HYDROGEOLOGY OF THE MUIR-UNICUP CATCHMENTS

WATER AND RIVERS COMMISSION REPORT
SLUI 22
2003
SALINITY AND LAND USE IMPACTS

Water and Rivers
Commission

HYDROGEOLOGY OF THE MUIR–UNICUP CATCHMENTS

by
Robin Smith
Resource Science Division
Water and Rivers Commission

WATER AND RIVERS COMMISSION
SALINITY AND LAND USE IMPACTS REPORT SERIES
REPORT NO. SLUI 22
APRIL 2003

Acknowledgments

This report was prepared with assistance from Jayath de Silva, Roger Hearn, Margaret Smith, Peter Taylor, Peter Van De Wyngaard and Alex Waterhouse.

For more information contact:

Robin Smith
Resource Science Division

3 Plain Street
EAST PERTH
WESTERN AUSTRALIA 6004

Telephone (08) 9278 0522
Facsimile (08) 9278 0586

Recommended Reference

The recommended reference for this publication is: SMITH, RA 2003, Hydrogeology of the Muir–Unicup catchments, Western Australia, Water and Rivers Commission, Salinity and Land Use Impacts Series Report SLUI 22, 34p.

We welcome your feedback
A publication feedback form can be found at the back of this publication,
or online at www.wrc.wa.gov.au/public/feedback/

ISBN 1-920849-12-2
ISSN 1447-7394

April, 2003

Cover photograph:

Small bedrock outcrops in the southwest of Lake Muir, by

Roger Hearn

Contents

Appendices

Figures

Tables

Maps

Summary

The Lake Muir–Unicup Natural Diversity Recovery Catchment comprises many water bodies, including Lake Muir and Unicup Lake, occupying a broad flat largely internally draining landscape. Within the catchment sediments of the Bremer Basin overlie part of the Albany–Fraser Groundwater Province and a small part of the Yilgarn–Southwest Groundwater Province. The catchment contains surficial aquifers, sedimentary aquifers, and weathered and-or fractured rock aquifers.

Groundwater ranges from fresh to mainly saline, and increasingly discharges to lakes and wetlands within the catchment in response to clearing of native vegetation. Water and salinity levels in many lakes are also rising, both deteriorating the condition of the Nature Reserves and impacting on other land uses. Surface water provides most fresh water supplies in the catchment.

Understanding the diverse groundwater-lake interactions will assist in tackling salinity and other issues in the Lake Muir–Unicup Natural Diversity Recovery Catchment. Essential to this understanding is integration of observations on surface water and groundwater (particularly from the 2003 drilling) with information such as land use and vegetation history.

Keywords: hydrogeology, aquifers, salinity, groundwater resources, lakes, wetlands, Lake Muir, Unicup Lake

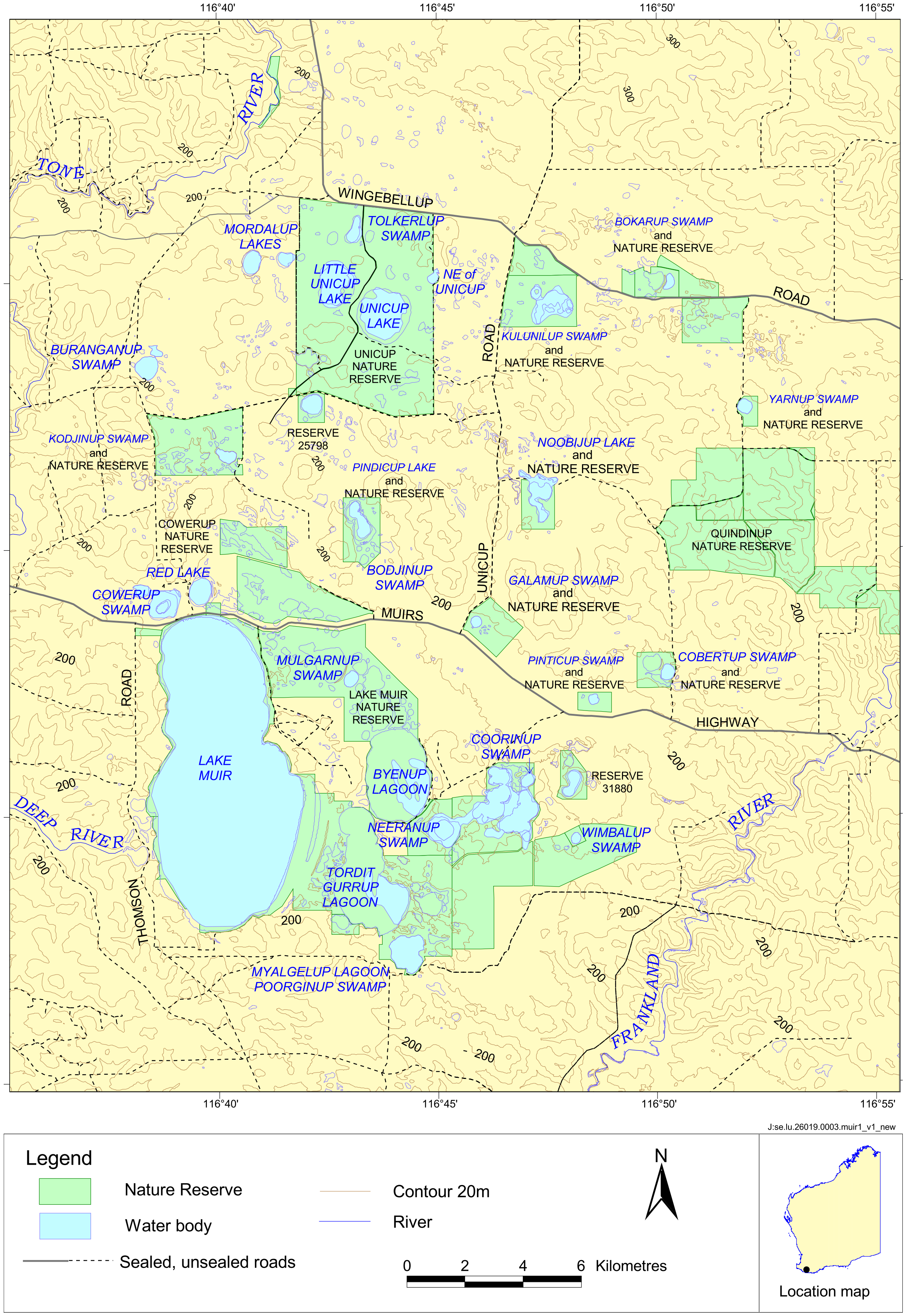


Figure 1. Location, relief, water bodies and nature reserves

1 Introduction

1.1 Location and land use

The Lake Muir–Unicup Natural Diversity Recovery Catchment (State Salinity Council 1998) is near the south coast of Western Australia, about 65 km southeast of Manjimup (Fig. 1). It is about 10 km south of Tonebridge, the nearest locality gazetted for a town, and 20 km northwest of Rocky Gully, the nearest town. The catchment is approximately 694 square kilometres in area and occupies about 70% of the area between about 463000–492000mE and 6173000–6209000mN, within MGA Zone 50 (based on GDA'94).

The catchment mainly drains internally and contains a complex of wetland systems with significant conservation values. The majority of the area is still under the natural vegetation, including karri, jarrah and marri forest, with much designated as State Forest and managed by CALM (Department of Conservation and Land Management). The catchment covers part of the CALM Manjimup District, in the Southern Forest Region. Good access is provided across the region by Muirs Highway as well as unsealed roads and farming, mining and forestry tracks.

1.2 Climate

The area has a Mediterranean-type climate with cool, wet winters and warm to hot, dry summers. Mean annual rainfall decreases northeast across the region from 900 to 700 mm and mean annual evaporation increases from 1300 to 1500 mm (Pen 1997).

1.3 Physiography

The Lake Muir–Unicup Natural Diversity Recovery Catchment shares imprecise boundaries with the south-flowing drainages of the Tone, Deep and Frankland rivers and does not have a delineated boundary (Fig. 2). It encompasses the surface water divide and 13 Nature Reserves managed by CALM (Map 1, Fig. 1 & Table 1 - Bokarup, Cobertup, Cowerup, Galamup, Kodjinup, Kulunilup, Lake Muir, Noobijup, Pindicup, Pinticup, Quindinup, Unicup, Yarnup). Cowerup and Quindinup Nature Reserves have no (mapped) wetland, Cowerup Swamp is not in Cowerup Nature Reserve (or any other reserve) and Buranganup is not in a Nature Reserve.

The catchment declines from about 290 m AHD (Australian Height Datum) on the Darling Plateau southward across the Ravensthorpe Ramp (Cope 1975) to about 190 m AHD and has a broadly undulating lateritic surface. The lowest elevations correspond to extensive alluvial and lacustrine broad valley flats that give rise to 15 informally named subcatchments (Fig. 2 & Table 1 – Buranganup, Byenup, Cobertup, Coorinup, Cowerup, De Campo, Lake Muir, Mordalup & South Mordalup, Noobijup, Pindicup & West Pindicup, Tordit-Gurrup, Unicup, Yarnup) that encompass a number of named localities and water bodies (Fig. 1).

