GOVERNMENT OF WESTERN AUSTRALIA

Hydrogeology of the Newdegate 1:250 000 Sheet

Hydrogeological Map Explanatory Notes Series

Water & Rivers Commission Report HM 5
1999

Water and Rivers Commission

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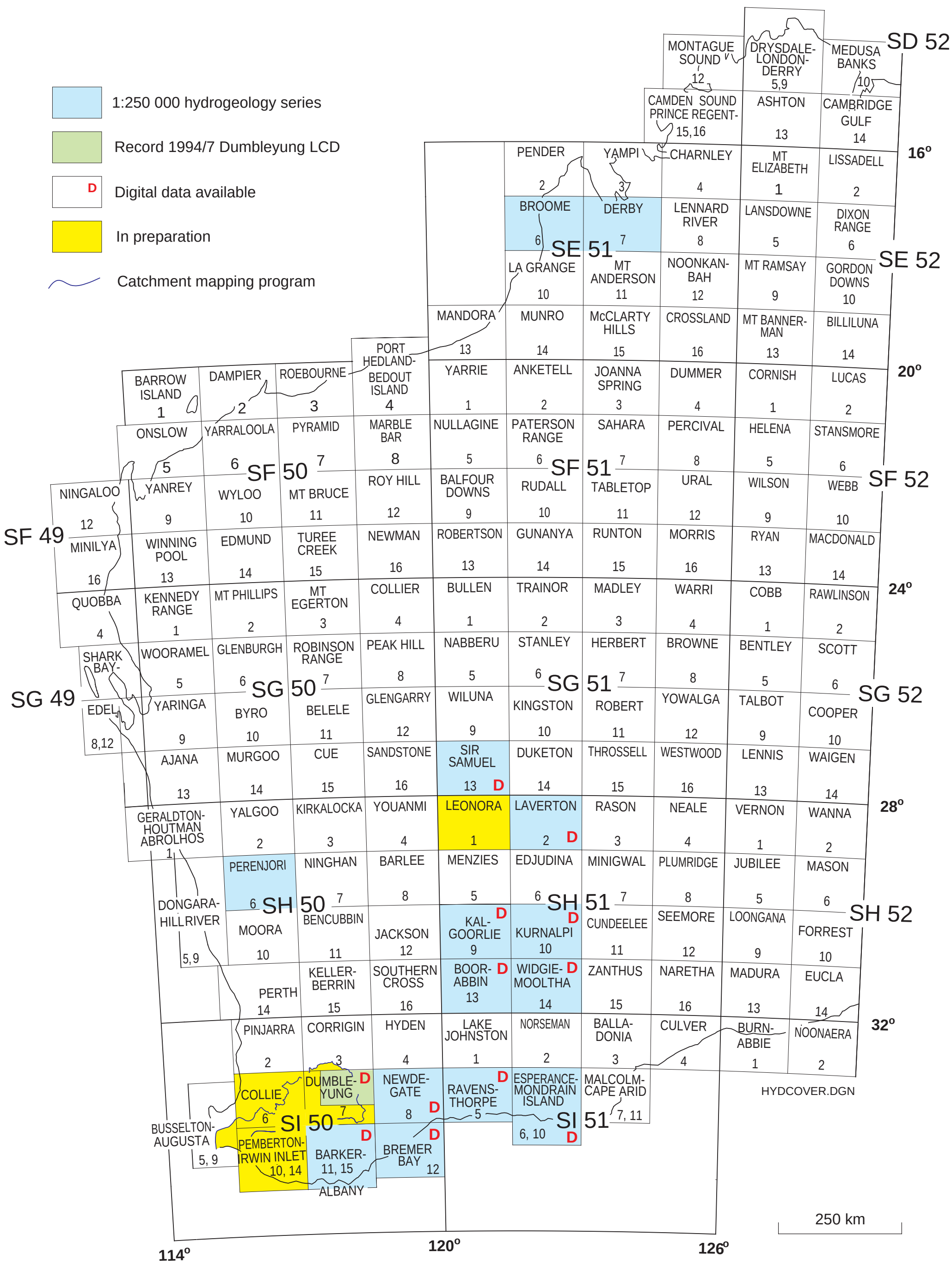

Cover Photograph: Native Pigface (Carpobrutus virescens) adorns the sandplain near a salt lake, Old Ravensthorpe Road

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by

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Resource Investigation Division

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Contents

Figures

Tables

Map

Appendix

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Abstract

The NEWDEGATE 1:250 000 hydrogeological sheet covers the southern corner of the Yilgarn–Southwest Groundwater Province, a small fraction of the Albany–Fraser Groundwater Province, and part of the Bremer Basin. Groundwater in the NEWDEGATE sheet area occurs in weathered and fractured granitoid and greenstone rocks, in weathered, fractured and fissured metasedimentary rocks of Proterozoic age, in Tertiary sedimentary rocks, and in Late Tertiary–Quaternary surficial sediments.

The weathered and fractured rocks occupy approximately 90% of NEWDEGATE but contain only minor groundwater supplies that are difficult to locate. Groundwater also occurs within Tertiary sedimentary rocks in the southern corner of the Fitzgerald River National Park and, elsewhere, in discrete palaeochannels. The Werillup Formation, and the basal sand within the palaeochannels, contain significant volumes of saline groundwater.

Potable groundwater is limited to isolated quartz-rich grit zones of the weathered profile adjacent to large granitic monadnocks, and to thin lenses in very localised sandy surficial sediments. Most of the groundwater on the remainder of the sheet is saline, with only very minor resources suitable for watering stock. The lowest salinity groundwater is located in upper catchment areas of valley slopes, where direct rainfall infiltration first intersects the regional watertable.

Towns within the sheet area rely on bitumen catchments that direct surface water to large dams. There are very few successful bores on NEWDEGATE and only a handful of bores suitable for watering stock. Stockwater supplies are also developed from soaks, or seasonal wet areas, by excavating dams or shallow wells, where fresh to brackish groundwater occurs at the watertable. Otherwise, the potential for groundwater development on NEWDEGATE is minimal.

Keywords: Hydrogeological maps, groundwater, aquifers, salinity, Newdegate, catchments.

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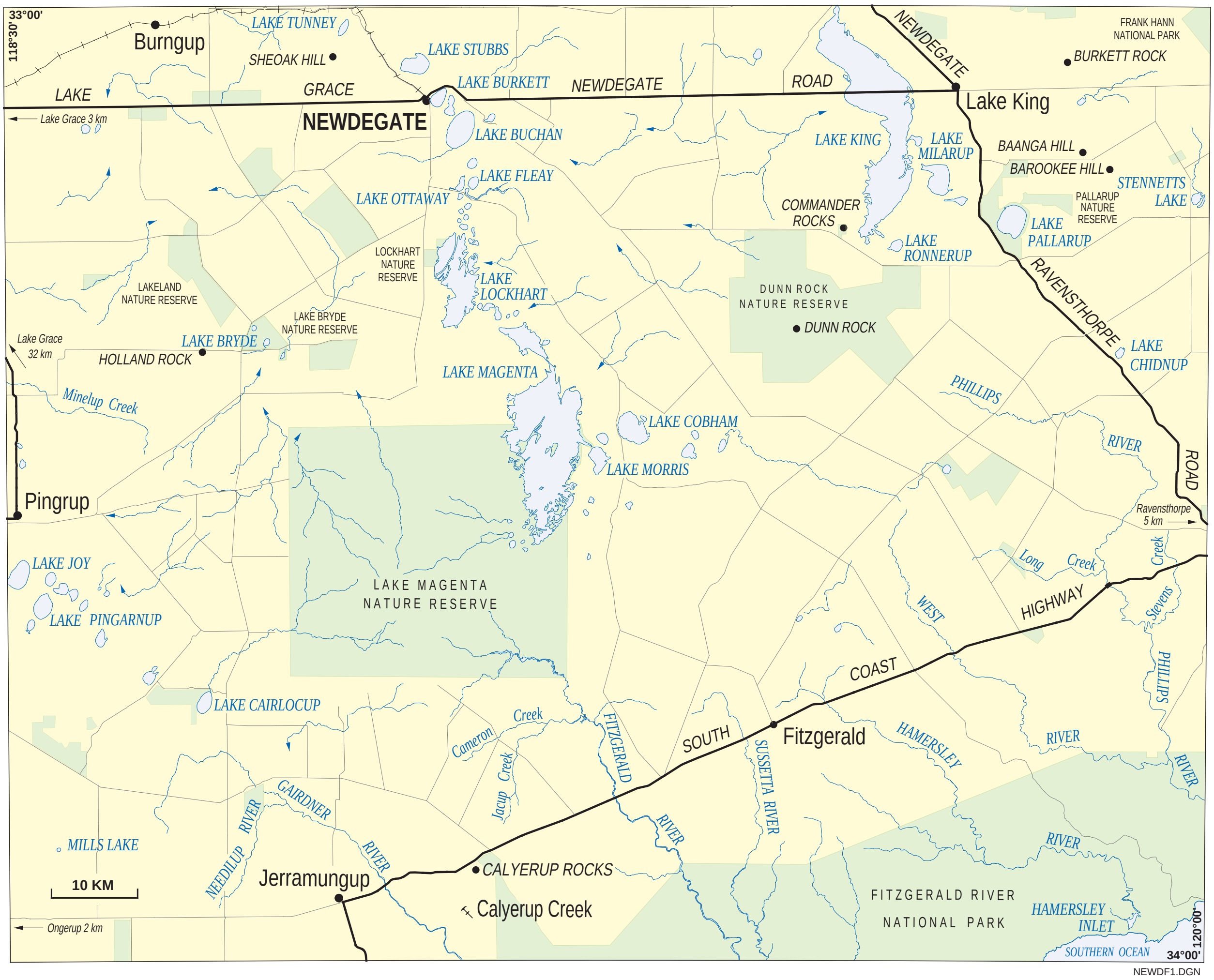

Figure 1. Location map

1. Introduction

1.1 Location and land use

The NEWDEGATE[1] 1:250 000 hydrogeological sheet (SI50-08 of the International Series), which is bounded by latitudes 33° 00' and 34° 00'S and longitudes 118° 30' and 120° 00'E, covers part of the southern Wheat Belt of Western Australia. The sheet is named after the small town of Newdegate, with a population of less than 200, approximately 400 km from Perth. Other towns on the sheet are Jerramungup, the largest, with a population of 450, Pingrup and Lake King. Sealed roads pass through Jerramungup in the south, Newdegate in the north, and Lake King in the northeast, but a network of gravel roads services most of the area (Fig. 1).

