.75 m AHD at DL5A to 19.05 m AHD at DL1A, indicating there is a westerly groundwater flow component (Figure 5). Regional flow appears to be to the southwest (Mory, 1995). This may be structurally controlled by the northerly trending faults that exist within the aquifer. South of the Arrowsmith River, groundwater flows to the north (Commander, 1978, 1981).

Direct rainfall recharge to the Yarragadee aquifer takes place in the Arrowsmith Region where the aquifer is unconfined. Downward heads of about 5 m are observed at sites DL2 and DL3, indicating possible downward leakage in the aquifer. Leakage and seepage from the Parmelia aquifer into the Yarragadee aquifer may occur through either fractures in the Otorowiri Siltstone or shear zones, such as the Urella Fault. Recharge to the aquifer from the surface is likely to be enhanced along drainage lines.

The Yarragadee aquifer is confined to semi-confined by clay layers within the aquifer, which on average are 5 to 10 m thick. The potentiometric head is above ground surface in DL1A because of confining clay layers in the upper part of the Yarragadee aquifer. Upward groundwater leakage may occur into the overlying superficial aquifer through these confining layers, as an upward potentiometric head of 0.5 m is observed in the hydrographs for LS34A and LS34B. There is an upward head difference of 18 m between the Yarragadee and superficial aquifers at DL1.

Potentiometric heads in the aquifer have risen between 0.4 to 1.6 m in the Arrowsmith Region since 1997 (Appendix A). At DL3, the potentiometric head has increased 1.6 m in DL3W and 1.1 m in DL3A over seven years. Other bores within the Yarragadee aquifer have shown similar increases of a lesser magnitude (Appendix A). One exception is DL4B, which has decreased 1 m in the same time. This was due to a large 3 m drop in water level between 2001 and 2002, and since then, water levels have continued to rise.

North of the Dongara Line, groundwater discharges from the Yarragadee aquifer into the Irwin River in the Arrowsmith Region. The groundwater discharging into the Irwin River is fresh, with measured electrical conductivity from Milo Road to Mountain Bridge less than 500 mS/m. The groundwater is saline in bores DL1W (10 600 mg/L) and in DL1A (3600 mg/L). Higher salinity at DL 1 may be due to the influence of seawater mixing and groundwater discharge. The salt water interface has been mapped just west of DL1 (Nidagal, 1994).

Groundwater in the Yarragadee aquifer is fresh (420 mg/L) in DL2W to marginal (540 mg/L) in DL 3W in the Arrowsmith Region, where the aquifer is unconfined. Groundwater in DL4B and DL5A is brackish (1560 mg/L and 1670 mg/L respectively) where the Yarragadee aquifer is confined beneath the Parmelia aquifer. Groundwater salinity increases with depth, where the Yarragadee is unconfined, which is likely to be due to low salinity rainwater recharging the aquifer in this area (Figure 6).