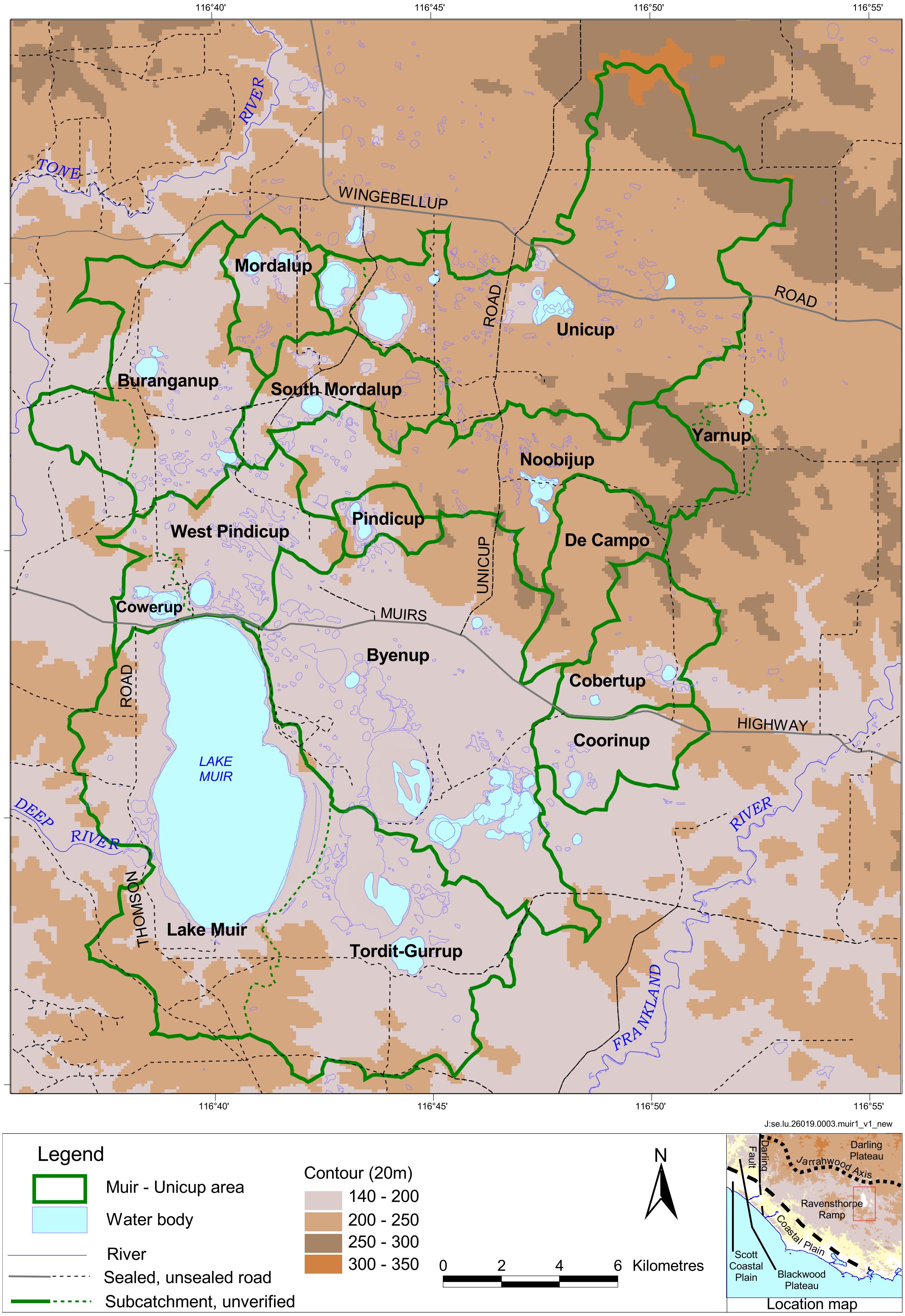


Figure 2. Physiographic divisions, topography and subcatchments

The broad flats have very low gradients and weakly developed, primarily local drainage. Farmers have constructed many shallow surface water (and possibly deeper, groundwater) drains on and near the flats (Map 1). These flats contain numerous lakes and swamps that belong to two large wetland systems, Lake Muir and Unicup, that together comprise about half the area shown in Figure 1. The surface water outlets of the Lake Muir-Unicup Natural Diversity Recovery Catchment comprise one to the Deep River from Lake Muir, two to the Tone River (northwest from Kulunilup Nature Reserve linked to Unicup Lake, and west from Kodjinup Nature Reserve), and two to the Frankland River (northeast from Yarnup Swamp assisted by constructed drains, and southeast from Poorginup Swamp along Poorginup Gully).

The Lake Muir wetland system, a large flat area of internal drainage, consists of approximately 370 square kilometres of small to very large permanent and intermittent lakes and swamps, and floodplains. Lake Muir is usually brackish (1000–3000 mg/L TDS) at the end of winter, saline by summer and dry throughout autumn. The lake, about 41 square kilometres in area, is the largest surface water body in the wetland. Other wetlands include Byenup Lagoon, Mulganup Swamp, Neeranup Swamp, Pindicup Lake, Red Lake, Tordit–Gurrup Lagoon but not Wimbalup Swamp (Table 1). Wimbalup Swamp, although part of the Lake Muir Nature Reserve, drains southeast to the Frankland River. Surface water is channelled into Lake Muir from the north and at Mulgarnup Bridge (Map 1). Although the Lake Muir subcatchment does not have well-developed surface drainage outlets, Lake Muir may, in flood, overflow southwest into the Deep River catchment (and possibly also southeast into the Frankland River via Poorginup Gully).

Unicup Lake is part of a second large wetland system covering about 173 square kilometres (97 of them upstream of Little Unicup Lake), comprising small to large permanent lakes, permanent and intermittent swamps, and floodplains. The Unicup subcatchment rarely discharges northwest into the Tone River (Pen 1997). Note that in addition to the water body names mentioned thus far Pen (1997) also names Tolkerlup Swamp in the Unicup wetlands and, in the Lake Muir wetlands, names Myalgelup Lagoon adjoining Poorginup Swamp (Table 1).

1.4 Vegetation

Vegetation across the catchment area has been mapped and described by Smith (1972) at 1:250 000 and refined by Beard (1981) at 1:100 000. At this regional scale the area is predominantly located within Beard's Kwornicup (generally poorly drained swampy plains) and Jingalup (generally lateritic uplands with dissected watercourses) vegetation systems. It comprises medium forest and woodlands of jarrah (Eucalyptus marginata), marri (Corymbia calophylla), yate (E. occidentalis), E. decipiens and wandoo (E. wandoo) in various combinations; low woodlands and closed forests of paperbarks (Melaleuca spp.), scrublands, teatree thickets (Melaleuca spp. and Kunzea spp.), sedgelands, reed swamps and fresh water and salt lakes.

Griffin (1984) and Gibson & Keighery (2000) undertook floristic surveys of the 13 Nature Reserves in the area, mapping more than 30 different structural vegetation units. Vegetation patterns were found to be complex mosaics with gradational changes. The complexity of vegetation patterns has been '… related to soil types, periods of inundation, quality and type of groundwater and fire history'. In all, about 1000 plant taxa have been recorded from the area, with about 30 of these considered rare or threatened.

Table 1. Wetlands and Nature Reserves in the Lake Muir–Unicup Natural Diversity Recovery Catchment

No.	*Water body/wetland (29 identified)*	*Subcatchment (15 informal)*	*Nature Reserve (13)*	*Direction from Unicup Rd-Muirs Hwy*	*Water quality (mg/L)*
1	Bodjinup Swamp	Byenup	Pindicup	nw	
2	Bokarup Swamp	Unicup	Bokarup	ne	1300–5400
3	Buranganup Swamp	Buranganup	nil	nw	
4	Byenup Lagoon	Byenup	L. Muir	ssw	1400–42000* 1000–4900
5	Cobertup Swamp	Cobertup	Cobertup	e	490–1200
6	No name 1 (kidney shaped, Res. 31880, Loc. 12561)	Coorinup	L. Muir	se	2000–28000
7	Coorinup Swamp	Byenup not Coorinup	L. Muir	se	
8	Cowerup Swamp	Cowerup	nil	wnw	
—	(nil)	De Campo	Quindinup	Ne	
9	Galamup Swamp	Byenup	Galamup	e	290–1100
10	Kodjinup Swamp (various)	Buranganup	Kodjinup	nw	1000–2900
11	Kulunilup Lake (also others S & W)	Unicup	Kulunilup	n	1800–2200 (others fresher)
12	Lake Muir	Lake Muir	Lake Muir	sw	720–96000*
13	Mordalup Lakes	Mordalup	Nil	nw	
14	No name 2 (Res. 25798, Loc. 12686)	South Mordalup	Unicup	nw	17000–23000
15	Mulgarnup Swamp	Byenup	L. Muir	w	1100–3100
16	Myalgelup Lagoon	Tordit-Gurrup	L. Muir	s	1600
17	Neeranup Swamp (includes Geordinup Swamp)	Byenup	L. Muir	s	was fresh, then 1300–4800
18	Noobijup Lake	Noobijup	Noobijup	ne	1300–1800
19	Pindicup Lake	Pindicup	Pindicup	nw	3600–6800
—	(nil)	West Pindicup	Cowerup	nw	
20	Pinticup Swamp	Cobertup	Pinticup	se	
21	Poorginup Swamp	Tordit-Gurrup	L. Muir	s	100–1500* 190–420
22	Red Lake	West Pindicup	nil	w	
23	Tolkerlup Swamp	North of Unicup	Unicup	nnw	
24	Tordit-Gurrup Lagoon	Tordit-Gurrup	L. Muir	ssw	650–15000* 1000–1300
25	Unicup Lake	Unicup	Unicup	nnw	650–42000* 3500–4900
26	& Little Unicup Lake	Unicup	Unicup	nnw	
27	No Name 3 (NE of Unicup)	Unicup	Unicup	nnw	650–1200
28	Wimbalup Swamp	(Frankland)	L. Muir	se	320
29	Yarnup Swamp	Yarnup (Frankland)	Yarnup	ne	540–2800* 1400–4500

* = long term monitoring by Lane (Hearn pers. comm.); other salinities from Storey (1998)

Soil, and hence vegetation, types are strongly controlled by the geology and climate with podzolic soils developing on acidic gneiss and red earths on basic gneiss. In the drier areas to the north of the region, gravelly lateritic soils are dominant and these soils tend to be underlain by pallid zone clays and deeply weathered horizons in which large amounts of soluble salts have accumulated (Steering Committee for Research of the Woodchip Industry 1980).