Land use in the area is generally rural, with sheep, wool and grains forming the main produce. A small freshwater crayfish industry also operates from farm dams in the southwest. Agriculture began in the area with Captain John Hassell, who was granted 20 000 acres of farming land in 1849 and who adopted the local aboriginal name for the area, 'Jarramongup'. In 1953, Jerramungup was developed as a war service settlement area. The Shire of Jerramungup, which covers most of NEWDEGATE, has a population of approximately 1500 people.

Jerramungup also caters for a seasonal influx of people visiting the Fitzgerald River National Park, where the main attractions are whale watching, fishing and wildflower tours.

1.2 Climate

The area has a semi-arid climate with warm to hot summers and cool winters. The average monthly maximum and minimum temperatures for Jerramungup are 24° and 10°C respectively.

Most rainfall occurs during the winter months and is associated with moist air in low-pressure systems passing over, or to the south of, the area. Average annual rainfall for Jerramungup is 472 mm, decreasing inland to 380 mm at Newdegate. Average annual rainfalls are lower and less reliable in the north of the sheet area.

The average annual pan evaporation for Jerramungup is approximately 1600 mm. The monthly pan evaporation exceeds the average monthly rainfall at Jerramungup for about 10 months of each year. Furthermore, the potential evaporation rate increases northwards across the sheet. At Newdegate the average annual pan evaporation is approximately 2100 mm. The monthly pan evaporation exceeds the average monthly rainfall at Newdegate all year round. Thus there is a general increase in aridity farther inland as rainfall decreases and the potential evaporation increases.

1.3 Physiography

The NEWDEGATE sheet generally comprises gently undulating topography, rising from approximately 300 m Australian Height Datum (AHD) in the south to nearly 400 m AHD in the north (Fig. 2). Granitic monadnocks separate long, north-northwesterly trending palaeo-valleys that contain large salt lakes, and the entire area is covered in parts by sandplain. The salt lakes are part of a broad, flat-lying drainage system that eventually links up with the Avon River. The southeast corner of NEWDEGATE, on the other hand, comprises rugged peaks of the northern Ravensthorpe Range and the peaks in the Fitzgerald River National Park, that are characterised by relatively greater relief. Mount Short (453 m AHD), the highest point on the sheet, is at the northern end of Ravensthorpe Range. Whoogarup Range and Annie Peak rise in excess of 300 m AHD near the coast. Between these peaks the Susetta and Hamersley Rivers have dissected a low-lying peneplain, leaving large mesas such as Roes Rock.

The major catchment divide, the South Coast watershed, separates NEWDEGATE into north-draining valleys and southeast-draining rivers. The watershed runs roughly along the Jarrahwood Axis, a structural hinge line created during Tertiary tectonism (Cope, 1975). This event partially reversed the course of the northward drainage system, leaving small lakes upstream, and rejuvenated the southeast-draining Gairdner, Fitzgerald, Hamersley, West and Phillips Rivers. The rejuvenated rivers have etched away the weathered profile and sandplain, exposing granite along the bottom of drainage lines and leaving remnant Tertiary sedimentary rock with laterite profiles exposed on the flanks of low hills.

[1] *Capitalised names refer to standard map sheets*

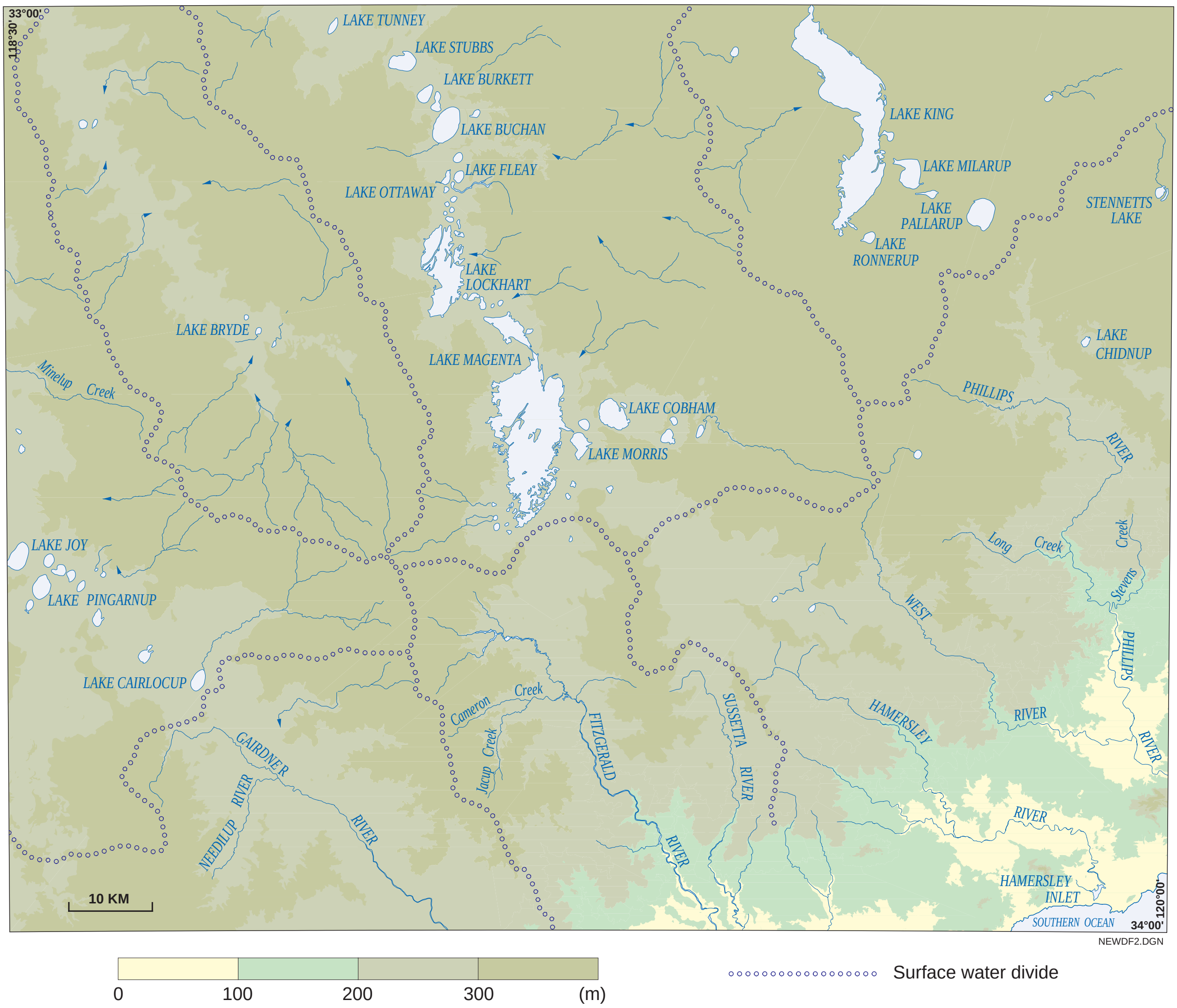

Figure 2. Topography

1.4 Vegetation

The vegetation of the Newdegate sheet has been divided by Beard (1976) into six main vegetation systems (Qualup System, Mount Barren System, Jerramungup System, Chidnup System, Hyden System, and Ravensthorpe Range System) and reflects the influence of climate, soils and geology. These vegetation systems are aligned approximately parallel to the southern coastline, except for the Mount Barren and Ravensthorpe Range Systems, which occur over specific geological terrane.

The coastal vegetation is part of the Qualup System and consists predominantly of mallee and mallee-heath. It covers dissected Tertiary sedimentary rocks between the peaks of the Fitzgerald River National Park south of the Ravensthorpe Range. Yate woodland and paperbark scrub could also be present in the swamps and small depressions that occur in the Tertiary rocks.

The Mount Barren System harbours a number of endemic eucalyptus species, and includes mallee heath, mallee and coastal scrub. This system occurs over the rocky outcrop surrounding the peaks of the Fitzgerald River National Park.

The Ravensthorpe Range System consists predominantly of *Eucalyptus nutans* and *E. gardneri* and is interspersed with woodland of salmon, yate and york gums over deep red soil with a higher water-holding capacity. This assemblage is unique to the Ravensthorpe Range on the comparatively rich soils derived from weathering of mainly mafic volcanic rocks.

The Jerramungup and Chidnup Systems consist of mallee and mallee heath dominated by *E. tetragona* and sporadic eucalypt woodland in valleys of the southward sloping hills of the Yilgarn Craton. The Hyden System occurs across the north of the sheet, where the mallee and mallee-heath consist of inland species of eucalypts, and the low-lying valleys change into salt-lake country containing a combination of eucalyptus woodland and halophytes.

North of the Fitzgerald River National Park much of NEWDEGATE has been cleared for agriculture, except for the area bounded by the Lake Magenta and the Dunn Rock Nature Reserves. Native vegetation survives in numerous small government reserves, road reserves, around some swamps, and in small remnant vegetation areas on private land.

1.5 Previous investigations

The earliest investigations into the geology of the NEWDEGATE sheet were concentrated on the volcanic rocks of the Cocanarup greenstones around Phillips River. Woodward (1909), Woodall (1955) and Sofoulis (1958) all described the occurrence of gold and base metal mineralisation in the area.

Regional geological reconnaissance began with Thom (1977) describing the Ravensthorpe Range, and later Thom and Chin (1984) providing the first geological map of the NEWDEGATE sheet. A description of the structural geology based on a synthesis of published and unpublished work was compiled by Myers (1990a,b, 1995). Witt (1996) carried out geological mapping of the COCANARUP 1:100 000 sheet area in the southeast of NEWDEGATE.

The Tertiary sedimentary rocks of the area were first recognised near Albany and named the Plantagenet Beds by Jutson and Simpson (1917). Clarke and Phillipps (1955) summarised the geology and depositional history of the Plantagenet Beds in the Fitzgerald River area. Cockbain (1968) and Cockbain and van de Graaff (1973) described lignite beds and the Tertiary sequence of the Bremer Basin in detail, and renamed them the Plantagenet Group. An overview of the Bremer Basin sedimentary rocks was presented by Hocking (1990).

A study of desert water supplies and gnamma holes in the Ongerup District, including the southwest corner of NEWDEGATE (Maclaren, 1912), is the earliest recorded groundwater investigation in this area. Drought conditions in 1969 prompted the Western Australian government to provide assistance in the search for groundwater supplies in thirteen areas (Lord, 1971) including the Lake Grace, Pingrup, Ongerup, and Ravensthorpe districts of NEWDEGATE. Information gained from the drought relief program of 1969 was a major contribution to the understanding of groundwater conditions in the district and was summarised by Davidson (1977). Laws (1982) produced a synthesis of the regional groundwater occurrence on the south coast from an interpretation of the results of drought-relief drilling.