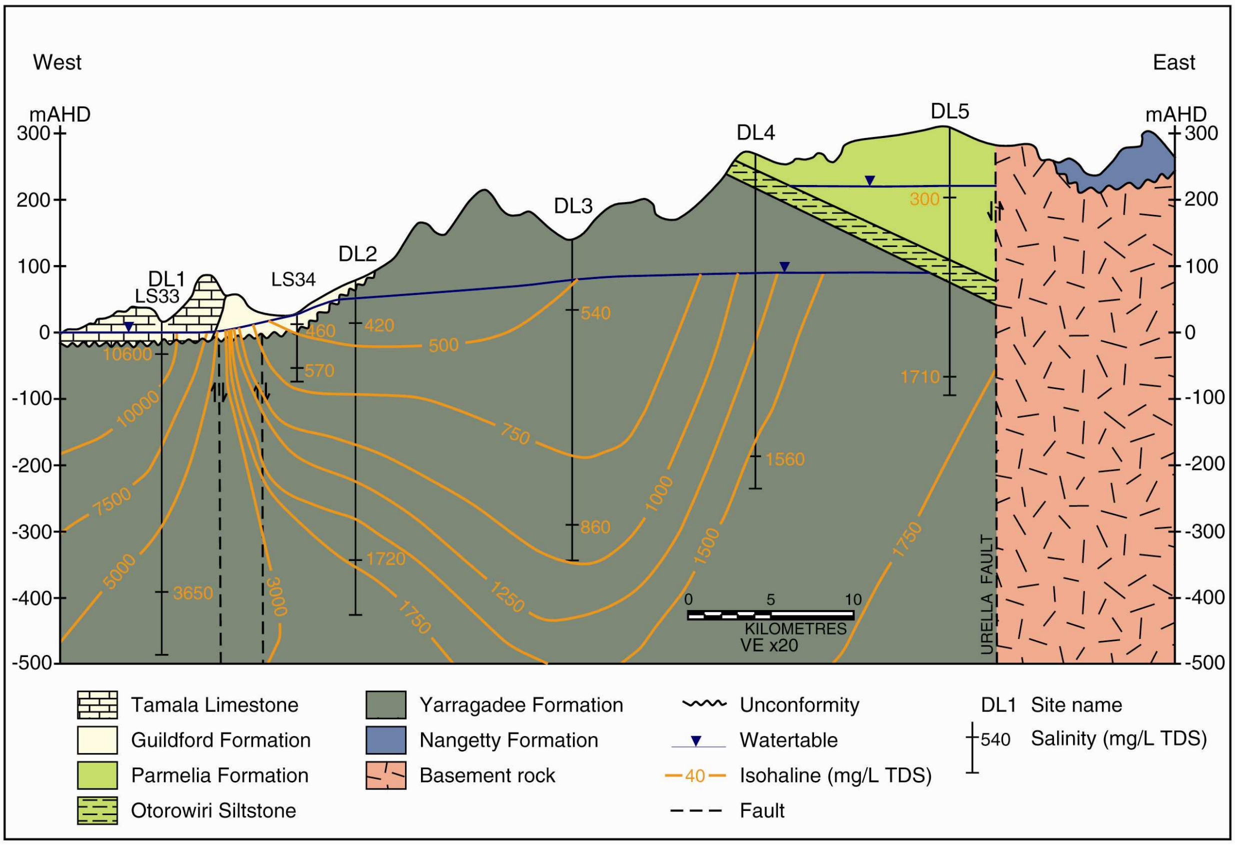

Figure 6. Groundwater salinity

5 Hydrochemistry

5.1 Groundwater chemistry

Groundwater chemical analyses indicate that in most cases, the water is of sodium chloride type, and that the major ion ratios are consistent with those of seawater (Table 3). Groundwater in bore DL1W has higher salinity and higher concentrations of all major elements, reflecting the influence of seawater on the water quality. Sulphate has been enriched in the shallow bores, possibly as a result of oxidation of the pyritic material within the rock because of increased dissolved oxygen concentrations. The groundwater pH in all bores is neutral to slightly acidic. Nitrate and aluminium are below 0.2 mg/L and iron is less than 0.4 mg/L in the deep bores. Fluorine and boron are consistently below detection limits.

5.2 Groundwater temperature

Groundwater temperature logs were run in the Dongara Line bores, but results indicate that temperature had not equilibrated at the time of logging. Groundwater temperature in bores DL3A, DL4B and DL5A were measured during airlifting. The maximum temperature was 39.2℃ in bore 1A and the m inimum temperature was 26.5℃ in bore DL5A.

Table 3. Hydrochemistry

Bore No.	Sampling date	pH	Cond. (mS/cm)	Colour Units	TDS meas.	TDS calc.	Total Hardness	Tot. Alk.	Ca	Mg	Na	K	Cl	HCO_3	CO_3	SO_4	NO_3	F	B	Fe	Si	SiO_2	Al
					mg/L																		
DL1A	26/06/1995	7.9	6.1	1	3600	3650	790	110	120	120	1240	54	2285	135	<1	160	<0.2	0.1	<0.1	<0.1	7.2	-	0.2
DL1W	22/08/1990	7	17.3	15	-	10600	2270	88	203	428	3160	125	5900	107	<2	726	<1	<0.1	0.1	-	-	18	-
DL2A	23/07/1995	7.7	2.9	<1	1660	1720	265	105	32	45	475	31	790	130	<1	140	<0.2	0.2	<0.1	0.3	8.3	-	0.2
DL2W	22/08/1990	7.2	0.73	15	-	420	30	37	2	6	131	6	183	45	<2	24	1	0.1	0.2	-	-	47	-
DL3A	24/08/1995	7.9	1.4	6	830	860	74	110	8.1	13	260	8.7	340	135	<1	110	<0.2	0.2	0.1	0.4	16	-	<0.1
DL3W	22/08/1990	6.9	0.96	10	-	540	46	19	2	10	160	8	262	23	<2	25	<1	0.1	0.1	-	-	58	-
DL4B	15/09/1995	7.6	1.58	1	1560	1580	235	72	23	43	450	20	730	88	<1	150	<0.2	0.2	0.1	<0.1	15	-	0.1
DL5A	15/09/1995	7.5	1.71	4	1670	1710	220	63	16	43	495	19	820	77	<1	155	<0.2	0.1	<0.1	<0.1	16	-	0.1
DL5W	22/08/1990	6.6	0.3	30	-	300	35	16	1	8	87	5	137	19	<2	18	1	<0.1	0.1	-	-	34	-