1.5 Previous investigations

An exploratory drilling program was carried out in 1997 (Panasiewicz et al. 1997) as a part of the compilation of the PEMBERTON–IRWIN INLET 1:250 000 Hydrogeological Map (De Silva 2000) and Explanatory Notes (De Silva 2003). This compilation forms the basis of this more focussed description of the hydrogeology of the Muir–Unicup catchments. Water point (bore) data used in compilation of the map were provided by the Water and Rivers Commission water point database (WIN) and bore census (Geste 1998), the Manjimup Office of the Department of Agriculture (including drilling for CALM) and the Department of Industry and Resources.

Earlier investigations also provided basic stratigraphic and groundwater information for the Muir–Unicup catchments:

- The determination of soluble salt in the Manjimup Woodchip Licence Area by Johnston et al. (1981) included 3 boreholes near Lake Muir.
- Dampier Mining Company Limited (1981) coal exploration drilling programs targeting Eocene sediments in Lake Muir provided stratigraphic information.
- Martin and Daetwyler (1980) and Martin (1982) considered the influence of hydrogeology on surface water quality in relation to peat mining and dryland salinity.
- Rockwater Pty Ltd (1986) assessed supply and quality of groundwater resources near Unicup Lake for potential horticultural development for the Department of Industrial Development.

V. & C. Semeniuk Research Group (1997) mapped and classified major wetlands in the Lake Muir–Unicup area. The styles and types of wetlands depend largely on climate, geology, geomorphology, hydrology and botanical provinces. Landforms and soils of the region were mapped and described by Churchward et al. (1988) and Churchward (1992).

Agraria–World Geoscience conducted an aerial geophysical survey covering the Lake Muir–Unicup catchments in 1998. This survey collected high-resolution magnetics and radiometric data that were interpreted to understand the hydrogeological process in catchments prone to land salinisation (Chakravartula and Street 2000).

An investigation-drilling program by CALM in 2003 will further define the aquifers, flow systems and water quality in the Muir–Unicup catchments (New 2003). This program will also examine the salt storage and acid sulfate soils (Smith 2003).

1.6 Purpose and scope

The Department of Conservation and Land Management as the lead agency is developing a management plan for the Lake Muir–Unicup Natural Diversity Recovery Catchment. The WRC (Water and Rivers Commission) is summarising, in this report, the expert advice provided on the geological setting, hydrogeological description, drilling and sampling, including the significance of acid sulfate soils (Smith 2003) for incorporation into the written management plan. Follow-up support will be provided, similar to that accessed by the community and inter-agency Warren Recovery Team, in evaluating the impact of hydrology on proposed management options for the Muir–Unicup catchments.

2 Geological setting

The geology is described in detail by Wilde and Walker (1984) and the tectonic history by Myers (1990a, 1990b). The stratigraphic sequence is presented in Table 2. The Muir–Unicup area is mostly located over the Proterozoic Albany–Fraser Orogen and extends onto the Archaean Yilgarn Craton only in the northeast (Fig. 3 & Map 2). The boundary between these two Precambrian rock units is marked by the Manjimup Fault. It continues west and joins the Darling Fault at the eastern edge of the Perth Basin (De Silva 2003). South of and parallel to this fault are the Pemberton and Northcliffe faults. The Northcliffe Fault divides the Albany–Fraser Orogen into the northern Biranup and southern Nornalup complexes. These major faults are associated with an east-west trending shear zone between the Yilgarn Craton and the Albany–Fraser Orogen (Muhling and Brakel 1985). Some of the faults may have been loci for brittle fracturing in the Tertiary in association with the separation of Australia from Antarctica (Chakravartula and Street 2000).

Archaean granite (Ag) of the extreme southwestern Yilgarn Craton forms the basement in the northeast of the Muir–Unicup area (Fig. 3). A minor rock type is dolerite (Ᵽd), intruded as the Gnowangerup dyke swarm with a pronounced easterly trend, but not deformed (Myers 1990b; Hawkes 1993).

In the Proterozoic Albany–Fraser Orogen the northerly Biranup Complex forms an intensely deformed metamorphic belt consisting of layered gneissic rocks. The BMR aeromagnetic map of ALBANY shows this complex is characterised by pronounced layering and high total magnetism (Myers 1995). Aeromagnetic maps also show that the rocks occur as steeply dipping tectonic slices, each 5 to 15 m thick. The southerly Nornalup Complex consists of granitic orthogneiss (*Ᵽ*n) and paragneiss (*Ᵽ*n) intruded elsewhere by a large volume of granite (Myers 1995). The gneisses (for full lithological descriptions refer to Wilde and Walker 1984) are less intensely deformed than the rocks of the Biranup Complex. Migmatites (*Ᵽ*m) also occur in association with Proterozoic granitic rocks. There is a general absence of mafic dykes in the Albany–Fraser Orogen that Wilde and Walker (1984) considered to be a real feature and not a function of rock exposure. However recent drilling indicates dykes are present and may be common (New 2003).

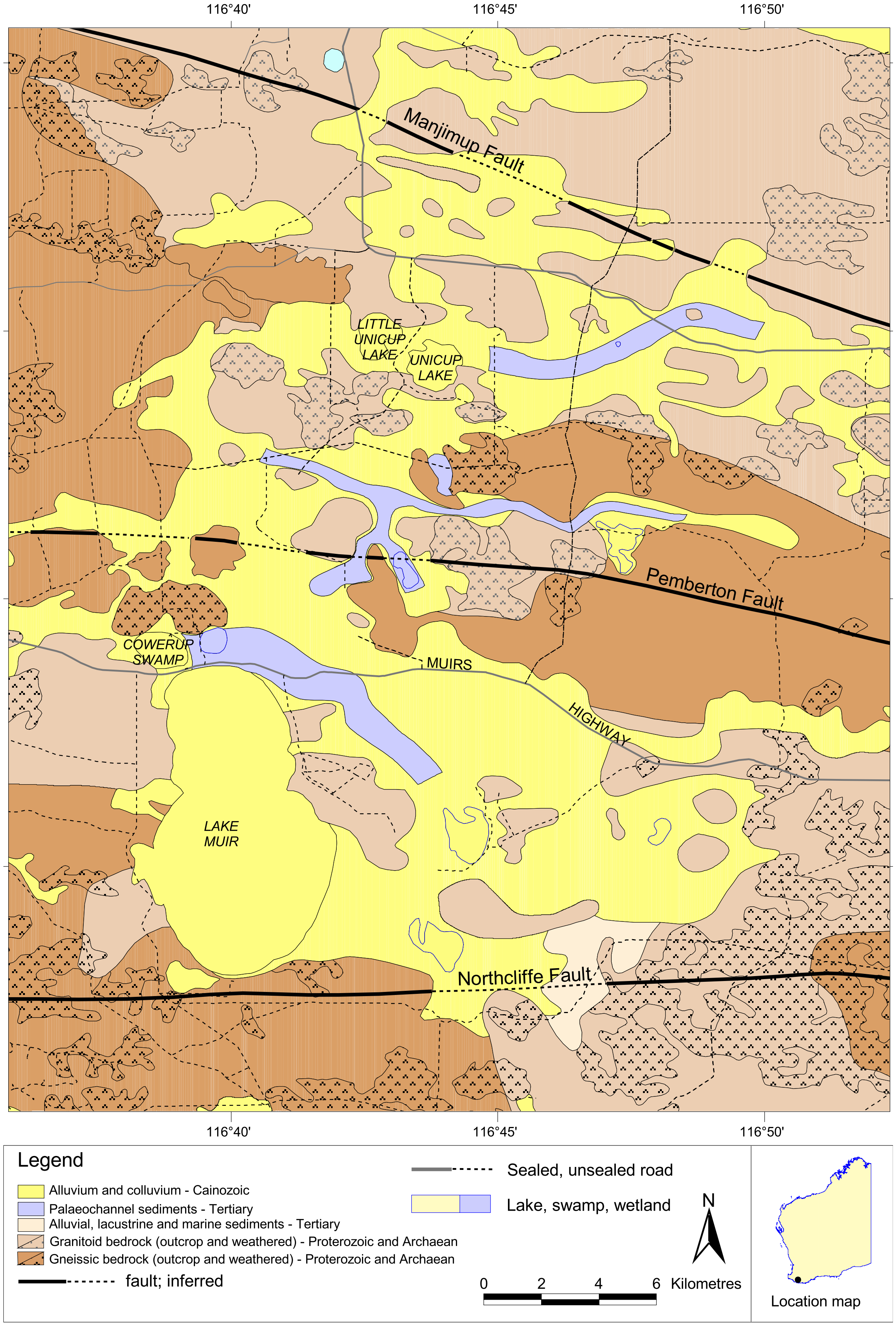
There are no Mesozoic sediments preserved in the Muir–Unicup area to correlate with the 6 km thick sequence of continental and fluviatile sandstones transported into the southern Perth Basin (Playford et al. 1976). The bedrock in the present Muir–Unicup area was not eroding sufficiently to have been a significant source of sediments both in the Mesozoic and as early as the Permian (glaciation).