Agriculture Western Australia (AgWA) have for some time been conducting investigations into soil and water salinity within the region. Groundwater investigations in relation to soil salinity were conducted in the Fitzgerald area by Henschke (1982), in the Jerramungup Shire by Martin (1992), and in the Mallee Road Catchment by Siewert and Abbott (1991). Ferdowsian and Ryder (1997) investigated the occurrence of fresh water at Mills Lake north of Ongerup, and the role of the underlying geology.

Additional hydrogeological data were obtained from unpublished reports on groundwater occurrence in local areas by the Geological Survey of Western Australia (GSWA). Recent waterlevel data were collated from AgWA reports on the rise of groundwater levels and its effect on land salinisation.

1.6 Map compilation

The NEWDEGATE hydrogeological sheet shows aquifer distribution and type, watertable level and topographic contours in metres AHD, groundwater salinity (isohalines), groundwater data point distribution, and cadastral data. The data used in compiling the map include: the topocadastre from AUSLIG 1:250 000 digital data and Department of Land Administration 1:50 000 series, geology from the GSWA ALBANY 1:1 000 000 (Myers, 1995), NEWDEGATE 1:250 000 (Thom and Chin, 1984), and COCANARUP 1:100 000 (Witt, 1996) sheets. The bore data were obtained from the Water and Rivers Commission (WRC) groundwater database (AQWABase), including data collated during a bore census conducted in 1996 by the Commission; from

AgWA bore and piezometer data collected during the Jerramungup Shire and Mallee Road Catchment drilling investigations (Agriculture Western Australia, 1990), and from WAMEX and WAPEX mineral and petroleum exploration drilling data and reports obtained from the Department of Minerals and Energy.

There were 830 water information points at the time of map compilation, of which 618 are either groundwater exploration holes subsequently abandoned, groundwater monitoring bores with casing, or groundwater bores currently in use. The other 212 water information points were of soaks, dams, lakes and coal exploration drilling with detailed geological logs. Of the 618 bores, 321 (or nearly 52%) were dry holes. Interpretation for the map sheet was carried out by using these point-source drilling data, including depth of penetration, screen interval, aquifer type, waterlevel and salinity measurements plotted over a base map of geology and topography. This system was used to interpret aquifer extent, watertable contours and groundwater isohalines by extrapolating boundaries and contours between point-source data. As the hydrogeological boundaries, watertable-level contours and groundwater isohalines are interpretative they are approximate. However, greater confidence in the interpretation can be applied to areas of greater bore density.

The NEWDEGATE hydrogeological map is, at 1:250 000 scale, a simplification of the available digital data, that were captured and stored as graphical layers of information at various scales. The data can be updated, and maps of catchments or specific areas reproduced at any scale for land and water resource management or planning.

2. Geology

2.1 Regional setting

The NEWDEGATE sheet is underlain almost entirely by the Yilgarn Craton, with a small corner in the southeast underlain by the Albany–Fraser Orogen. The Yilgarn Craton comprises mainly Archaean granitoid rocks, as well as greenstone rocks of the Ravensthorpe greenstone belt, with cross-cutting dolerite dykes associated with the Gnowangerup dyke swarm. The Albany–Fraser Orogen comprises Proterozoic metasedimentary rocks of the Mount Barren Group that were intruded by dolerite of the Cowerdup Sill and thrust over the Yilgarn Craton. The structural geology is summarised in Figure 3.

Cainozoic sedimentary rocks form a discontinuous, highly dissected cover over the Yilgarn Craton and Albany–Fraser Orogen. The Cainozoic sedimentary rocks include Tertiary rocks of the onshore Bremer Basin Plantagenet Group in the southeast, and lateral equivalents within the Avon River catchment in the north. The Plantagenet Group and equivalent sediments were deposited during the Middle to Late Eocene, filling the drainage system with sediment as the climate became drier (Hocking, 1990).

Extensive weathering, which began during the time of the Gondwanan super-plate separation (Twidale, 1994), and lateritisation after the breakup of Gondwana, have resulted in a deep laterite profile over the rocks of the Yilgarn Craton and Albany–Fraser Orogen. Erosion and reworking of the laterite profile and the Middle to Late Eocene sediments has resulted in the deposition of colluvial sediments within low valleys, further filling the drainage system in the north with sediment. Eolian and colluvial reworking of the colluvium has developed a thin sandplain that covers much of NEWDEGATE. Gypsiferous dune sand occurs adjacent to lacustrine sediments in playa lakes that overlie the in-filled palaeodrainage systems. Quaternary sediments comprising shelly sandstone and dune sand also outcrop along the coast in the southeast. The generalised stratigraphy of NEWDEGATE is given in Table 1.

2.2 Archaean

2.2.1 Yilgarn Craton granitoid

Granitoid rocks on the NEWDEGATE sheet comprise two distinct groups. Granitoid gneiss, which is compositionally banded and foliated, is the older rock type and occurs predominantly in the northwest of NEWDEGATE and along the western edge of the Ravensthorpe greenstone belt (Thom and Chin, 1984). The composition is generally that of a granodiorite, with local abundant mafic xenoliths entrained within banding, and medium to coarse grains. The other group is post-tectonic granitoid rock that consists mainly of medium- to coarse-grained monzogranite and granodiorite, with local compositional variations and porphyritic varieties (Witt, 1997).

The granitoid rocks are well exposed along the margins of broad valleys, as small monadnocks in the north of the sheet, or etched out along south-trending drainage. They appear massive in outcrop and their major structural trend is north-northwest.

The Manyutup Tonalite of the Ravensthorpe Terrane in the southeast of NEWDEGATE consists mostly of coarse-grained, equigranular granite with 5–15% ferromagnesian minerals (Witt, 1997). Local porphyritic tonalite occurs along the margins, as well as northwest-trending feldspar–quartz dykes. The Manyutup Tonalite also contains northeast-trending feldspar porphyry dykes. The Manyutup Tonalite is equivalent to the Ravensthorpe Quartzdiorite and is mapped as granite (Thom and Chin, 1984).

2.2.2 Ravensthorpe greenstone belt

The Ravensthorpe greenstone belt traverses the southeast of the NEWDEGATE sheet and consists of Archaean metasedimentary rocks, intermediate, mafic and ultramafic volcanic rocks assigned to the Cocanarup greenstone and the Annabelle Volcanics (Witt, 1997). Associated granitoid rocks of the Ravensthorpe Terrane are mapped with the Archaean granitiod rocks.

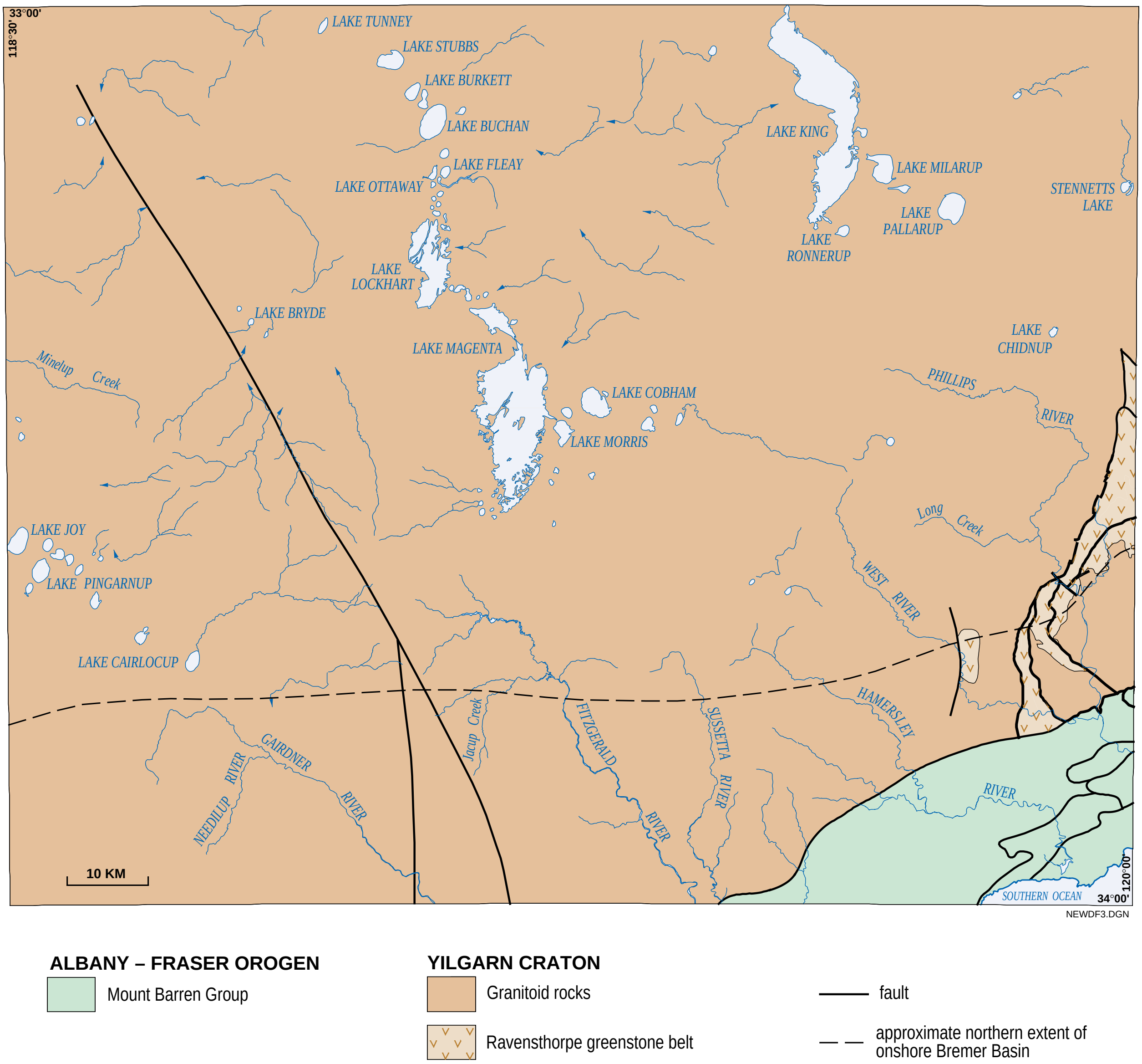

Figure 3. Geological structure

Isolated small enclaves of greenstone also lie within the Archaean granitoid rocks throughout NEWDEGATE. These consist of metasedimentary, mafic and ultramafic rocks and are probably relics of eroded greenstone terranes. Examples are at Calyerup Creek, west of Baanga Hill, and south of Burngup.

The Annabelle Volcanics consists of massive to coarsely bedded, metamorphosed mafic pyroclastic rocks. The rocks were originally fine-grained tuff (consolidated ash) to medium-grained volcanic fragments, later metamorphosed to amphibolite, schist and gneiss. The gneiss generally consists of quartz–plagioclase–amphibole and plagioclase–hornblende–quartz assemblages (Witt, 1997).