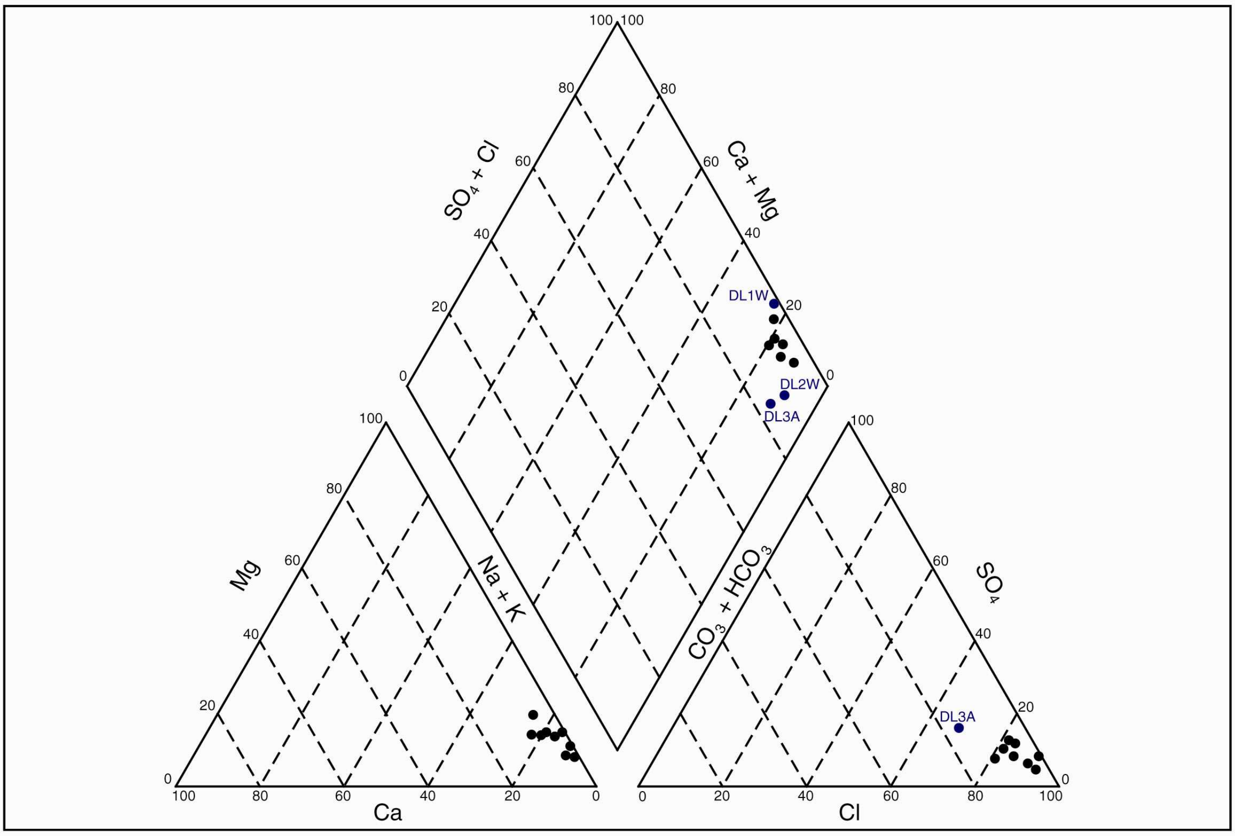

Figure 7. Piper trilinear plot of major ions

6 Conclusions

The Dongara Borehole Line was drilled by the Geological Survey of Western Australia in 1995. As a result of this investigation, the superficial, Yarragadee and Parmelia aquifers were identified using lithological, palynological and geophysical techniques.

The Parmelia Formation has been eroded west of the Dandaragan Scarp, where the Otorowiri Siltstone member outcrops. The Yarragadee Formation is near the surface in the Arrowsmith Region and overlain by the superficial formations west of the Gingin Scarp. Strata within the formations have been dated, indicating that the formations dip east towards the Urella Fault, where they terminate.

The superficial aquifer is unconfined and covers the area west of the Gingin Scarp. Limestone in the aquifer near the coast has a high permeability and, as a result, water levels in the aquifer are near sea level. Groundwater in the aquifer is fresh, becoming more saline due to seawater mixing near the coast where the hydraulic gradient is low.

The Parmelia aquifer has been identified east of the Dandaragan Scarp, and has been eroded west of the scarp in the Arrowsmith Region. This aquifer is perched above the Yarragadee aquifer, with downward groundwater flow impeded by the Otorowiri Siltstone Member. Regional groundwater flow is to the south, though there is some seepage across the Otorowiri Siltstone to the west. Seepages and springs of groundwater appear at the ground surface, where the watertable is higher than the upper surface of the siltstone. Groundwater in this aquifer is fresh and the watertable has risen 3 m since the Dongara Line was drilled, probably as a result of land clearing in the region.

The Yarragadee aquifer is unconfined over most of the Arrowsmith Region, but can be confined where overlain by the superficial and Parmelia aquifers. Groundwater flow is westerly and leakage is downward in the aquifer, except near the coast, where there is an upward head difference between the Yarragadee and superficial aquifer. Groundwater is fresh near the watertable in the Arrowsmith Region where direct rainfall recharge prevails. Salinity increases with depth, and near the coast where there is mixing with seawater.