Cainozoic sediments overlying the Precambrian basement rocks cover about half of the study area. Many of these are associated with WNW-trending palaeodrainages, active in the Jurassic–Cretaceous (213–65 million yeas ago (ma)), but possibly dating from the Permian (286–253 ma). The (palaeo)channels in the floors of these drainages were cut into bedrock but ceased activity by the Eocene (55 ma). They became clogged by mainly fluvial sediments (Werillup Formation) in the Late Eocene (42–<38 ma) prior to the Eocene marine transgression that extended the Bremer Basin sediments northward.

The transgression and ensuing regression may have been the result of both sea level changes related to global interruption of subduction and plate edge stretch, rebound and sag during separation from Antarctica. Late Tertiary (<38 ma) regression left widespread thin Tertiary sediments at up to 300 m AHD (Hocking 1990) and subsequent laterisation formed various geological units. Southward tilting of the Ravensthorpe Ramp, possibly as early as the Oligocene (Smith 1997) led to partial dissection by new relatively short, south-flowing drainages.

Table 2. Stratigraphy

Age	*Geological unit*	*Maximum thickness intersected (m)*	*Lithology*
Quaternary	Alluvial, & lacustrine sediments (Qa)		Sand, clay, silt and peat
	Alluvium and colluvium (Cza)	24 (in bore PM5)	Sand and clay
~~	~~~~~~~~~~~~~~~~~~~~~~~~	Unconformity	~~~~~~~~~~~~~~~~~~~~~~~~
Cainozoic Tertiary	Laterite (Czl)		Laterite over various older units
	Alluvial, lacustrine and shallow marine deposits (Tgc)		Clay, sand, grit and conglomerate
	Plantagenet Group		
	Pallinup Siltstone (TP*p*)	36 (in bore PM7)	Siltstone
	Werillup Formation (TP*w*)	65 (in bore LM7)	Sand, clay, gravel and peat
Mesozoic ~~~~~~~~	~~~~~~~~~~~~~~~~~~~~~~~~	Unconformity	~~~~~~~~~~~~~~~~~~~~~~~~
Precambrian	Mafic dykes (d)		Dolerite, gabbro
Undetermined	Quartz dykes and veins (q)		Quartz (not quartzite Aq)
Proterozoic	Albany – Fraser Orogen		
	Biranup Complex (Ᵽn)		Gneiss, quartzite, sandy clay
	Nornalup Complex (Ᵽn, Ᵽg, Ᵽm)		Gneiss, granite, migmatite, sandy clay
	Gnowangerup dyke swarm (Ᵽd)		Dolerite intruding Ag
Archaean	Yilgarn Craton (Ag)		Granite, sandy clay
	Quartzite (Aq)		Quartzite (not in catchment)



J:se.lu.26019.0003.muir1_v1_new

Figure 3. Hydrogeology

3 Hydrogeology

3.1 Groundwater occurrence

The three hydrogeological divisions recognised in the Muir–Unicup catchments are the hard rock Yilgarn–Southwest and Albany–Fraser provinces (Smith et al. 1999) with the sedimentary Bremer Basin overlying both. The hydrogeology (De Silva 2000) is reproduced in Map 2, with the projection transformed to MGA (GDA'94) coordinates, and depicted in Figure 3. Most of the units listed in Table 2 contain groundwater but few form significant aquifers (Table 3).

Table 3. Groundwater occurrence and potential (after De Silva 2003)

Aquifer	Maximum yield recorded (m^3/day)	Groundwater salinity (mg/L TDS)	Comments
Surficial (Cza and Qa)	100	500–1000 (medium rainfall) >3000 (low rainfall)	Minor domestic and stock
Sedimentary (TP*w*, not TP*p* or Tgc)	1400	1000–5000	Major stock
Weathered and-or fractured rock (Ag, Ᵽd, Ᵽg, Ᵽn, Ᵽm)	100	100–1000 (high rainfall) >14 000 (low rainfall)	Minor stock
Fractured rock (Aq, Ᵽq, q)	500	100–500	Minor domestic and stock

In the Yilgarn–Southwest and the Albany–Fraser provinces groundwater mainly occurs in the weathered profile and in the fractures and joints of the mainly granitic (Ag, Ᵽg) and gneissic (Ᵽn) bedrock. These aquifers, together with migmatite (Ᵽm), quartzite (Aq, Ᵽq) and quartz (q), are collectively referred to as weathered and-or fractured rock aquifers.

Sedimentary aquifers comprise the Tertiary terrestrial and shallow marine sediments of the Plantagenet Group (mainly TP*w*), overlying bedrock in the Bremer Basin.

Surficial aquifers (Cza, Qa) that overlie both these aquifer groups comprise the unconsolidated sediments of Cainozoic, mainly Quaternary, age.

Groundwater movement is extremely slow and is controlled by topography with most groundwater discharging from shallow flow systems into dissecting drainages or lakes (Fig. 4). Five types of stratigraphic profiles were identified in the catchment (Fig. 4 and Appendix 1) from the re-interpretation of drilling logs (Appendix 2). This classification indicates whether the bedrock outcrops (Type 1), is capped by laterite (2), or is covered by thin surficial (3), medium Tertiary (4) or thick palaeochannel (5) deposits. The hydrogeology is described below, commencing with the younger, and most significant, stratigraphic units.

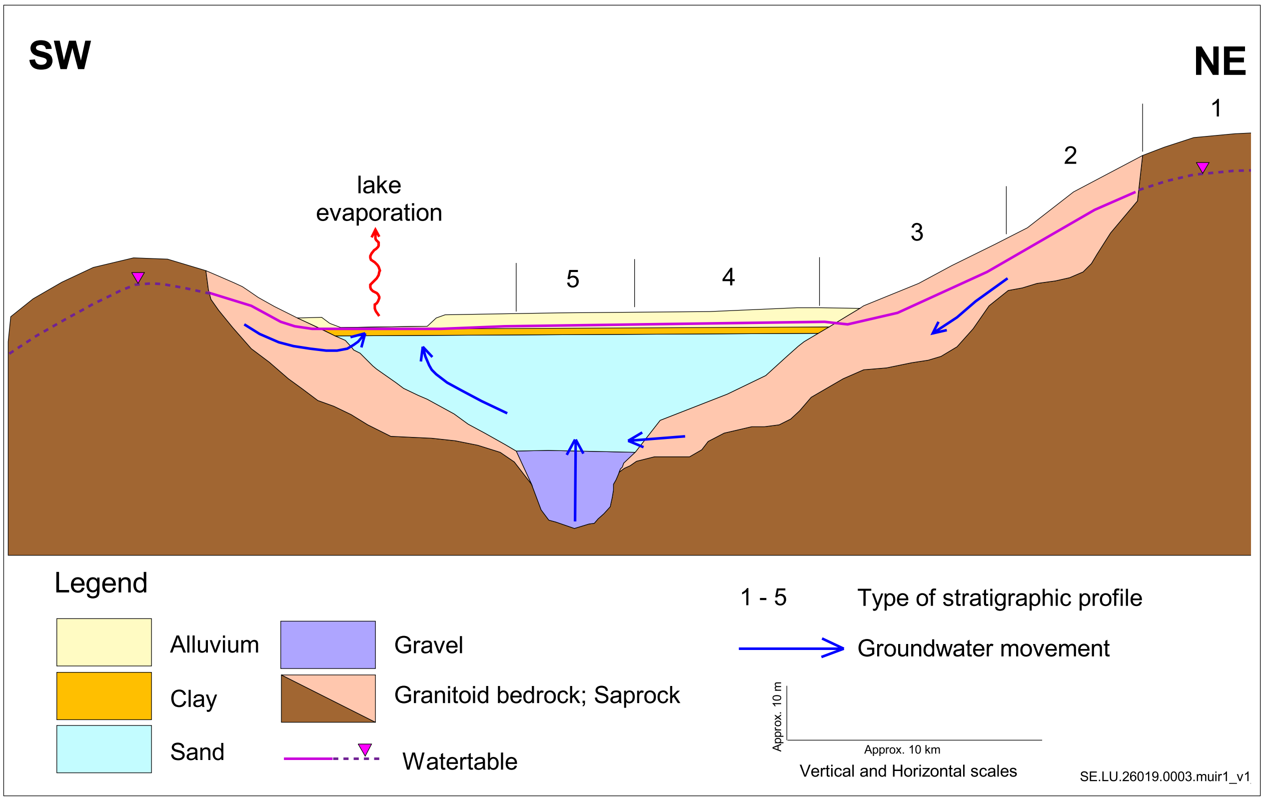


Figure 4. Diagrammatic section across the Lake Muir paleochannel (after De Silva 2003) with typical stratigraphic profiles for the Muir-Unicup catchments

3.2 Surficial aquifers (Cza and Qa)

Cainozoic alluvial and colluvial sediments (Cza), an unassigned Tertiary unit, overlie both Plantagenet Group sediments and weathered basement. They mark the course of a pre-Tertiary drainage system in the Yilgarn–Southwest and Albany–Fraser provinces and are variously dissected by the present drainage (Wilde and Walker 1984). Quaternary (<2 ma) alluvial and lacustrine deposits (Qa) occupy the major stretches of the rivers and swamps.