The Cocanarup greenstone consists mainly of psammitic (coarse grained) and pelitic (fine grained) metasedimentary rocks and minor ultramafic and mafic volcanic rocks. The greenstones are exposed in a north-northeasterly trending arc near West River in the southeast of the sheet (Witt, 1997).

The psammitic metasedimentary rocks consist of quartz–felspathic schists and minor quartzites, whereas

Table 1. Stratigraphy

	Age	*Formation*	*Max. thickness intersected (m)*		*Lithology*
CAINOZOIC	Late Tertiary—Quaternary	Alluvium *(Qa)*	12		Silt, clay and sand
		Coastal sediments *(Qs)*	~40		Shelly sandstone, dune sand
		Lacustrine sediment *(Ql)*	~23		Gypsiferous clay and silt, evaporite
		Colluvium and alluvium *(Cz)*	~25		Sandy clay, silt, clayey sand, calcrete, ferricrete
	~~	~~~~~*unconformity*~~~~~	~~~~~~~~~~~~~~		~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
	Tertiary— Eocene	**Plantagenet Group**	Bremer	Swan–Avon	
		Pallinup Siltstone *(TPp)*	60	~23	Siltstone, spongolite, minor sandstone, clay, sandy clay.
		Werillup Formation *(TPw)*	60	~34	Silt, sand, carbonaceous clay, lignite, conglomerate
PRECAMBRIAN	Proterozoic	Mafic dyke *(Pd)*	–		Dolerite
		~~*unconformity*~~~~~	~~~~~~~~~~~~~~		~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
		Mount Barren Group			
		Kundip Quartzite *(PBk)* (inc. Steere Formation)	~100		Quartzite, micaceous sandstone (quartzite breccia, dolomite)
		Kybulup Schist *(PBy)* (inc. Cowerdup Sill)	300		Schist, phyllite, shale (altered dolerite, quartz dolerite)
	Archaean	**Yilgarn Craton** *(Ag/An)*	–		Granite/gneiss, weathered
		Manyutup Tonalite *(Ag)*	–		Tonalite (granite)
		Ravensthorpe greenstone belt			
		Annabelle Volcanics *(Ab)*	–		Metamorphosed agglomerate and tuff, gneiss and amphibolite
		Cocanarup greenstone *(As, Ab)*	–		Metasediments, mafic and ultramafic, altered basalt and minor banded iron

Note: (–) thickness is not determined

the pelitic rocks consist of micaceous schists. The metasedimentary rocks are generally even bedded, with limited relict sedimentary structures. Conglomerates of coarser grained origin (>2 mm) have been metamorphosed to garnet-bearing paragneiss and banded gneiss (Witt, 1997). Thin, continuous beds of banded iron-formation and banded ferruginous cherts are associated with these rocks.

The mafic and ultramafic rocks outcrop in thin slices adjacent to the metasedimentary rocks, with ultramafic rocks consisting mainly of metamorphosed komatiite and basalt. The komatiite is metamorphosed to chlorite–tremolite and talc–serpentinite fine-grained schists. The mafic rocks are metamorphosed to amphibolite schist and medium-grained gneiss.

2.3 Proterozoic

The Proterozoic rocks on Newdegate are assigned to the Mount Barren Group of the Albany–Fraser Orogen and consist of the Kundip Quartzite, including the Steere Formation, and the Kybulup Schist, including the Cowerdup Sill (Thom and Chin, 1984).

Dolerite dykes of the Proterozoic Gnowangerup dyke swarm are most numerous in the southern third of Newdegate and they cut mainly Archaean granitoid rocks. The major trend is east-northeast, subparallel to the Albany–Fraser Orogen, with a minor northwest trend following the structural lineation within the Archaean granitoids. The dykes range from several metres to tens of metres in width and are from hundreds of metres to several kilometres in length.

2.3.1 Kundip Quartzite

The Kundip Quartzite consists of massive to coarse-bedded, grey to white quartzite in a siliceous matrix, and a minor quartzitic conglomerate. The quartzite trends in a northeasterly direction and dips between 10 and 30° to the south. It is generally bounded by low-angle thrust faults over the Kybulup Schist and is up to 100 m thick. The Kundip Quartzite outcrops as prominent topographic features such as Whoogarup Range and Eyre Range of the Fitzgerald River National Park in the southeastern corner of NEWDEGATE.

Included with the Kundip Quartzite is the Steere Formation, which consists of a basal conglomerate and dolomite up to 12 m thick (Witt, 1997). It is exposed beneath the Kundip Quartzite and outcrops locally along the Phillips River, south of Moir Road. The Steere Formation represents the contact between the Archaean basement and the Mount Barren Group; however, it is not laterally continuous. The conglomerate contains large clasts (100 mm) of rounded volcanic and quartzitic rocks in a recrystallised fine-grained quartzose matrix. The dolomite is massive to thinly bedded and brecciated (Witt, 1997).

2.3.2 Kybulup Schist

The Kybulup Schist consists of shale, phyllite, schist and minor sandstone. The schistose rocks are characterised by chlorite–quartz and muscovite–chlorite–quartz mineral assemblages. The Kybulup Schist is the dominant component of the Mount Barren Group and is poorly exposed as rubble outcrop within the Fitzgerald River National Park. The thickness of the unit is unknown owing to intense folding. The rock typically weathers to a micaceous clay with a well-preserved original texture (Dodson, 1997).

Included with the Kybulup Schist is the metamorphosed dolerite of the Cowerdup Sill, which is intruded between the Kybulup Schist and the Kundip Quartzite. The Cowerdup Sill is also found as rubble and outcrop between the peaks of the Kundip Quartzite. It is generally fine to medium grained with granophyre texture and is strongly altered to a quartz–feldspar–amphibole–chlorite mineral assemblage (Thom and Chin, 1984).

2.4 Cainozoic

2.4.1 Tertiary Plantagenet Group

Middle to Late Eocene sedimentary rocks of the Plantagenet Group south of the Jarrahwood Axis comprise basal sand and lacustrine clay that are overlain by shallow marine siltstone, claystone and spongolite. The Plantagenet Group is sub-divided into two formations, the Werillup Formation and the Pallinup Siltstone.

Within the Swan–Avon Palaeodrainage, north of the Jarrahwood Axis, Tertiary sedimentary rocks related to the Bremer Basin sequence, but lying outside the basin boundary, have not been formally named (Hocking, 1990). These sediments consist of similar basal fluvial sand overlain by lacustrine clay. Where exploratory drilling has intersected the basal sand or the Werillup Formation, a *TPw* label accompanies the bore symbol on the map.

2.4.1.1 Werillup Formation

The Werillup Formation, including the unnamed equivalents, consists of quartz sand with basal quartz-pebble conglomerate, and grey to brown unconsolidated, carbonaceous clay, silt and lignite. The basal sand lies unconformably over the Archaean bedrock with the coarsest sediment at the base of palaeochannels. The Werillup Formation contains palynomorph assemblages of Middle to Late Eocene age consistent with a continental fluvial environment of deposition grading to a lacustrine environment.

Within the onshore Bremer Basin, the Werillup Formation is known to exceed 60 m in thickness on BREMER BAY (Dodson, 1997). The Werillup Formation is conformably overlain by the Pallinup Siltstone and does not outcrop on NEWDEGATE. It is presumed to lie beneath the Pallinup Siltstone within the Fitzgerald River National Park, but has not been intersected by drilling in the area.

In the Swan–Avon Palaeodrainage, north of the Jarrahwood Axis near Lake King, the thickest recorded section of the basal sand and clay is 34 m (Muggeridge, 1982). The geological bore logs indicate that the basal sand is conformably overlain by lacustrine clay or, where the lacustrine clay is absent, unconformably overlain by

Late Tertiary–Quaternary colluvial valley-fill sediment or gypsiferous clay.

2.4.1.2 Pallinup Siltstone

The Pallinup Siltstone conformably overlies the Werillup Formation and outcrops as part of a relict peneplain in the southeast corner of NEWDEGATE. The Pallinup Siltstone consists of multicoloured siltstone, spongolite and minor sandstone. The dominant facies within the onshore Bremer Basin are grey to brown, silicified spongolite and red to brown claystone.

North of the Jarrahwood Axis the unnamed equivalent of the Pallinup Siltstone consists of blue grey, grey to pale brown and white clay, with minor medium to coarse quartz sandy clay interlayers (Muggeridge, 1982). It occurs mainly within palaeovalleys and is concealed by Late Tertiary–Quaternary sediments, but it may be found along the valley sides. Along the Jarrahwood Axis, in the east of the sheet, the siltstone has been stripped back or is completely absent (Muggeridge, 1982), as is the case near catchment divides within the Roe Palaeodrainage (Kern and Commander, 1993). The thicker recorded intersections are 23 m near Old Ravensthorpe Road, 2 km north of the intersection with Ardler Road (Panasiewicz et al., 1996), and 15 m in a lignite exploration drillhole between Lake Magenta and Lake Lockhart (Muggeridge, 1982).

2.4.2 Late Tertiary–Quaternary surficial sediments

Late Tertiary–Quaternary surficial sediments form a veneer over the Archaean and Tertiary rocks. Laterite and sandplain are widespread, with the laterite generally occurring as isolated plateaus of ferruginous duricrust above weathered basement or Plantagenet Group. Overlying and concealing the Plantagenet Group in part are pallid white to yellow clay and sandy clay of weathered colluvial valley-fill sediments. Sandplain occurs over approximately 60% of NEWDEGATE and overlies the valley-fill sediments, extending over low shallow basement hills separating palaeodrainages. The sandplain consists of yellow and white to grey fine- to coarse-grained quartz sand with gravel of limonite nodules.

Siliceous duricrust up to 3 m thick is common on the NEWDEGATE sheet. It generally forms within the weathered basement profile beneath laterite and is exposed where the laterite is eroded. Calcareous duricrust occurs adjacent to, or overlying, palaeovalleys within the weathered valley-fill sediments. Quartzose and gypsiferous eolian sand and silt deposits (dunes) up to 6 m high occur around playa lakes within palaeovalleys. Quaternary lacustrine sediments lie beneath the playa lakes and consist of saline and gypsiferous clay and silt deposits. The playa lakes conceal Tertiary sedimentary rocks or weathered basement and commonly abut resistant granitic outcrop. The thickness of the lacustrine deposits is uncertain; however, gypsiferous clay has been intersected at a depth of 23 m below Lake King in a lignite exploration drill hole (Muggeridge, 1982).