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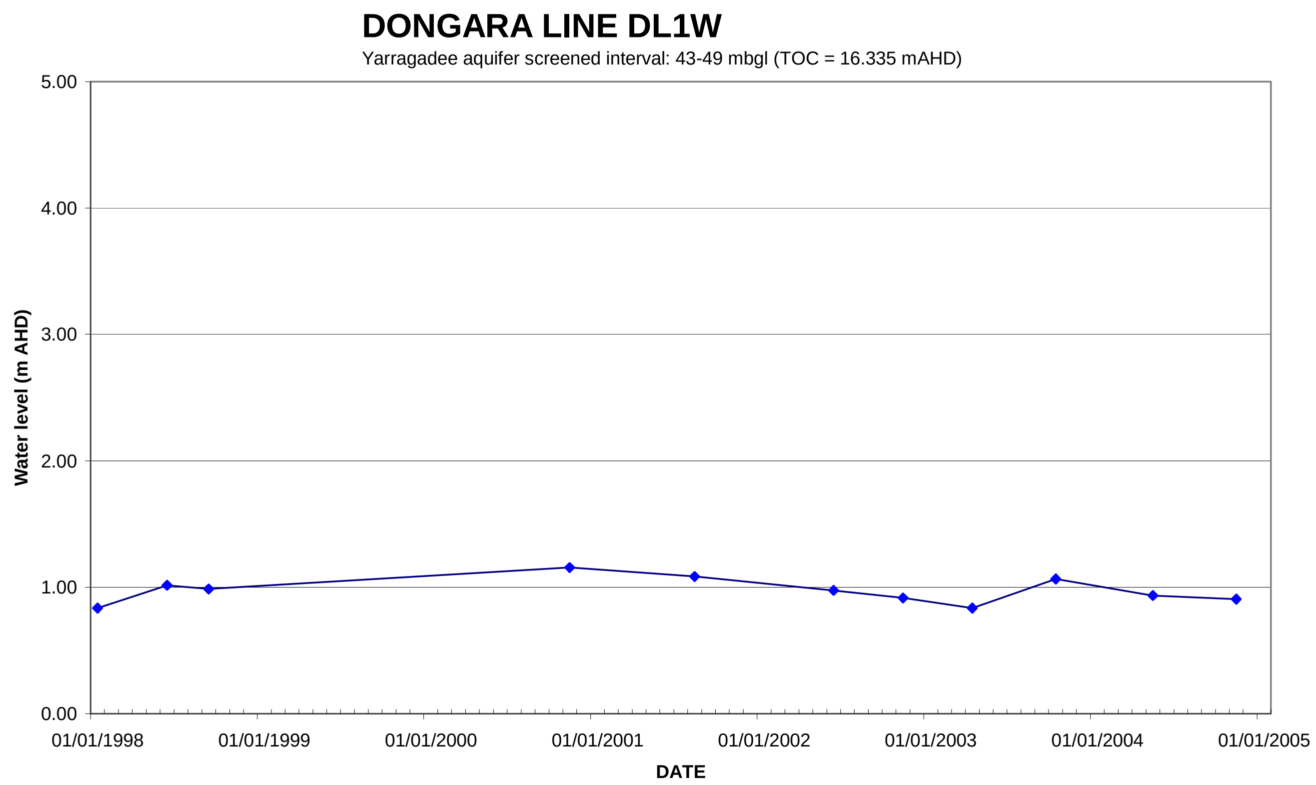