Alluvial, colluvial and lacustrine deposits (Cza and Qa) are widespread in valleys, broad flats and wetlands. They consist of sands, clays and gravels, overlying either the basement rocks or Tertiary sediments, and are between 5 and 20 m thick. They form generally unconfined aquifers in which the depth to water is 1 to 2 m. Yields from this aquifer depend on the lithology. Sandier profiles can yield groundwater whereas clayey or peaty profiles produce little or no water (Panasiewicz et al. 1997). Groundwater salinity varies significantly depending on long-term rainfall. Apart from direct infiltration of rainfall and localised stream runoff, this aquifer receives throughflow from the adjoining weathered (and fractured bedrock) aquifer. Groundwater discharge is mainly through evapotranspiration. This aquifer can be considered as a good water supply source only in higher rainfall areas, southwest of the Muir–Unicup catchments (Table 3).

3.3 Sedimentary aquifers (Tgc, TP*p* and TP*w*)

Tertiary sediments, ranging in age from Late Eocene to possibly Pliocene (42–2 ma) and unconformable on (Precambrian) basement rocks, can be correlated to the Plantagenet Group of the Bremer Basin. Sedimentary sequences such as near Mobrup (Milne 1999; Hundi 1999) and Manjimup (Backhouse 1994; Thorpe 1994) can also be correlated with the Plantagenet Group, based on palynological evidence and the characteristics of sediments.

The Bremer Basin, overlying the southern Yilgarn–Southwest Province and the Albany–Fraser Province, consists of numerous sediment-filled depressions rather than a single continuous basin (Hocking 1990). The Werillup Formation (TP*w*), the lower unit of the Late Eocene Plantagenet Group (of the Bremer Basin), was deposited in palaeovalleys and topographic depressions on eroded or weathered basement.

The sediments of the Plantagenet Group are found both in modern valleys that are common above the palaeodrainages in the Muir–Unicup catchments and also higher in landscapes rejuvenated by these drainage lines. The formation has been intersected at a wide range of elevations on PEMBERTON–IRWIN INLET (De Silva 2003), from 30 m AHD near Broke Inlet to 240 m AHD near Mobrup. The thickest profile of Late Eocene sediments is 70 m in LM7, about 8 km northeast of Lake Muir (show on Fig. 3).

The Werillup Formation (TP*w*) consists of predominantly fluvial and lacustrine sediments and is unconformable on fresh and weathered bedrock. The maximum thickness recorded is 65 m in LM7 where the sediments comprise multiple layers of carbonaceous clay, lignite and carbonaceous sand (Dampier Mining Company Limited 1981). The formation is overlain conformably by the Pallinup Siltstone (TP*p*), or unconformably by Quaternary sediments where the Pallinup Siltstone has been eroded. The top of the formation is planar, where not eroded, declining south or southeast from about 200 to 170 m AHD (Map 2 shows spot heights from borelogs).

Tertiary conglomerate, quartz grit, sand and clay deposits (Tgc) on the Precambrian bedrock are mainly of alluvial or lacustrine origin, although some are possibly shallow marine sediments (Wilde and Walker 1984). They may be remnants of the Werillup Formation exposed by erosion since uplift during the Late Tertiary (probably Oligocene).

The Pallinup Siltstone (TP*p*) is a shallow marine transgression sequence and consists typically of white to grey-brown siltstone and spongolite that either overlies the Werillup Formation or lies directly on (Precambrian) basement. In PM10 spicules of sponges were observed in khaki-brown weakly-consolidated silt that can be correlated with the Pallinup Siltstone (Panasiewicz et al. 1997). This sequence is 14 m thick overlying Werillup Formation but the maximum recorded thickness of the sediments is 36 m in PM7 where they lie directly on weathered basement (De Silva 2003). The absence of the Pallinup Siltstone in many drill holes in the south of the area (re-interpreted logs are in Appendix 2) indicates these sediments have been largely removed from these low-lying areas and its depositional thickness is uncertain. It may be intersected near Noobijup Lake by CALM drilling and be preserved on higher ground west of Buranganup Swamp.

The alluvial, lacustrine and shallow marine deposits (Tgc) and Pallinup Siltstone (TP*w*), form aquitards or minor local aquifers. These deposits overlie either the Werillup Formation (TP*w*) or fresh to weathered basement rocks and may be up to 30 m thick. As they mostly contain clays, they form a limited aquifer and act as an aquitard for any deeper aquifer. Groundwater salinity ranges from less than 500 up to 1500 mg/L TDS.

The Werillup Formation (TP*w*) forms a semi-confined to confined aquifer mainly within palaeochannels at Unicup, Noobijup and Lake Muir (De Silva 2000). The movement of water through this aquifer is shown diagrammatically in Figure 4. In some localities, the aquifer is confined by clay of the Pallinup Siltstone (TP*p*). The potentiometric head may be below ground level. The salinity ranges up to about 23 500 mg/L TDS.

3.3.1 Unicup palaeochannel (TP*w*)

The Unicup palaeochannel is mapped as 750 m wide and about 10 km long (De Silva 2000). The Werillup Formation (TP*w*) sedimentary aquifer probably extends westwards and eastwards beneath the flats and terraces of Cainozoic sediments. This palaeochannel was intersected at PM4 and PM12 with sediments exceeding 42 m thick at PM4 (Panasiewicz et al. 1997). The sediments and sands tend to thin eastwards. The palaeochannel sediments consist of plastic clay, carbonaceous clay, silt and sand. Groundwater mainly occurs in a sand layer that extends from 16 to 38 m deep, a confined aquifer between carbonaceous clay layers. The potentiometric head ranges from 4.5 to 0.2 m below ground level but, during winter recharge, may rise to 0.4 m above the ground level. Groundwater salinity is 3400 mg/L in PM4 and 12 800 mg/L in PM12.

3.3.2 Noobijup palaeochannel (TP*w*)

The Noobijup palaeochannel has been traced running west-northwest for about 12 kms from north of Noobijup Lake to Pindicup Road with a tributary channel joining from the south (De Silva 2000). The Werillup Formation (TP*w*) is between 37 and 73 m thick, increasing westward. The sediments consist of carbonaceous clay and sand, sand, clay and silt. Two production bores drilled in the tributary yielded 800 to 1400 m^3/day from coarse-grained quartz river sand below 16 m depth. The groundwater salinity ranges from 250 to 5600 mg/L.

3.3.3 Lake Muir palaeochannel (TP*w*)

The Lake Muir palaeochannel (Fig. 4), about 1250 m wide and 7.5 km long, has been identified from coal and groundwater exploration drilling (De Silva 2000). The Werillup Formation (TP*w*) is between 37 and 46 m thick and comprises sand, clay and carbonaceous clay. A sand layer extending from 17 to 41 m in PM1A (Panasiewicz et al. 1997) forms a confined aquifer. The potentiometric head during summer varies from 0.2 to 1 m below ground level but in response to winter recharge ranges up to 0.4 m above the natural surface. Groundwater yields are between 50 and 100 m^3/day. Groundwater salinity is about 23 500 mg/L (De Silva 2003). A salinity as high as the 96 000 mg/L reported by V. & C. Semeniuk Research Group (1997) is considered to represent the drying lake bed rather than groundwater beneath it (there are no deep lakebed bores).

3.4 Weathered and-or fractured rock aquifers

3.4.1 Extensive weathered and-or fractured rock aquifers (Ag, *Ᵽ*g, *Ᵽ*n and *Ᵽ*m)

The weathered rock aquifer is developed extensively over moderately to highly weathered granitic (Ag and *Ᵽ*g), gneissic (*Ᵽ*n) and migmatitic (*Ᵽ*m) rocks. The weathered profile overlies fresh or fractured bedrock and ranges from about 5 to 30 m thick. Groundwater mainly occurs in the permeable zones of the weathered profile that have a high content of coarse-grained quartz sand or grit in the clay matrix. This permeable zone in the weathered profile is commonly referred as the saprolite grit. Among the weathered rock aquifers, the sandier profiles tend to be derived from weathered granitic rocks and the more clayey profiles tend to be weathered from gneissic rocks. Thus the weathered profile of granitic rocks can produce higher yields than the weathered profile of gneissic rocks. This aquifer is usually semi-confined or confined by the pallid clay developed within the weathered profile.

Groundwater flow within the weathered rock aquifer is mainly characterised by local flow systems originating close to the surface water catchment divide and discharging at the nearest drainage line. Recharge to this aquifer is mainly by direct infiltration of rainfall or runoff and there may be some throughflow from aquifers higher in the landscape. Groundwater discharges to watercourses, wetlands and through evapotranspiration from a shallow watertable. Groundwater from the weathered rock aquifer also discharges into surficial and Tertiary sediments that occupy broad flats and valleys.