Quaternary sediments also exist in the coastal area of the southeastern corner of the NEWDEGATE sheet. They consist of quartzose and calcareous beach sand and unstable eolian dune sand overlying consolidated shelly sandstone (Thom and Chin, 1984). The most recent sediments in the NEWDEGATE sheet comprise alluvium deposits that occur in river terraces along the Susetta and Fitzgerald Rivers. These sediments consist of up to 12 m of unconsolidated, poorly sorted gravel, sand, silt and clay derived from the erosion of the Tertiary duricrust and basement rock (Cockbain and van de Graaff, 1973).

The total thickness of the Cainozoic surficial sediments is variable and is greatest within palaeodrainages where valley-fill colluvium overlies the Plantagenet Group. Investigation drilling for groundwater has intersected up to 27 m of unconsolidated, white to yellow clay and sandy clay in the valley north of Lake Bride on Ryans Road (Panasiewicz et al., 1996).

3. Hydrogeology

3.1 Groundwater occurrence

Groundwater occurs in thirteen major rock units, whose distribution is shown on the NEWDEGATE map sheet. A conceptual model of the hydrogeology is illustrated schematically in Figure 4 and in sections A–B and C–D on the map. In general, the rock types of NEWDEGATE are poor aquifers owing to the predominantly crystalline basement, relative thin saturated weathered profiles, and limited occurrence of permeable sedimentary rocks. The most significant aquifers are the Werillup Formation and basal sand of the Swan–Avon Palaeodrainage, although these aquifers contain mainly hypersaline groundwater.

Groundwater is contained in fractured and weathered Archaean granitoid and greenstone rocks, which underlie most of the NEWDEGATE sheet. Fissured and fractured metasedimentary rocks of the Mount Barren Group occur in the far southeast with groundwater contained within joints and fractures of the Kundip Quartzite and quartz veins and fractures of the Kybulup Schist. The hydrogeology of fractured, fissured and weathered basement rocks is generally complex with high yielding groundwater bores associated only with joints, fractures or sandy sections of the weathering profile.

Dolerite dykes within the Archaean granitoid–greenstone terrain exhibit major east-northeasterly and minor northwesterly trends across the NEWDEGATE sheet. They typically appear to lack fractures, and are more resistant to weathering than the granitoid rocks. When the dykes weather, they form relatively impermeable clay that can impede groundwater flow.

Sedimentary rocks of the Tertiary Plantagenet Group and its equivalents north of the Jarrahwood Axis are characterised by low permeability due to their silty and clayey nature. They occupy broad, flat depressions and locally lie within palaeochannels on the uneven basement palaeosurface. The Werillup Formation of the Bremer Basin and the basal sand of the Swan–Avon Palaeodrainage that lie within palaeochannels are of greater permeability than surrounding rock types and contain significant volumes of groundwater.

Late Tertiary–Quaternary colluvium and alluvium that overlie palaeochannels north of the Jarrahwood Axis are also characterised by low permeability, although sandy intervals with intergranular porosity form significant local aquifers. South of the Jarrahwood Axis, the Late Tertiary–Quaternary surficial sediments consist of alluvium and coastal sand which may be saturated only on a seasonal basis. These sedimentary rocks are generally thin (<10 m) and the potential for groundwater storage is small. However, the alluvium is significant as a source of groundwater for watering farm stock.

Small quantities of fresh groundwater exist within the NEWDEGATE Sandplain, particularly where sand overlies relatively impermeable basement or clay. The fresh water occurrence is both localised and seasonal, and the quantity of groundwater stored is dependent on land use. Owing to their localised nature, these small aquifers are not shown on NEWDEGATE.

3.2 Regional watertable

The regional watertable, the interface below which all pore space and fractures within rocks are saturated, is non-continuous on NEWDEGATE where granitoid rocks outcrop and where basement highs occur in the subsurface. The depth to the watertable is dependent on rock type, topography, and groundwater recharge and discharge. The regional watertable is depicted on the map sheet by contours that have been interpreted from historical and recent non-synoptic bore waterlevels, including monitoring piezometers.

Over most of NEWDEGATE the watertable forms a subdued image of the topography, and hence is very flat. The depth to groundwater is usually less than 5 m in low-lying areas, but may exceed 30 m on hills. For most of the Yilgarn–Southwest Groundwater Province of NEWDEGATE, the watertable ranges from a maximum of 340 m AHD in the northeast to 280 m AHD in the southwest. Groundwater may not occur in elevated areas where crystalline basement rocks extend above the regional watertable.

There are four distinct sub-parallel palaeovalleys depicted by lakes on NEWDEGATE, three of which abut the Jarrahwood Axis; these are Lake Grace north of

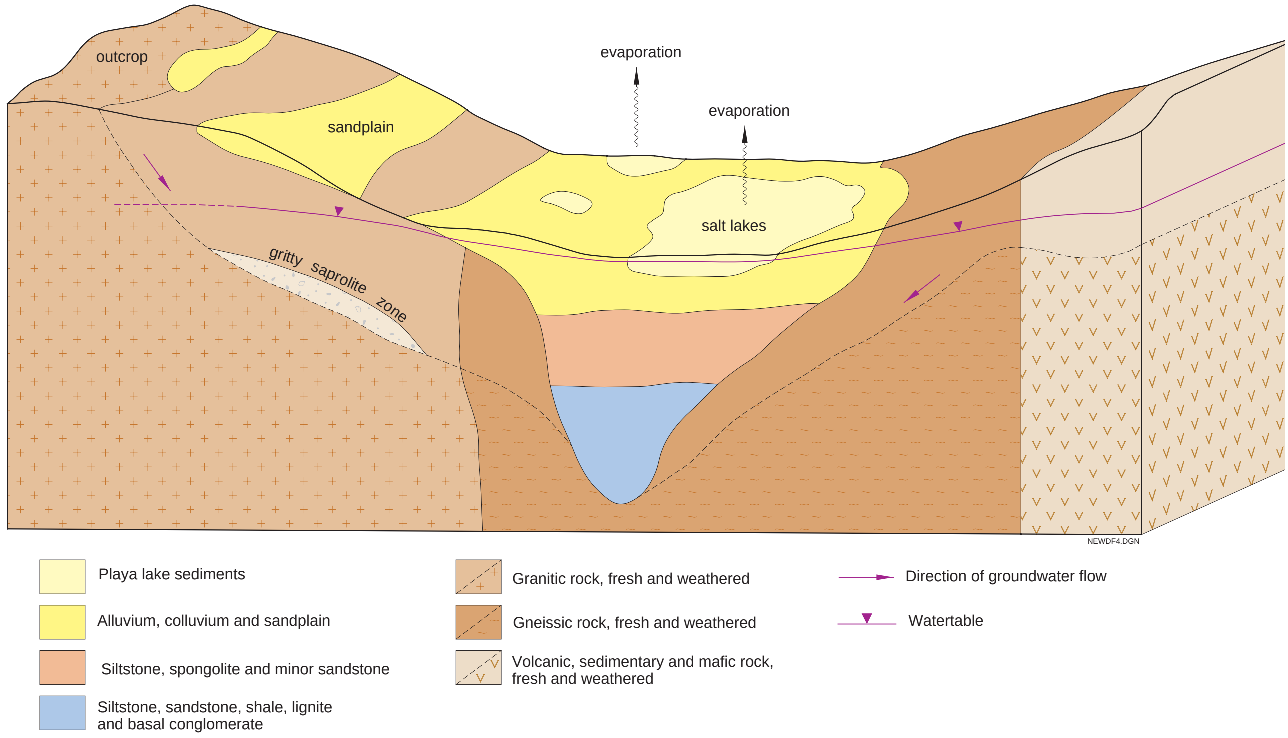

Figure 4. Block diagram showing groundwater occurrence

Ongerup, Lake Magenta, and Lake King. The watertable along the length of each palaeovalley is essentially flat, only a few metres deep, and fluctuates with the amount of rainfall and seasonal variation in evapotranspiration rates. However, there is a gradational west to east increase in watertable elevation at the Jarrahwood Axis between each palaeovalley. The watertable elevation in the palaeovalley north of Ongerup fluctuates around 285 m AHD, at Lake Magenta it is about 300 m AHD, and within the Lake King palaeovalley it is 310 m AHD. The impermeable basement rocks dividing the valleys make flow between them unlikely.

In the southeast, where the Tertiary Plantagenet Group of sediments outcrop, the watertable gradient becomes steeper towards incised drainage, such as the Hamersley and Susetta Rivers, and depths to groundwater are anticipated to be 20 m or greater. Over the Ravensthorpe greenstone belt and Mount Barren Group rocks the relief is far greater, and the watertable is poorly defined owing to a lack of data. Generally, the depth to the watertable will be greater in elevated areas.

3.3 Groundwater flow and discharge

In the southeastern portion of NEWDEGATE, groundwater flow is mostly southwards, discharging into the south-flowing rivers. This discharge commonly forms saline pools that may persist throughout the year. In the northern part of the sheet area, groundwater flow is towards the salt lakes lying in the palaeovalleys, where most discharge occurs. Groundwater flow to the north is likely to be small owing to the low hydraulic gradient (approximately 1m in 10 km).

Locally, groundwater flow is affected by basement topography, particularly around monadnocks of granitoid bedrock and subsurface granitoid highs, and by low-permeability weathered dolerite dykes.

3.4 Aquifers

3.4.1 Surficial aquifer *(Qa, Qs, Ql,* and *Cz)*

The surficial aquifer on NEWDEGATE consists of four Late Tertiary–Quaternary sediments that differ in characteristics and extent. They comprise recent alluvium, coastal sediments, lacustrine sediments and colluvium. Recharge to the surficial sediments is direct from infiltration of rainfall and indirect from surface runoff from adjacent basement or clay surfaces. In the North Stirling Soils Conservation District, Appleyard (1994) estimated recharge for cleared agricultural land at 3% of direct rainfall from the analysis of hydrographs. Extremely low hydraulic gradients (10^{-4}–10^{-5}), reflecting the low topographic relief of NEWDEGATE, indicate groundwater throughflow to be negligible. Groundwater discharge is mostly by evaporation from the extensive salt lakes.

The alluvium *(Qa)* lies along drainage channels. The aquifer is locally significant, particularly where soaks and wells have been sunk for stock water supplies, as along tributaries to the Gairdner River. Analysis of AQWABase records indicates that developed soaks typically yield less than 5 m^3/day. The salinity of water abstracted from the alluvium is commonly less than 1000 mg/L total dissolved solids (TDS), but rises with increasing time between river flows.

The coastal sediments *(Qs)* are in the immediate area surrounding the Hamersley Inlet of the Fitzgerald River National Park. Elsewhere, along the south coast from Albany to Esperance, the coastal sediments overlie, and are in hydraulic connection with, locally significant aquifers that provide water supplies for coastal settlements such as Albany (Smith, 1997), Bremer Bay (Dodson, 1997), Hopetoun and Esperance. The aquifer is moderately to highly permeable, although of very limited extent on NEWDEGATE.