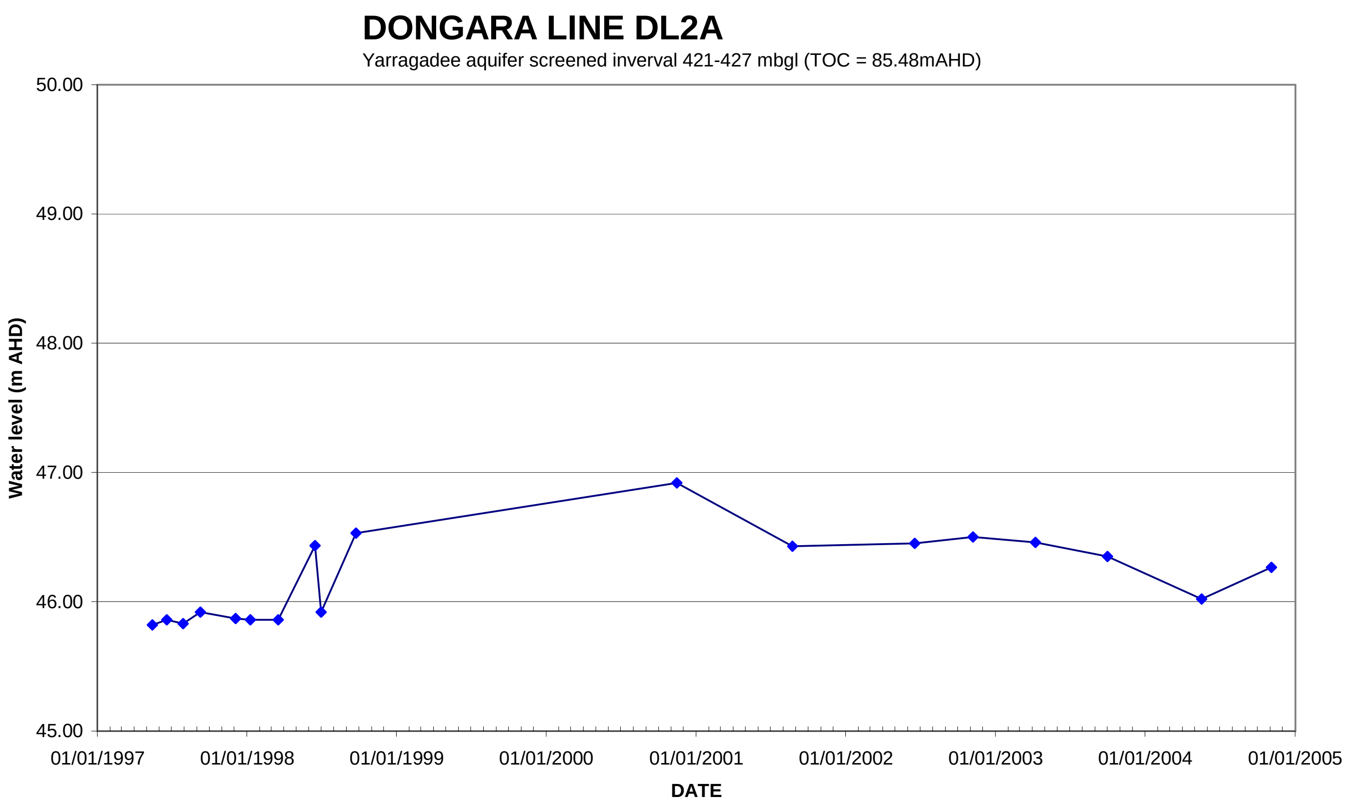
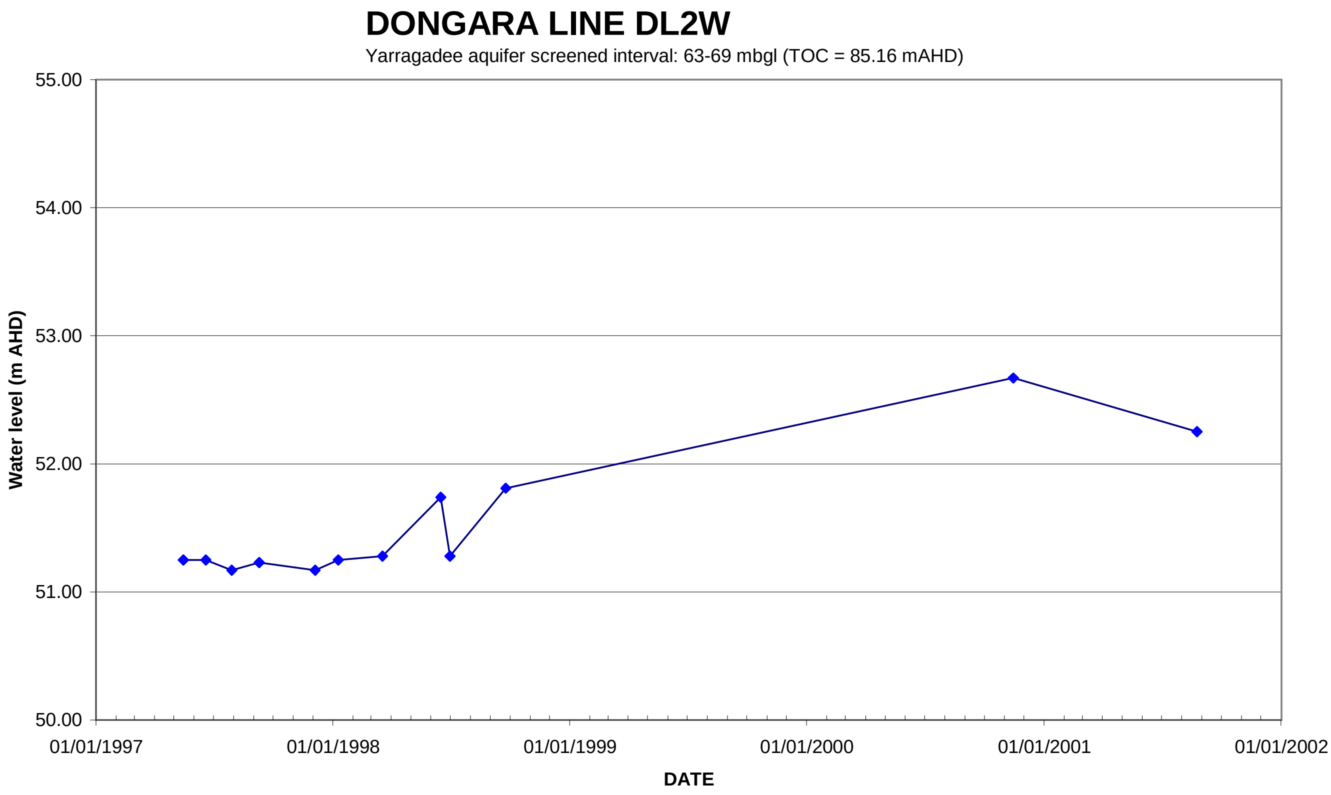