Groundwater salinity is lower in more undulating terrain than in flat or gently sloping areas. This is attributed to undulating terrains having more dynamic groundwater systems and well-developed surface water drainage that can flush salt from the weathered profile. In contrast, flat to gently sloping areas with stagnant groundwater systems and poor surface water drainage accumulate salt in the weathered profile. Consequently, at the catchment scale, groundwater salinity increases from upper-middle slope areas to lower slope areas.

The major regional shear zones, crossing the catchment from east to west, are mapped as the Manjimup, Pemberton and Northcliffe faults (Fig. 3). The fracturing and jointing associated with these regional faults form fractured rock aquifers beneath the weathered rock aquifer (Chakravartula and Street 2000). These faults have deep fractures in the bedrock that can accommodate significant volumes of groundwater. Fractured rock aquifers also occur within the hard rock areas outside these faults zones, but here fracturing may be restricted to within 10 m beneath the limit of weathering (De Silva 2003). Groundwater yields of up to 86 m^3/day can be obtained from these fractured rock aquifers. Yields are dependent on the intensity of jointing and fracturing in the bedrock, the lithology of the rock, the amount of recharge and the topographic position.

3.4.2 Minor weathered and-or fractured rock aquifers (*Ᵽ*d or d)

Dolerite dykes (*Ᵽ*d or d) are mapped mainly within the Yilgarn–Southwest Province with only minor occurrences in the Albany–Fraser Orogen. The weathered profile of dolerite dykes tends to have higher clay content than the weathered profiles of other basement rocks such as granites and gneisses and, consequently, forms a poorer aquifer. Engel et al. (1987) found that weathered dolerite dykes can act as barriers to groundwater flow within the weathered profiles of basement rocks.

3.4.3 Fractured rock aquifers (q, Aq, Ꝑq)

Quartz veins and quartzite, due to their brittle nature, have a higher density of joints and fractures than surrounding bedrock and can store significant volumes of groundwater. They yield up to 500 m^3/day of low salinity groundwater near Manjimup (Prangley 1994) but have not been mapped in the catchment.

3.5 Current investigations

The CALM drilling program in 2003 targeted 4 of the 5 types of stratigraphic profiles (Fig. 4 and Appendix 1) at up to 29 sites (Appendix 3). Most profiles are expected to be in the range between Type 3 (thin Cainozoic, possibly Tertiary) and Type 4 (medium Tertiary including Werillup Formation). The Werillup Formation targeted is within in the palaeovalley but not the actual palaeochannel (Type 5).

3.6 Groundwater development

There is no significant development of groundwater in the catchment and the potential for groundwater development within the catchment is small. The weathered and-or fractured rock aquifers have local to intermediate groundwater flow patterns and limited potential groundwater resources. Moderate to high groundwater salinity further limits their groundwater potential. The sedimentary aquifers have significant potential for development of water resources where they are well drained and receive high rainfall recharge. The surficial aquifers have limited storage capacity and their potential decreases inland due to increasing groundwater salinity. Table 3 summarises the potential of these aquifers for groundwater development.

4 Groundwater quality

4.1 Groundwater salinity

Groundwater salinity in the Muir–Unicup catchments ranges from fresh to saline and shows both a regional trend of increasing to the NNE and local patterns of increasing downslope. Within the weathered (and-or fractured) bedrock aquifer groundwater salinity, ranging from less than 1000 to more than 14 000 mg/L TDS, reflects the variation in the rainfall, land use and topography.

Corresponding with local surface water catchments, groundwater salinity increases from upper to lower slope areas due to mobilisation and concentration of salt. Groundwater salinity increases towards the major lakes, such as Lake Muir, due to concentration of salt in groundwater through evaporative discharge. This variation in groundwater salinity is common along a groundwater flow path (Fig. 4), whether from the weathered rock aquifer to the sedimentary and surficial aquifers or just within the sedimentary and surficial aquifers. Groundwater is fresh (250 mg/L TDS) where recharged higher in the landscape and saline beneath the flats (23 500 mg/L TDS). Salinity may also vary laterally and with depth in the Tertiary sedimentary aquifers, especially near the palaeochannels and lakes.

4.2 Hydrochemistry

De Silva (2003) reports the groundwater is mainly sodium chloride type. Even the proportion of sulfate ions, found in significant concentrations in the highly saline groundwaters, is lower than in seawater. Potassium is generally depleted (Panasiewicz et al. 1997). The CALM 2003 drilling investigation (New 2003) will provide data on potential acid sulfate soils.

Nitrate concentrations are low and generally less than 2 mg/L. Iron concentrations range up to 3.2 mg/L for the weathered rock aquifer but, because ferrous ion is not stable under oxidising conditions, the confirmation of high concentrations requires filtered and acidified samples analysed within 24 hours (AS/NZS 5667.1:1998). The pH of groundwater ranges from about 3 to 9. Moderately high pH (about pH 8) groundwater may indicate buffering within marine Pallinup Siltstone or by shells in the lacustrine sediments. The highest pH readings probably indicate boreholes contaminated with cement or drilling mud (during construction). Most of the low pH groundwater is associated with the Werillup Formation sedimentary aquifer.

4.3 Acid sulfate soils

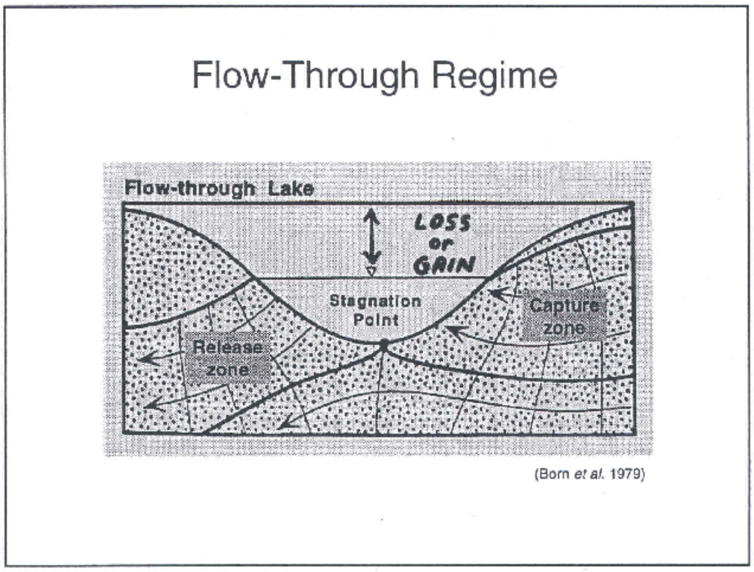
The acidic groundwater identified from regional monitoring indicates the Cainozoic sediments may contain metallic sulfides, especially pyrite. The Eocene marine transgression (and regression) may have provided a depositional environment for acid sulfate soils (ASS), namely low energy sheltered coastal wetlands. Iron sulfide is stable under anaerobic reducing conditions so, while such sediments remain undisturbed, the pH is often weakly acidic to weakly alkaline. When ASS are disturbed, oxidation of the iron sulfide produces sulfuric acid (Sammut 1955) and very low pH groundwater. Potential ASS should be carefully investigated prior to disturbance such as drain construction.

5 Rising watertable and land salinisation

The risk of land salinisation due to shallow water levels varies significantly from no risk to high risk depending mainly on the geology, topography (drainage) and distribution of rainfall. Clayey weathered-rock profiles beneath lateritic subsoils invariably have soil solute concentrations over 2000 mg/L TDS, with some in excess of 20 000 mg/L TDS in areas where the average annual rainfall is less than 900 mm (Steering Committee for Research of the Woodchip Industry 1980). High salt stores were accumulated over thousands of years of limited flushing as deep-rooted vegetation transpired infiltrating water and mostly kept the weathered profile unsaturated. This salt storage in the weathered bedrock profile increases northeast as rainfall decreases. Thus the upper Warren catchment in the moderate rainfall zone (700 mm/yr), particularly the Tone subcatchment but also to a lesser degree the generally forested Perup subcatchment, has a higher risk of land salinisation than the lower to middle Warren catchment that receives more rain. About 80% of the Warren River salt load currently comes from cleared, low rainfall areas (Rogers et al. 1999).