Lacustrine sediments *(Ql)* lie within palaeovalleys beneath the salt lakes. They are intermittently saturated, because the regional watertable is close to the surface in playa lake environments. However, the lakes are usually dry for much of the year, being replenished only after heavy rainfall. The sediments are generally fine-grained gypsiferous clay and minor sandy clay, with bore yields likely to be low. They are not utilised for water supply on NEWDEGATE as the groundwater is generally hypersaline.

The colluvium *(Cz)* consists of reworked basement, laterite profile and Tertiary sediments, and also includes in situ duricrust such as calcrete, and the overlying NEWDEGATE sandplain. The aquifer is present mainly within the four tributaries of the Swan–Avon Palaeodrainage, as well as in several small internally drained catchments in the east. The aquifer matrix contains very fine- to coarse-grained material with varying degrees of induration (Panasiewicz et al., 1996). The maximum saturated thickness intersected is 25 m, near Ryans Road. Coarse sandy material, where present, such as at Ryans Road, is highly permeable, and airlift yields are in excess of 300 m^3/day (Panasiewicz et al., 1996).

Groundwater contained within the surficial aquifer is invariably saline to hypersaline. However, minor isolated fresh to brackish groundwater can occur at the regional watertable. Where the watertable is near surface or intersects the surface the area is called a soak, owing to the saturated soil. There are 132 records of soaks, some of which have been developed into dams. Roughly 70% have salinity lower than 3000 mg/L TDS and as such, they represent an important resource for watering stock (Fig. 5).

3.4.2 Tertiary aquifers *(Tpp* and *Tpw)*

The Middle to Late Eocene Plantagenet Group comprises the Pallinup Siltstone and Werillup Formation. The Pallinup Siltstone *(TPp)* is an unconfined to semi-confined aquifer of horizontally bedded spongolite and minor sandstone, occurring mainly in the southeast of the Fitzgerald River National Park on NEWDEGATE. Most of the Pallinup Siltstone is siltstone or claystone that does not yield groundwater. The fine-grained lithology and cementation of the spongolite and sandstone matrix generally results in low bore yields. In the north of BREMER BAY, where the drainage over large areas of the Pallinup Siltstone is internal, bore yields range from less than 5 to 40 m^3/day (Dodson, 1997). On NEWDEGATE the saturated thickness is reduced, owing to incision of the Hamersley, Twertup and Susetta Rivers, and bore yields are likely to be lower than on BREMER BAY.

Recharge to the aquifer is by rainfall infiltration and surface runoff from basement areas onto Pallinup Siltstone outcrops. Groundwater is discharged by evapotranspiration, slow vertical leakage to underlying aquifers where downward heads occur, and by throughflow to incised drainage where saline pools persist throughout the year in ephemeral rivers. Groundwater is saline, ranging from 3000 to 10 000 mg/L, with areas of lower salinity adjacent to basement outcrop.

Immediately north of the Jarrahwood Axis, the occurrence of the unnamed equivalent of the Pallinup

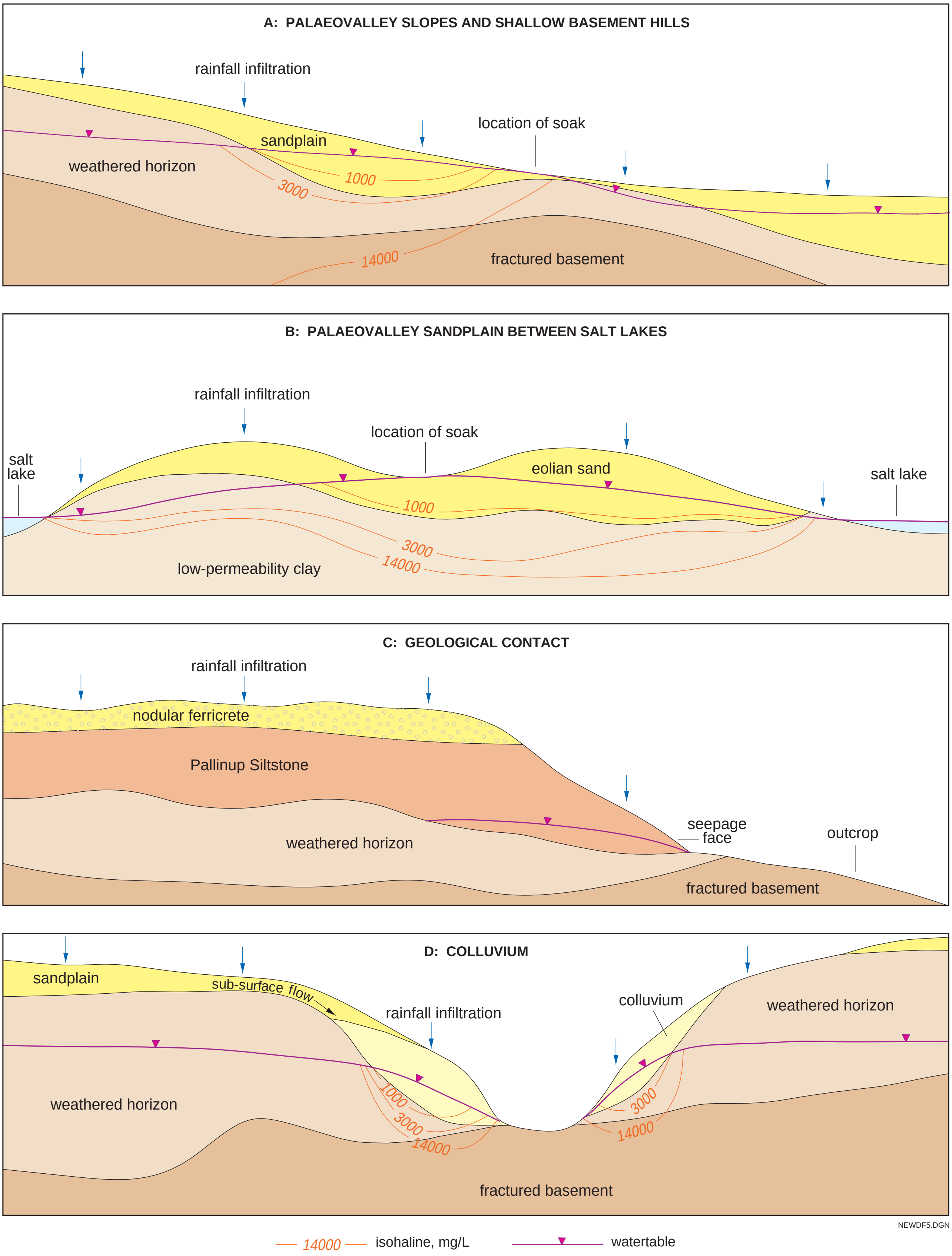

Figure 5. Schematic representation of the occurrence of freshwater soaks

Siltstone is restricted to palaeovalleys and is generally overlain by Late Tertiary–Quaternary colluvium. Geological logs from lignite exploration drilling indicate that the formation equivalent essentially contains clay (Muggeridge, 1982). The clay forms a confining bed over the basal palaeochannel sand and performs a role similar to that by the Perkolilli Shale of the Roe Palaeodrainage (Commander et al., 1992). Groundwater is generally saline to hypersaline owing to the low hydraulic gradient, low hydraulic conductivity and semi-arid climate.

The Werillup Formation *(TPw)*, and its unnamed equivalent north of the Jarrahwood Axis, is largely a confined, heterogeneous aquifer. The formation exists within discrete palaeochannels north of the Jarrahwood Axis and is inferred to be present beneath the Pallinup Siltstone in the southeast. The Werillup Formation comprises fluvial and lacustrine deposits with fine- to coarse-grained quartz sand overlain by clay and lignite. This unit has a variable thickness and thins at the margins of the palaeovalleys, although its extent is poorly defined. The similarity between the composition, mode of deposition and age of the Werillup Formation and of the Wollubar Sandstone of the Roe Palaeodrainage indicates that the hydraulic conductivities would be comparable; between 20 and 70 m/day reported by Commander et al. (1992).

Within the palaeovalleys, recharge to the aquifer is expected to be small, owing to the overlying confining bed of clay, and the semi-arid climate. Near the Jarrahwood Axis, at Lake Magenta, a thin layer of sandy surficial colluvium directly overlies the Werillup Formation where the Pallinup Siltstone has been eroded. Direct recharge to the Werillup Formation can take place only in these upper reaches of the palaeochannel where the confining clay is absent. Elsewhere, recharge will be from inflow from the surrounding bedrock aquifer and from vertical leakage through the confining layer where downward heads occur. (As a rule, recharge will be small as the aquifer is full and cannot drain because of the low hydraulic gradient.)

Groundwater in the Werillup Formation is commonly saline to hypersaline, although brackish groundwater may exist where the formation is near surface and unconfined, as near the Gairdner River Nature Reserve. The lower salinity is a result of local recharge through sandy surficial sediments and groundwater throughflow by discharge to the Gairdner River. Analysis of data from AQWABase indicates that very few bores are screened within, or intersect, the Werillup Formation and its unnamed equivalent, except for investigation and monitoring holes. The saline to hypersaline groundwater intersected within the formation has little use.

3.4.3 Mount Barren Group (*PBk* and *PBy)*

The Mount Barren Group lies within the Fitzgerald River National Park in the southeastern corner of NEWDEGATE and is composed of interbedded quartzose Steere Formation and Kundip Quartzite *(PBk)*, and the fine-grained Kybulup Schist and Cowerdup Sill dolerite *(PBy)*. The mapped boundaries on NEWDEGATE are based on the solid geology interpreted by Witt (1997). The quartzose rocks act as a fissured and fractured aquifer consisting mainly of fine- to coarse-grained quartz in a siliceous matrix, with well-defined jointing and fractures. The Kybulup Schist is characterised by fine-grained, metamorphosed fissile rocks and has a low permeability. The Cowerdup Sill is characterised by a fine- to medium-grained igneous texture that may have low permeability. The Kybulup Schist and Cowerdup Sill are also characterised by a weathering profile up to 15 m thick, and weather to clay (Panasiewicz et al., 1996).

Groundwater is present within joints and fractures of the quartzite and within the weathered profile and fractures of the Kybulup Schist and Cowerdup Sill. The quartzite beds are generally less than 100 m thick and are separated by several hundreds of metres of low-permeability schistose rock. Recharge occurs from direct rainfall infiltration and groundwater flows radially away from topographic highs. Groundwater probably discharges to overlying Tertiary sediments and by evapotranspiration.