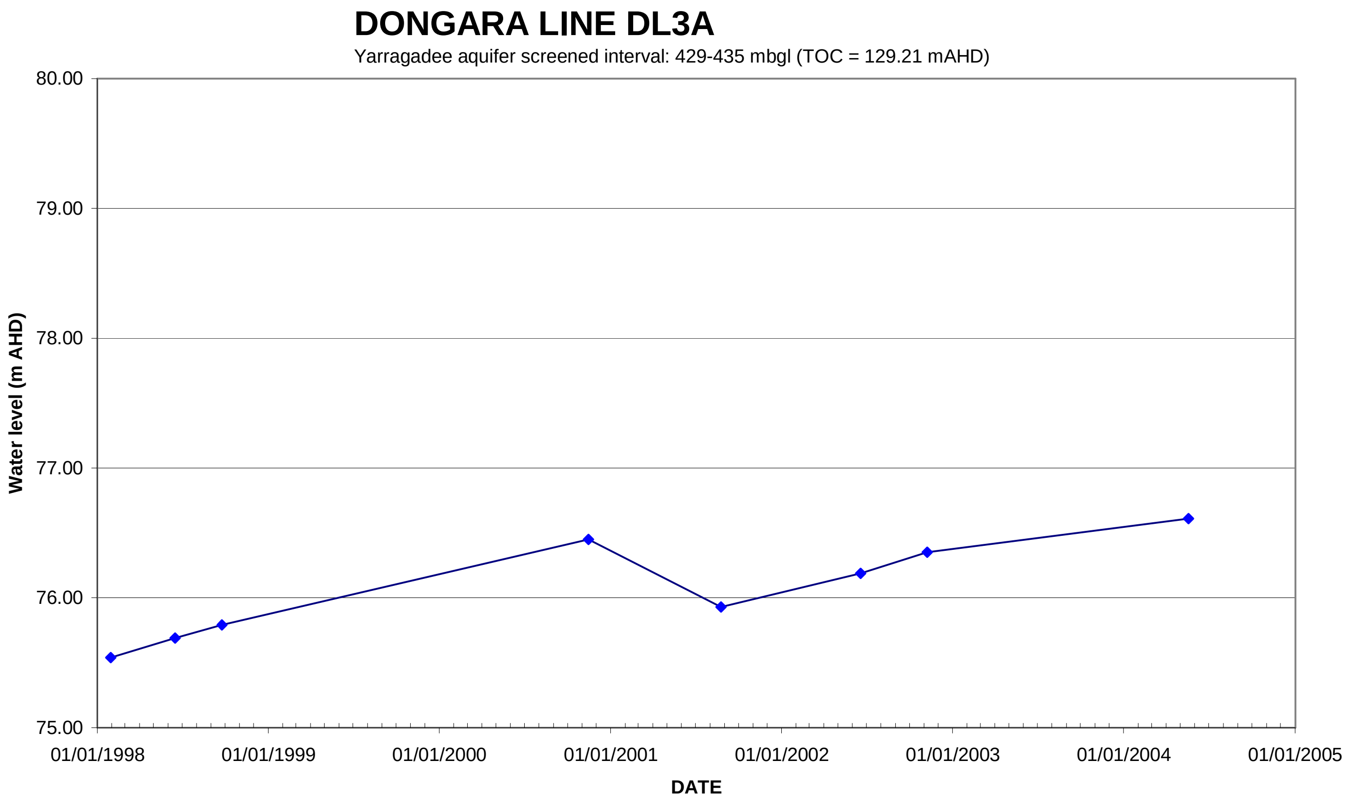
Appendix A — Groundwater monitoring: bore hydrographs