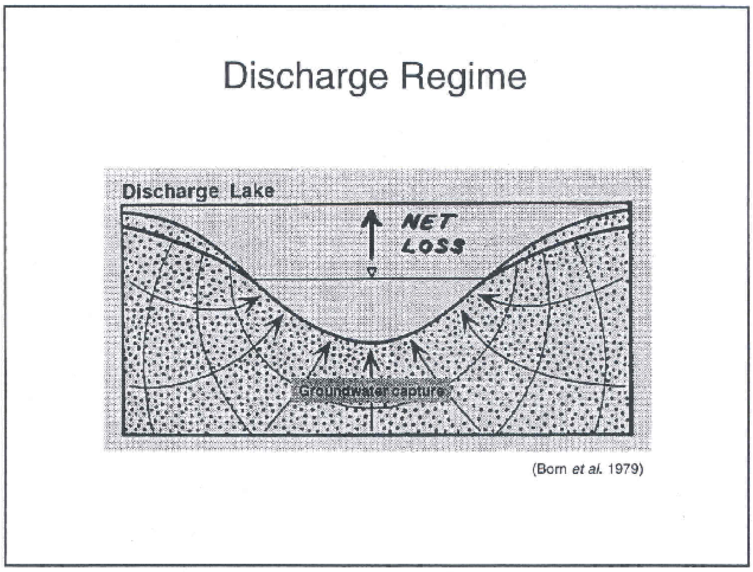
The clearing of native vegetation (mostly to establish agricultural crops and pastures) is the major cause of increasing land and water salinisation in the southwest of Western Australia. Removal of deep-rooted vegetation alters the water balance by reducing the evapotranspiration and interception components, leading to increased groundwater recharge and to rising water levels over most, if not all, of the catchment. Rising groundwater increases in salinity by dissolving salt within the unsaturated zone. Once groundwater is within about 2 m of the ground surface, it can be drawn up by capillary action and evaporated, leaving the salt in the soil. The increased soil salinity reduces agricultural production and in severe cases forms salt scalding at the surface, especially in combination with waterlogging. The land becomes unproductive and eventually pasture and vegetation die. Salt accumulated on the surface and within the (shallow) soil profile increases stream salinity when mobilised by runoff. Rising water levels and groundwater discharge also lead to intermittent swamps or wetlands becoming more saline and permanently inundated/waterlogged. The broad flats that contain wetlands such as Lake Muir and Unicup Lake have the highest risk of land salinisation due to poor surface and groundwater drainage, combined with saline shallow groundwater (Fig. 5).

Rising groundwater levels can possibly be controlled by measures that include revegetation, agro-forestry, high-water-use crops and pastures, shallow and deep drains and groundwater pumping. Biological options such as revegetation can be considered as a long-term strategy for controlling groundwater recharge. Engineering options for managing groundwater discharge may be needed in the short to medium term. Monitoring of the watertable near the water bodies alone will not be sufficient to determine impacts of management change on the 3-dimensional aquifers systems. A salinity-risk map could be one of the outcomes from the current drilling and sampling investigations. It would integrate data on depth to water level, topography, slope and landforms to identify areas with risk of developing a shallow watertable or salinity.



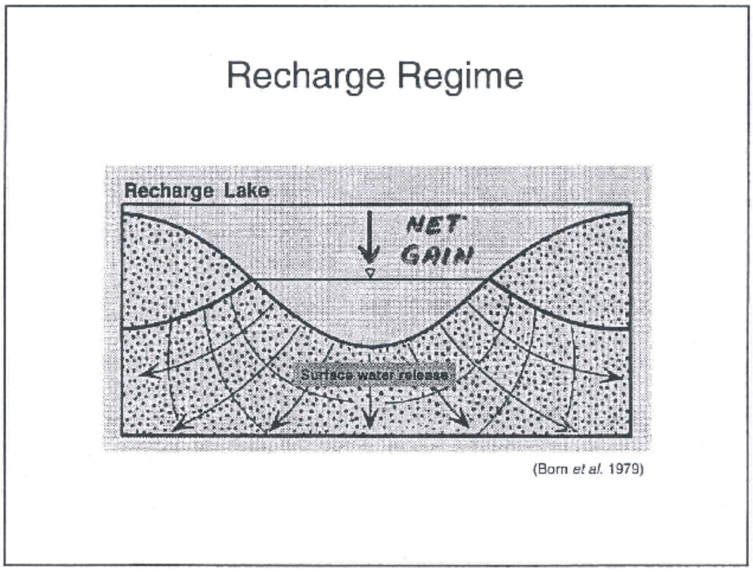
Flow-Through Regime

(Born *et al.* 1979)



Discharge Regime

(Born *et al.* 1979)



Recharge Regime

(Born *et al.* 1979)

J:se.lu.26019.0003.muir1_v1_new

Figure 5. Diagrams of groundwater-lake interactions

6 Groundwater–lake interactions

Where the groundwater level is well below the lakebed there is no groundwater–lake interaction. The lake water-balance comprises surface water inflow, evaporation and leakage. Land clearing at Lake Nunijup in the Kent River catchment (De Silva and Bari in prep.) resulted in groundwater levels rising to establish one or more of the flow-through, discharge and recharge regimes (Fig. 5a–c) described by Born et al. (1979). Under different seasons this lake conforms to the flow-through, discharge or recharge regime. De Silva and Bari (in prep.) describe and model Lake Nunijup using these three regimes. Groundwater now discharges into the Lake Nunijup, particularly when lake levels are low.

Townley (2001) provides a website that allows modelling of lake behaviour. Groundwater and surface water levels and salinities are influenced to varying degrees by seasonal precipitation and evapotranspiration. In addition to seasonal factors the interaction between groundwater and a lake is influenced by the dimensions of both the lake and the groundwater system, and the composition and dynamics of their interface.

Understanding the past and present groundwater–lake interactions is therefore important for salinity management where intervention may be to change the movement of surface and groundwater. For example drainage, by altering water movement times, may influence lake behaviour and the movement of nutrients and may, if lowering water tables, lead to the development of acid sulfate soils and low pH water.

Lake Toolibin (Dogramaci et al. 2003; George & Dogramaci 2002) is managed partly by surface water control and groundwater pumping. It is maintained as a recharge lake by sacrificing Lake Taarblin downstream. Similarly Lake Muir might be managed as the ‘sacrificial wetland’ or sump for drained wetlands higher in its catchment. An alternative to diverting saline early winter runoff to minimise groundwater recharge might be, if runoff is fresh, to retain upgradient wetlands that are recharging the groundwater.

The Muir–Unicup lakes (Table 1) mostly have permeable lake floor sediments and-or large areal extent and so are likely to have a groundwater flow-through regime, yet many could also exhibit a seasonal (short-term) discharge or recharge regime. Such detailed classification of the regime of a lake requires substantially more information than the hydrogeological setting and similarity to well-studied lakes (Table 4). Readily available but incomplete information has been used to interpret and describe some characteristics of a few of the Muir–Unicup lakes (Chakravartula and Street 2000). Taylor (Appendix 4) provided notes on:

- Lake Muir - the biggest with stable hydrology;
- Unicup Lake - four-fold salinity increase in the 1990s;
- Tordit-Gurrup Lagoon - fluctuating relationship between depth and salinity but no long-term trends;
- Poorginup - no trend;
- Byenup Lagoon - suspected increase in salt in the 1990s;
- Yarnup Swamp - increased salinity and water levels in the 1990s.

Table 4. Data requirements for lake characterisation

Information	*Where to source*
Hydrogeological setting	PEMBERTON map & Notes, drilling records
Lakebed sediments	PEMBERTON map & Notes, drilling records
Groundwater levels	At least summer & winter for several years
Groundwater salinity	At least summer & winter for several years
Lake models	Literature eg Lake Nunijup (Kent catchment)
Lake water levels	At least summer & winter for several years
Lake salinity range	At least summer & winter for several years
Lake volume	Lake area, bathometry, elevation
Water balance	Calculate from various components
Groundwater inflow	Groundwater movement, aquifers, gradients
Groundwater outflow	Groundwater movement, quality
Surface water inflow	Flow rates and periods, stream gauging OR catchment area times rainfall runoff
Surface water outflow	Lake flushing history, flow rates and periods
Rainfall	Precipitation, proportion as runoff
Evaporation	Potential evaporation
Salt balance	Calculate from various components
Volume of inflows and outflows	See above
Quality of inflows and outflow	See above
Catchment area & type	Define boundary, topographic contours
Clearing history	Progressive % cleared, air photos
Salinity ratio lake/groundwater	Calculate
Correlation lake WL & salinity	Calculate
Correlation lake WL & salinity	Calculate

Following the current drilling (New 2003) it will be possible to prepare additional diagrammatic sections and estimate lake water and salt balances. These would be used with long and short-term data, particularly lake salinities (Table 1). An appraisal of 11 of these indicated a variety of groundwater-lake interactions. Consequently the individual characterisation of wetlands, rather than say a catchment-scale map of salinity risk areas, will be needed to determine their separate management options.

References

AS/NZS 1998, *Water quality – sampling – Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples*, Standards Australian & Standards New Zealand, Australian/New Zealand Standards AS/NZS 5667.1:1998.

Backhouse, J 1994, *Manjimup drilling project, stage 3, palynology of boreholes 17, 20 and 21*, Western Australia Geological Survey, Palaeontology Report no. 1994/2 (unpublished).

Beard, JS 1981, *Vegetation survey of Western Australia, Swan 1:1 000 000 Vegetation Series, Explanatory notes to Sheet 7, The vegetation of the Swan Area*, University of Western Australia Press.

Born, SM, Smith, SA & Stephenson, DA 1979, *Hydrogeology of glacial-terrain lakes, with management and planning applications*, Journal of Hydrology, v. 43, p. 7–43.

Chakravartula, PN & Street, G 2000, *Hydrogeological interpretation of airborne geophysical data Lake Muir Unicup Catchment, Western Australia,* Agraria Limited, Western Australia.

Churchward, HM 1992, *Soils and Landforms of the Manjimup area, Western Australia,* Western Australia, Department of Agriculture.

Churchward, HM, McArthur, WM, Sewell, PL & Bartle, GA 1988, *Landforms and soils of the south coast and hinterland, Western Australia, Northcliffe to Manypeaks,* Commonwealth Scientific and Industrial Research Organisation, Division of Water Resources, Divisional Report 88/1, Australia.