Rocks of the Mount Barren Group are poorly explored on NEWDEGATE owing to their location within the National Park, but they may form local fractured aquifers. Bore yields and groundwater salinity can be inferred from nearby areas on RAVENSTHORPE, where bore yields within the Kundip Quartzite range from 10 to 50 m^3/day depending on fracture intensity (Johnson, 1998). Bore yields within the schist are highly variable, owing to the secondary porosity developed by fractures that enhance groundwater storage. Yields range from negligible to greater than 100 m^3/day on Bremer Bay (Dodson, 1997). Groundwater salinity within the Kundip

Quartzite ranges from 2600 to 6600 mg/L TDS on RAVENSTHORPE (Baddock, 1997), and from 2300 to 20 000 mg/L within the Kybulup Schist on BREMER BAY (Dodson, 1997).

3.4.4 Granitoid rocks *(Ag* and *An)*

The Archaean granitoid rocks *(Ag* and *An)* constitute nearly 90% of the underlying basement rock on NEWDEGATE, and include the Manyutup Tonalite of the Ravensthorpe Terrane. They are characterised by fine- to coarse-grained, acidic to mafic granular textured rocks (Witt, 1997; Thom and Chin, 1984). Granitoid rocks are exposed as topographically high monadnocks and lie adjacent to playa lakes within palaeovalleys. They are also etched out along south-trending drainages, such as the Gairdner River. The monadnocks are massive in outcrop, with minor foliation or jointing, and are generally impervious.

The granitoid rocks may also be deeply weathered to depths as much as 40 m. Small supplies of groundwater are commonly located within weathered granitoid rocks where quartz-rich grit exists at the base of the weathering profile, or within fractures of the uppermost 5 to 10 m of fresh rock. On much of NEWDEGATE, the weathering profile is unsaturated and 58% of bores within granitoid rocks are recorded as dry. Small supplies of groundwater are generally found only on the slopes leading to the palaeovalleys. Groundwater is recharged directly from rainfall and flows radially away from topographic highs towards lower lying areas, which are palaeovalleys north of the south coast watershed, or the incised drainages to the south. Groundwater levels are rising within the weathered basement profile below pasture and cereal crops at approximately 0.3 m/year in some instances (Martin, 1992), indicating that recharge is occurring at a rate greater than groundwater discharge. Groundwater discharges to overlying Tertiary sediments, or along valley slopes, or is removed through evapotranspiration. Bore data from AQWABase indicate that granitoid rocks on NEWDEGATE are low yielding, with yields ranging from negligible to 20 m^3/day.

Groundwater in areas underlain by granitoid rocks is typically saline to hypersaline. Analysis of AQWABase salinity data indicates that of 144 bores, only 18% contain groundwater less than 7000 mg/L TDS. This relatively low salinity groundwater characterises areas adjacent to large, bare rock-face, where surface runoff contributes recharge to permeable sand that is in connection with a deeper quartz-rich grit within the weathered profile, such as at Hollands Rock.

3.4.5. Mafic and ultramafic rocks *(Ab)*

The mafic and ultramafic rocks *(Ab)* are characterised by very fine-grained, either mafic igneous textures or fissile schistose rocks. The rocks are variably weathered to impermeable clay to depths of 40 m. However, fractures and joints in competent outcrop of low-grade metamorphic and undeformed basalt and komatiite have greater potential for groundwater storage within open fractures at depth.

The mafic and ultramafic rocks are poorly explored for groundwater on NEWDEGATE owing to their location within the Fitzgerald River National Park, the rugged terrain and high salinity. Johnson (1998) reported airlift bore yields of up to 105 m^3/day in fractured ultramafic rock in the greenstone belt on RAVENSTHORPE.

3.4.6. Metasedimentary rocks *(As)*

The metasedimentary rocks *(As)* from the Ravensthorpe greenstone belt comprise a complex succession of largely undivided, metamorphosed quartzose and micaceous schists adjacent to mafic and ultramafic rocks. The metasedimentary rocks are derived from quartz-rich siltstone, shales and minor sandstones and are generally deeply weathered to impermeable clay. Although the metasedimentary rocks are poorly explored on NEWDEGATE, they are considered very poor aquifers, due to their clay-rich weathering products. Bore yields are anticipated to be less than 5 m^3/day, and the groundwater is typically saline.

4. Groundwater quality

4.1 Regional groundwater salinity

The groundwater is predominantly saline to hypersaline, ranging from less than 1000 mg/L TDS in isolated areas of the surficial sediments, to more than 35 000 mg/L TDS in the Tertiary basal sand aquifer beneath the salt lakes. In general, groundwater salinity is greater north of the Jarrahwood Axis, owing to a combination of lower rainfall and higher evaporation. The distribution of groundwater salinity is represented on NEWDEGATE by isohalines in (mg/L TDS) that have been derived from non-synoptic borewater samples. The isohalines represent the groundwater salinity near the watertable as would be encountered by a pumping bore, below which the salinity may increase with depth.

Potable groundwater of salinity less than 1000 mg/L is very limited on NEWDEGATE, and is commonly restricted to areas of permeable sand where low-salinity groundwater may discharge into soaks (Fig. 5). The sandplain soaks are usually seasonal and may fail under extended drought conditions, or be affected by changes in land use. Potable groundwater may also be found where sandy surficial sediments at the base of monadnocks overlie quartz-rich grit in the weathered profile. Examples are the northeast face of Hollands Rock on NEWDEGATE, and Allens Rock and Marble Rock on HYDEN (Commander, 1980).

Low-salinity groundwater (1000–7000 mg/L TDS) is confined to the flanks of palaeovalleys within quartz-rich grit of the weathered basement rock, or to open fractures. Local variations in salinity within fractured rock aquifers occur where open fractures allow preferred groundwater flow. Low-salinity groundwater may also be located within the first few metres of the watertable within sandy surficial sediments; however, the salinity will increase dramatically with depth. Low-salinity groundwater is likely to be contained in the Pallinup Siltstone near the Hamersley and Susetta Rivers of the southeast. Facies changes from sand to clay within sedimentary rocks may affect groundwater salinity, particularly in the unconfined aquifers.

Groundwater salinity exceeds 7000 mg/L TDS within the surficial aquifer and the fractured-basement rock over the remainder of NEWDEGATE.

4.2 Hydrochemistry

The chemical analyses of groundwater samples from selected WRC bores, AgWA monitoring piezometers and private bores are given in Table 2. In most aquifer types, sodium and chloride are the most dominant ions in groundwater sampled on NEWDEGATE. The exception is in the coastal area of the southeast corner of the sheet, where groundwater may contain significant calcium and bicarbonate ions due to the dissolution of calcium carbonate in the Quaternary coastal sediments.

The source of sodium and chloride is cyclic salt carried by rainfall (Hingston and Gailitis, 1976). The accumulation of salt within the soil profile and groundwater is attributed to evapotranspiration, the native vegetation being capable of using all the infiltrated rainfall before clearing. Poor surface drainage, much of which is internal, and low hydraulic gradient result in salts being concentrated and retained in the groundwater.

The chemical analyses indicate that the groundwater is acidic, with a pH range from 3 to 7. The low-pH groundwater within the sedimentary aquifers is attributed to the reduction of sulphate by sulphate-reducing bacteria that act as a catalyst, resulting in the oxidation of organic matter producing carbon dioxide-charged acidic water. This results in the smell of hydrogen sulphide gas, which is a common by-product of the process. Nitrate levels are typically low, mostly below 10 mg/L, although the nitrate level in one sample was 140 mg/L, which indicates application of soil fertilisers as the likely source.

Table 2. Selected chemical analyses of groundwater

Bore /well	*Eastings/Northings*	*pH*	*EC (a) (mS/m at 25oC)*	*TDS (b)*	*Total Hardness (as CaCO3)*	*Ca*	*Mg*	*Na*	*K*	*HCO3*	*Cl*	*SO4*	*NO3*	*Fe+*
				(mg/L)										
Quaternary lacustrine clay														
Loc. 655	705694mE 6291558mN	4.4	73800	57200	8110	230	1800	18000	350	-	30000	3200	-	0.5
Cainozoic colluvium & alluvium														
J54	665232mE 6266491mN	6.7	41900	30300	5060	310	1000	8200	160	580	16000	1600	-	0.2
Loc. 995	710930mE 6291435mN	3.2	64200	48 900	5440	16	1300	15000	360	-	26000	2100	-	3
SCR50	669652mE 6302333mN	3.4	70300	54900	9590	280	2200	15000	130	-	28000	4000	-	2
SCR53	671434mE 6302162mN	3.3	66800	52900	9700	590	2000	15000	150	-	26000	3900	-	1
SCR57	662913mE 6307421mN	5.9	8230	5240	1040	9	250	1300	210	21	2500	290	-	-
Tertiary Werillup Formation														
J27	665682mE 6265718mN	7.0	47400	34500	6090	310	1300	9800	170	710	18000	1800	-	0.2
J108A	704969mE 6273154mN	6.8	62100	46300	6960	160	1600	14000	220	370	23000	3100	-	0.7
Archaean Granitoid (Ag, An)														
Loc. 916	702622mE 6335730mN	6.5	72500	23100	3450	52	810	6000	120	270	11000	1300	-	-
Loc. 574	660993mE 6326649mN	6.5	16600	10700	1490	59	330	3200	34	150	5400	780	140	-
Loc. 1596	751739mE 6334769mN	6.1	15400	9800	1040	24	240	2900	69	57	5000	640	-	-
SCR58	665500mE 6302650mN	6.8	20100	13100	1790	49	400	3800	52	110	6900	760	-	-

Notes: (a) EC=Electrical conductivity; (b) TDS=Total dissolved solids; - = not detected

5. Rising watertable and land salinisation

The clearing of native vegetation and replacement by annual crops and pastures for agricultural production has resulted in an imbalance in the natural groundwater flow system. The native vegetation once intercepted most of the rainfall before it reached the land surface. Furthermore, the annual crops and pasture collectively transpire less of the infiltrating rainfall than does the native perennial vegetation. The consequent increase in rainfall infiltration results in increased recharge and a rise in the watertable level.

The majority of NEWDEGATE soils are alkaline with high salt storage. Martin (1992) documented salt storage within the unsaturated zone for catchments in the south of NEWDEGATE. In general, the salt storage ranged from 90 to 140 t/ha for each metre to bedrock within the six catchments surveyed, all with diverse soil types. Martin (1992) reported that deeper weathered profiles have higher stored salt compared with shallow soils, but this is more a function of depth, than of higher average stored salt. Analysis of soil type from soil descriptions indicates that the highest average salt storage correlated with clay–loam of the pallid weathered profile, whereas lower salt storage corresponded with sandy loam of the NEWDEGATE sandplain over shallow basement.