DONGARA LINE DL1W
Yarragadee aquifer screened interval: 43-49 mbgl (TOC = 16.335 mAHD)
5.00
4.00
3.00
2.00
1.00
0.00
Water level (m AHD)
01/01/1998
01/01/1999
01/01/2000
01/01/2001
01/01/2002
01/01/2003
01/01/2004
01/01/2005
DATE

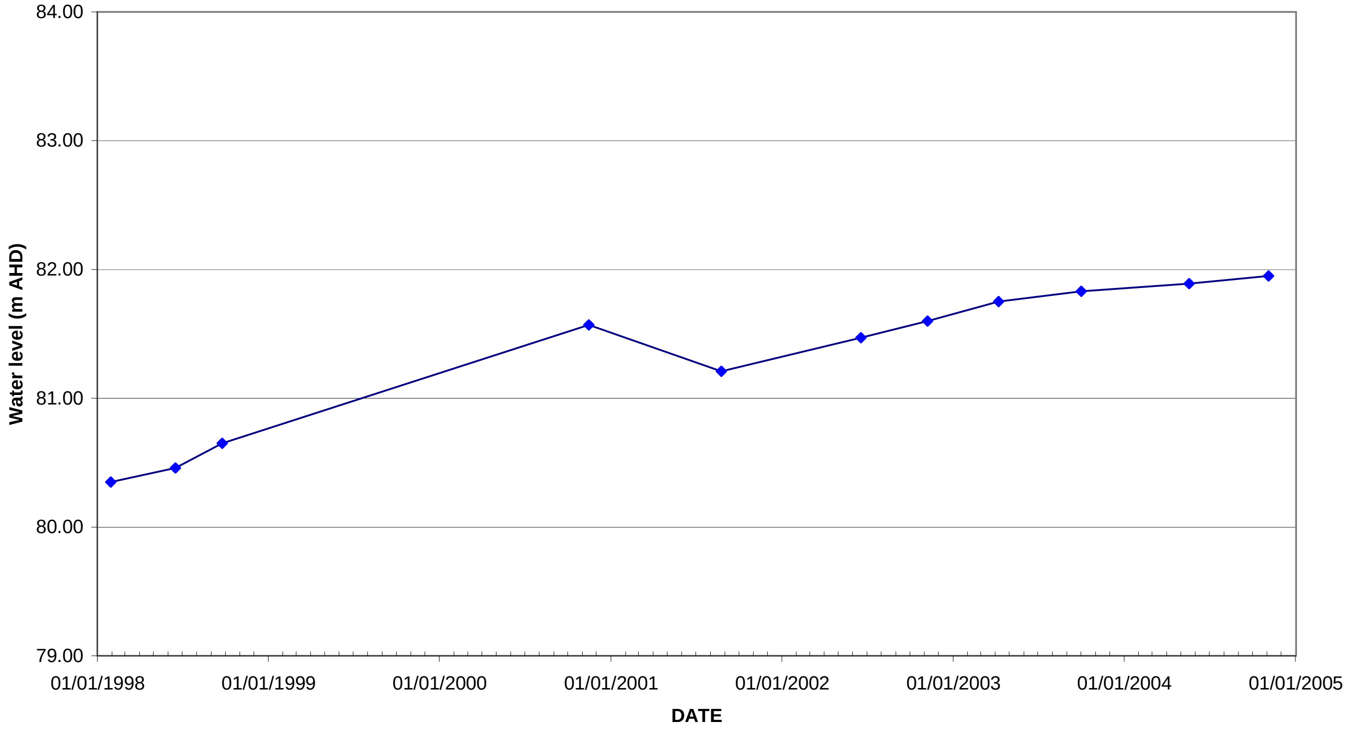

DONGARA LINE DL2A
Yarragadee aquifer screened inverval 421-427 mbgl (TOC = 85.48mAHD)
50.00
49.00
48.00
47.00
46.00
45.00
Water level (m AHD)
01/01/1997
01/01/1998
01/01/1999
01/01/2000
01/01/2001
01/01/2002
01/01/2003
01/01/2004
01/01/2005
DATE


DONGARA LINE DL2W
Yarragadee aquifer screened interval: 63-69 mbgl (TOC = 85.16 mAHD)
55.00
54.00
53.00
52.00
51.00
50.00
Water level (m AHD)
01/01/1997
01/01/1998
01/01/1999
01/01/2000
01/01/2001
01/01/2002
DATE


DONGARA LINE DL3A
Yarragadee aquifer screened interval: 429-435 mbgl (TOC = 129.21 mAHD)
80.00
79.00
78.00
77.00
76.00
75.00
Water level (m AHD)
01/01/1998
01/01/1999
01/01/2000
01/01/2001
01/01/2002
01/01/2003
01/01/2004
01/01/2005
DATE

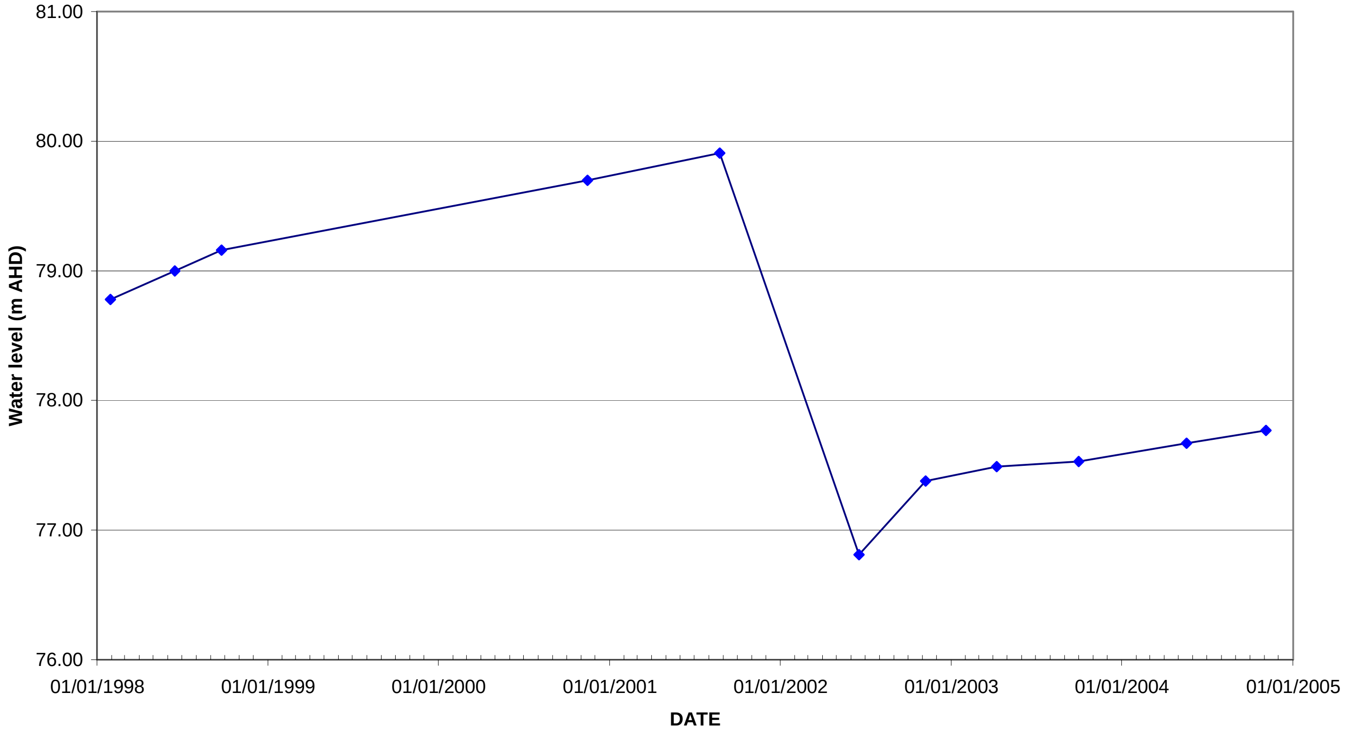
DONGARA LINE DL3W

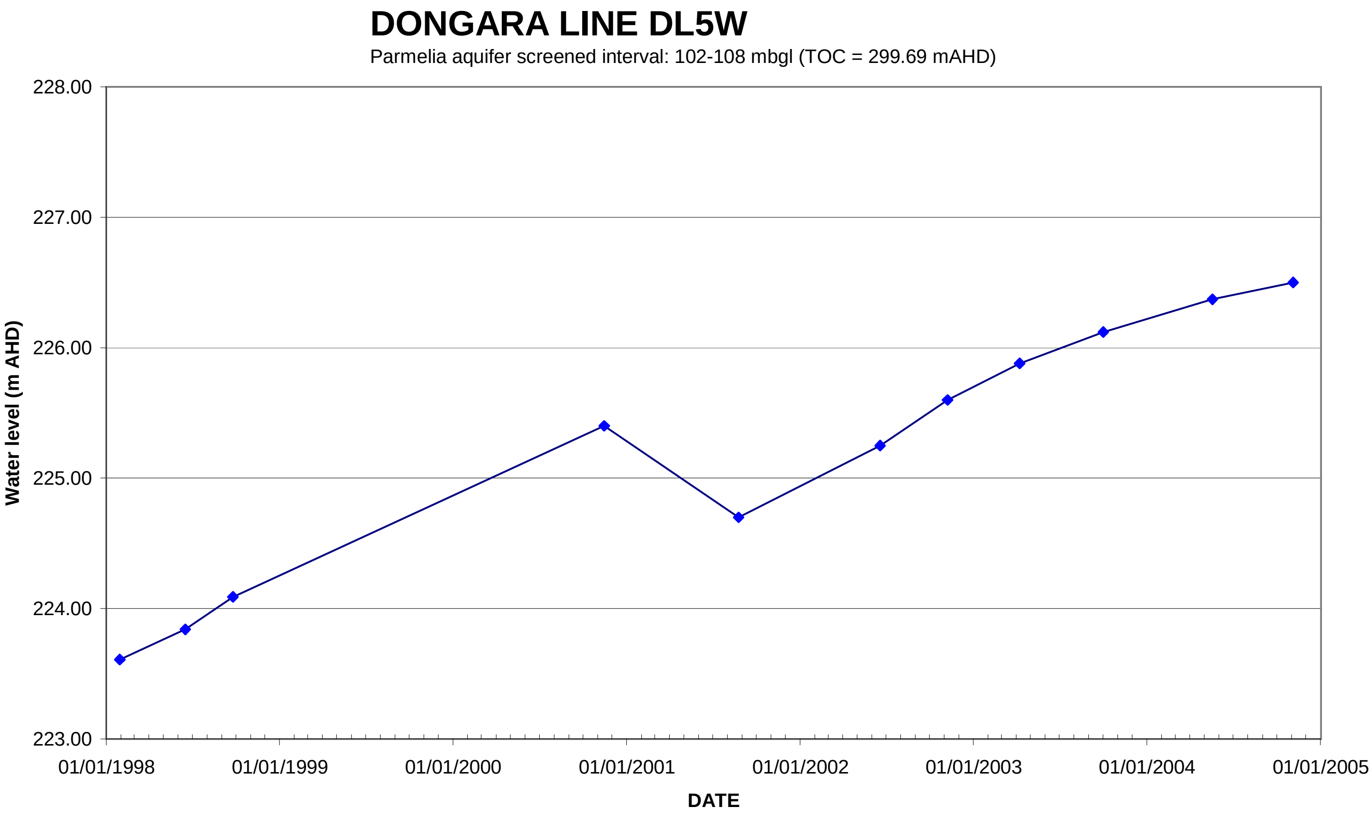
Yarrgadee aquifer screened interval: 103-109 mbgl (TOC = 129.13 mAHD)



DONGARA LINE DL4B

Yarragadee aquifer screened intverval: 459-465 mbgl (TOC = 258.3 mAHD)




DONGARA LINE DL5W
Parmelia aquifer screened interval: 102-108 mbgl (TOC = 299.69 mAHD)
Water level (m AHD)
228.00
227.00
226.00
225.00
224.00
223.00
01/01/1998
01/01/1999
01/01/2000
01/01/2001
01/01/2002
01/01/2003
01/01/2004
01/01/2005
DATE

Contributors

This report, prepared by Rochelle Irwin of the Water Resource Management Division in the Department of Water, is based on a previous groundwater investigation undertaken by the Geological Survey of Western Australia in 1990 and 1995. The original data was compiled in an unpublished Geological Survey of Western Australia report (HR1995/44) by Lara Groves in 1995. Seth Johnson, Alex Kern and Philip Commander from Water Resource Management Division provided valuable input and edited this document.