As the watertable rises it mobilises salt stored within the soil profile, thereby increasing the salinity at the watertable. The rate of rise of the watertable in parts of NEWDEGATE is currently being monitored by a series of piezometer nests installed by the Albany Office of AgWA within the Jerramungup Land Conservation District. The monitoring network exists mainly within the Archaean weathered basement rock *(Ag* and *An)* and the surficial colluvium *(Cz).* Monitoring of waterlevels in piezometer nests indicates that groundwater is rising at rates as high as 0.3 m/year, with an average of 0.2 m/year since 1989 (Martin, 1992).

Rising saline groundwater is causing increasing salinisation of farm dams, and leads to increased discharge of saline groundwater into rivers and lakes. Land salinisation as a result of rising groundwater is particularly severe in the palaeovalleys, and in valleys with shallow basement and large catchment areas. Increased periods of inundation in low-lying areas have the potential to kill the native vegetation, as well as destroy inland lakes (such as Mills Lake) that formerly contained intermittent fresh water.

Reducing recharge or increasing discharge within a catchment area can halt the rate of rise of groundwater levels. Groundwater levels may also be lowered locally by groundwater abstraction, although most aquifers within NEWDEGATE have low permeabilities and are unsuitable for producing large volumes of water required to lower the watertable. Moreover, as is the case with draining waterlogged or salinised land, the disposal of saline water is a problem. Hence, a holistic approach to catchment planning, employing land-management techniques that intercept rainfall and use more direct rainfall infiltration through evapotranspiration over an entire catchment, is required to reduce recharge. Siewert and Abbot (1991) demonstrated in the Mallee Road Catchment area that effective management of the catchment as a whole, based on a knowledge of soil type and position in landscape, could not only increase crop yield but also reduce recharge to the watertable by increasing water use by crops. This, accompanied with the use of perennial pastures, the replanting of native vegetation or halophytes on salt-affected land, protection of existing native vegetation, and generally using techniques in agriculture production that utilise more rainfall (such as harvesting surface runoff to dams for use by stock), may reduce the rising salinity trend.

6. Groundwater development

6.1 Existing water supply

Groundwater development on the NEWDEGATE sheet is minimal, due mainly to very high salinity in the area. The towns of Jerramungup, Newdegate and Lake King utilise cleared, bituminised catchments that feed rainfall runoff to excavated or above-ground clay dams. Pingrup and Lake Grace (west of NEWDEGATE) are also supplied by bituminised catchments, although the supply can be augmented via the Great Southern Town Water Supply scheme from the Harris Dam near Collie.

Ongerup town water supply is also provided by bituminised catchment that feeds three excavated dams. Water supply has been augmented from the freshwater Mills Lake in times of drought, although this has not been necessary since 1994. However, rising saline groundwater now threatens the viability of Mills Lake to augment water supply for the town of Ongerup (Ferdowsian and Ryder, 1997). The location of new dams and expansion of existing dams for town water supplies is hampered by shallow bedrock and saline groundwater; thus, site selection for future dams is critical.

Roof-fed rainwater tanks provide potable on-farm water supplies, whereas supplies for stock are obtained from excavated dams where runoff is enhanced by drains or contour banks. Dam sites in low-lying palaeovalleys are at risk of intrusion from the rising saline watertable. Many dams are constructed at soak sites. However, where there is only a thin layer of low-salinity groundwater, rising saline groundwater may render the overall salinity unsuitable for stock (Fig. 5, A and B). There are very few bores on NEWDEGATE used for watering stock, and the drought-relief drilling program of 1996 failed to find any additional groundwater resources (Baddock et al., 1996).

6.2 Potential groundwater supply

The potential for groundwater supplies on NEWDEGATE is minimal. The aquifers are generally of low permeability and the groundwater is saline to hypersaline (Baddock, et al., 1995). The high salinity of the groundwater renders it generally unsuitable for stock consumption.

However, limited exploration for groundwater has encountered some stock water supplies. The most prospective sites for groundwater suitable for watering stock are adjacent to the runoff face of large granitic monadnocks with sandy sediments at their base. Recharge is concentrated at the base of the monadnocks and, where the sediments are of sufficient thickness, groundwater storage may be sufficient to provide small supplies of groundwater.

As most of the groundwater on NEWDEGATE is saline (>7000 mg/L TDS), groundwater of lower salinity may be present only near the margins of palaeovalleys within quartz-rich grit or fractures of the weathered basement rock, or within sandy intervals of the Cainozoic sediments in upper catchment areas. Depending on the size of the catchment area, exploration drilling should intersect the watertable at an elevation greater than the average watertable elevation at the catchment outlet. When a groundwater exploration bore is dry, drilling should be relocated down slope; if groundwater encountered is saline, drilling should proceed higher in the catchment. However, the uneven nature of the bedrock subsurface results in anomalies in the thickness of the weathered profile and, coupled with the heterogeneity of weathered-profile material, makes locating groundwater less than 7000 mg/L within a permeable aquifer difficult.

Within palaeovalleys the groundwater is invariably saline, and the only source of stock-quality groundwater is immediately below the watertable where there are permeable surficial sediments. Groundwater may be utilised by shallow, large-diameter wells or by developing soaks, although these are subject to variable supplies owing to the rise and fall of the watertable with wet and dry seasons. Furthermore, wells and excavated soaks are at risk from a rising saline watertable.

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Appendix

NEWDEGATE 1:250 000 hydrogeological series digital data reference files and documentation

Design file	*Level*	*On*	*Description*
Newdtopo.*dgn*	1		Highways,
			Roads
	2		Tracks
	4		Railway
	6		Landing ground
	7	OFF	Dams, tanks not shown on map
	11		Dams, tanks
			Pools
	15		Southern Ocean
	19		Submerged rocks
	20		Lakes intermittent, names
	21		Rivers, creeks, names
	22		Lakes, permanent
	24		DL stream
	27		Swamps
	30	OFF	Mining localities, mining centre names
	31	OFF	Mine symbols
	32	OFF	Mineral occurrence & symbols
	33	OFF	Mineral field boundary
	35		Topographic contours, values
	36		National parks, nature reserves
	41		Beaches, points, heads
			Destinations
	42		Road names, Highway names, Sidings
	43		Peaks/mountains/hills, Rocks, Ranges
	44		Control points:
			Major
			Minor
	45		Localities
	46		Towns:
			Population 100–1000
			Population <100
	50	OFF	Road names not shown on map
Newdgeo.*dgn*	1		Geological boundaries
	2		Outcrop boundary
	3		Ql boundaries
	5		Faults
	17		Dolerite dykes
	40		Geological labels & lead lines
	41		X-section lines & labels
	45		AGM Grid
	53		GIS, Poly labels

Design file	*Level*	*On*	*Description*
Newdgeo.*dgn* (cont.)	60		Ticks, text for lat & long grid
	62	OFF	Latitude & longitude grid
	63	OFF	Map border
Newdsal.*dgn*	1		Isohalines
	2		Isohalines, local aquifers
	45	OFF	AMG Grid
	60	OFF	Latitude & longitude grid
Newdgwc.*dgn*	1		40m contours & values
	2	OFF	60m contours & values
	3		80m contours & values
	4	OFF	100m contours & values
	5		120m contours & values
	6	OFF	140m contours & values
	7		160m contours & values
	8	OFF	180m contours & values
	9		200m contours & values
	10	OFF	220m contours & values
	11		240m contours & values
	12	OFF	260m contours & values
	13		280m contours & values
	14	OFF	300m contours & values
	15		320m contours & values
	16		Major Surface Water Divide
	17		Minor Surface Water Divide
	45	OFF	AMG grid
	60	OFF	Lat & Long grid
	63	OFF	Map border
Newdbore.*dgn*	1		Cased water bore, yield >50m^3/d
	2		Cased water bore, yield >50m^3/d, abandoned
	3		Cased water bore, yield <50m^3/d
	4		Uncased water bore, yield <50m^3/d, abandoned
	5		Cased water bore, <50m^3/d, abandoned
	6		Dry bore
	7		Abandoned lost or dry well
	8		Monitoring bores, piezometers
	9		Mineral exploration bores and geology
	10		Wells; >50m^3/d, <50m^3/d, dry
	12		Soaks, perched groundwater, seepage areas
	13		Natural springs
	14	OFF	Water samples from lakes, dams, perched lakes
	15	OFF	Water samples from rivers, creeks, pools
	30	OFF	Attributes to bores (ID, aquifers, depth, supply, TDS, WL)
	61	OFF	Coastline
	62	OFF	Latitude & longitude grid
	63	OFF	Map border

Design file	*Level*	*On*	*Description*
Newdply.*dgn*	1		*Qa*
	2		*Ql*
	3		*Qs*
	4		*Cz*
	5		*Tpp*
	6		*Tpw*
	7		*Tpp/Tpw*
	8		*Pd*
	9		*Pby*
	10		*Pbyo*
	11		*Pbk*
	12		*Pbko*
	13		*Ag*
	14		*Ago*
	15		*An*
	16		*Ano*
	17		*As*
	18		*Aso*
Newdply.*dgn*	19		*Ab*
	20		*Abo*
	25		*Tpp/Tpw* patterning
	41	OFF	Spare polygon
	62	OFF	Text IDs, GIS Labels
	63	OFF	Clean linework
Newpan.*dgn*	1		Linework for polygonisation
	2		Extent of weathering, section only
	3		Bore distribution – bores only
	4		Groundwater features – legend
	5		Surface water features – legend, coastline – graphs, blue linear features
	6		Isohalines – legend
	7		Topographic contour- legend
	8		Hidden linework for polygonisation
	40		Geological labels and lead lines
	42		Dolerite dyke – legend
	45		AMG grid; grey linear features
	46		Map border, WRC logo – water only
	47		WRC logo – leaves only (green)
	50		Gov logo – black outline
	53		Gov logo – white
	54		Gov logo – BLK 30%
	58		Gov logo – BLK
	59		Gov logo – BLK 80%
	60		Black text, labels
	63		GIS labels, text IDs for polygons

Design file	*Level*	*On*	*Description*
Panply.*dgn*	1		*Qa*
	2		*Ql*
	3		*Qs*
	4		*Cz*
	5		*Tpp*
	6		*Tpw*
	7		*Tpp/Tpw*
	8		*Pd*
	9		*Pby*
	10		*Pbyo*
	11		*Pbk*
	12		*Pbko*
	13		*Ag*
	14		*Ago*
	15		*An*
	16		*Ano*
	17		*As*
	18		*Aso*
	19		*Ab*
	20		*Abo*
	21		Landmass, yellow
	22		Salinity 0–3000
	23		Salinity 3000–7000
	24		Salinity 7000–14000
	25		Salintiy 14000–30000
	26		Salinity >30000
	27		Map border
	28		Depth to water table 0–5m
	29		Depth to water table 5–20m
	30		Depth to water table >20m