Cope, RN 1975, *Tertiary epeirogeny in the southern part of Western Australia*, Western Australia Geological Survey, Annual Report 1974, p. 40–46.

Dampier Mining Company Limited 1981, *Coal exploration in Lake Muir area*, Western Australia Geological Survey, Microfiche Record C 68/2236.

Department of Conservation and Land Management 1998, *Perup Forest, Lake Muir Nature Reserve, Unicup Nature Reserve Draft Management Plan*, Department of Conservation and Land Management, NPNCA, Lands and Forest Commission, Perth (unpublished).

De Silva, J 2000, *Pemberton–Irwin Inlet W.A. Sheet SI 50-10 and part of SI 50-14, Western Australia*, Water and Rivers Commission, 1:250 000 Hydrogeological Series.

De Silva, J 2003, *Hydrogeology of the Pemberton–Irwin Inlet 1:250 000 sheet, Western Australia,* Water and Rivers Commission, Hydrogeological Explanatory Notes Series, Report HM 8.

De Silva, J & Bari, *M in prep., Hydrology of Lake Nunijup, Western Australia,* Water and Rivers Commission, Salinity and Land Use Impacts Series, Report SLUI 26.

Dogramaci, S, George, R, Mauger, G & Ruprecht, J 2003, *Water balance and salinity trend, Toolibin catchment, Western Australia,* Western Australia Department of Conservation and Land Management.

Engel, R, McFarlane, DJ & Street, G 1987, *The influence of dolerite dykes on saline seeps in south-western Australia,* Australian Journal of Soil Research, v. 25, p. 125–136.

George, R & Dogramaci, S 2002, Toolibin—*A life and death struggle for the last freshwater Wheatbelt lake, in Hydro 2000 Interactive Hydrology*, Volume 1: 3rd International Hydrology and Water Resources Symposium of the Institution of Engineers Australia, Perth, 20–23 November 2000, p. 733–738.

Geste, P 1998, *Bore census records: Pemberton–Irwin Inlet map sheet, Western Australia*, Water and Rivers Commission, File 6552 (unpublished).

Gibson, N & Keighery, GJ 2000, *Flora and vegetation of the Byenup-Muir reserve system, south-west Western Australia*, CALMScience **3**, 323–402.

Griffin, EA & Associates 1984, *Vegetation survey of three Nature Reserves in the Lake Unicup complex (Lake Unicup, Kulunilup Lake and Yarnup Swamp), Perth*, Department of Fisheries and Wildlife.

Hawkes, GE 1993, *Manjimup shallow basins drilling project,* Western Australia Geological Survey, Hydrogeological Report 1993/17 (unpublished).

Hearn, R in prep., *Muir–Unicup management plan,* Western Australia Department of Conservation and Land Management (unpublished).

Hocking, RM 1990, *Bremer Basin, in Geology and mineral resources of Western Australia*, Western Australian Geological Survey, Memoir 3, p. 561–563.

Hundi, N 1999, *Mobrup catchment salinity investigation - Bore completion report,* Western Australia Water and Rivers Commission, Hydrogeology Report HR 147 (unpublished).

Johnston, CD, McArthur, WM & Peck, AJ 1980, *Distribution of soluble salts in soils of the Manjimup Woodchip Licence Area, Western Australia*, CSIRO, Australia, Land Resources Technical Paper No. 5.

Martin, M 1982, *Byenup, Tordit-Gurrup and Poorginup Lagoons—Water quality criteria in relation to peat mining,* Western Australia Geological Survey, Hydrogeology Report HR 2110 (unpublished).

Martin, M & Daetwyler, N 1980, *Saline river diversion studies—Tone and Kent Rivers—Geological investigation,* Western Australia Geological Survey, Hydrogeology Report HR 2433 (unpublished).

Milne, LA 1999, *Palynology report: three samples from Mobrup drilling project: ME/BP57,* Report to Western Australia Water and Rivers Commission.

Muhling, PC & Brakel, AT 1985, *Explanatory notes on the Mount Barker–Albany geological sheet,* Western Australia Geological Survey, 1:250 000 Geological Series.

Myers, JS 1990a, *Western Gneiss Terrane, in Geology and mineral resources of Western Australia,* Western Australian Geological Survey, Memoir 3, p. 13–32.

Myers, JS 1990b, *Albany–Fraser Orogen, in Geology and mineral resources of Western Australia,* Western Australian Geological Survey, Memoir 3, p. 255–264.

Myers, JS 1995, *Explanatory Notes on Geology of the Albany 1:1 000 000 sheet,* Western Australia Geological Survey.

New, CES 2003, *Muir–Unicup catchments drilling bore completion report,* Western Australia Department of Conservation and Land Management.

New, CES in prep., *Muir–Unicup catchments drilling program results and implications for future management,* Western Australia Department of Conservation and Land Management.

Panasiewicz, R, De Silva, J & McGann, MP 1997, *Pemberton and Blackwood drilling programs: bore completion report,* Western Australia Water and Rivers Commission, Hydrogeology Report HR 86 (unpublished).

Pen, L 1997, *A systematic overview of environmental values of the wetlands, rivers and estuaries of the Busselton–Walpole Region,* Western Australia Water and Rivers Commission, Water Resource Allocation and Planning Report Series WRAP 7.

Playford, PE, Cockbain, AE & Low, GH 1976, *Geology of the Perth Basin, Western Australia,* Western Australia Geological Survey Bulletin 124.

Prangley, CJ 1994, *Manjimup fractured rock drilling project bore completion report,* Western Australia Geological Survey, Hydrogeology Report 1994/21 (unpublished).

Rockwater Pty Ltd 1986, *Unicup hydrological study,* Report to Western Australia Department of Industrial Development (unpublished).

Rogers, ADA, Mauger, GM & Davies, JR 1999, *Hydrologic modelling of salinity in the water resource recovery catchments: Volume 5: Tone and Perup river catchments,* Western Australia Water and Rivers Commission, Water Resource Technical Series, Report WRT9.

Sammut, J 1995, *Introduction to acid sulfate soils*, Natural Heritage Trust, 2nd edition.

Smith, FG 1972, *Vegetation survey of Western Australia – Vegetation map of Pemberton and Irwin Inlet, Scale 1:250 000,* Western Australian Department of Agriculture.

Smith, MG 2003, *Groundwater and sediment sampling for the proposed Muir–Unicup drilling investigation,* Western Australia, Water and Rivers Commission, Hydrogeology Report HR 209.

Smith, MG, Ansell, HM & Smith, RA 1999, *A bibliography of published reports on groundwater in Western Australia,* Western Australia, Water and Rivers Commission, Hydrogeological Record Series HG 1.

Smith, RA 1997, *Hydrogeology of the Mount Barker–Albany 1:250 000 sheet,* Western Australia Water and Rivers Commission, Hydrogeological Explanatory Notes Series, Report HM 1.

State Salinity Council 1998, *Western Australia Salinity Action Plan*, Government of Western Australia, Draft Update, 1998.

Steering Committee for Research on the Woodchip Industry 1980, *Research into the effects of the woodchip industry on water resources in south Western Australia*, Western Australia, Department of Conservation and Environment, Bulletin 81.

Storey, AW 1998, *Assessment of the nature conservation values of the Byenup–Muir peat swamp system, southwestern Australia — physico-chemistry, aquatic macroinvertebrates and fishes,* UWA Wetland Research and Management Group, prepared for CALM.

Thorpe, PM 1994, *Manjimup shallow basins drilling project phase 3, Western Australia* Geological Survey, Hydrogeology Report 1994/2 (unpublished).

Townley, LR & Barr, AD 2001, *FlowThru***,** www.townley.com.au/flowthru

V. & C. Semeniuk Research Group, *Mapping and classification of wetlands from Augusta to Walpole in the South West of Western Australia*, Western Australia Water and Rivers Commission, Water Resource Technical Series No. WRT 12.

Wilde, SA & Walker, IW 1984, *Pemberton–Irwin Inlet sheet SI 50-10 and SI 50-14,* Western Australian Geological Survey, 1:250 000 Geological Series.

Appendix 1 – Classification of predicted stratigraphic profiles

(29 revised drill-sites)

Stratigraphy Types			***Outcrop* 1**	***Laterite* 2**	***Surficial* 3**	***Tertiary* 4**	***Channel* 5**
Surficial Unit	Code		nil	Tl	Cz	(TP +) TP*w*	
	Thickness		nil	thin	thin	medium	thick
Weathered Bedrock			nil to thick	thick	thick	medium	thin
Bedrock	Granite	A	4,8,13s,17-18	1,9,20,23	2,5-7,21	10-13n-16	
		P			27-28	29	
	Gneiss	A					
		P		26	19,22,24-25		
TOTAL			**5**	**5**	**11**	**8**	**0**

Archaean, **P**roterozoic, **T**ertiary **l**aterite, **C**ainozoic, (**T**ertiary **P**lantagenet) or just **W**erillup Formation
Sites with suffix **s** or **n** have been relocated south or north respectively of the original location

Appendix 2 – Summary of re-interpreted bore logs (follows)

Appendix 3 – Details of proposed drilling 2003 (follows)

Appendix 2. Summary of re-interpreted bore logs

Reference	WIN Site ID	Easting MGA	Northing GDA'94	Elevation (mAHD)	Depth From	Depth To	Top Tpw (mAHD)	Stratigraphy	Lithology 1	Lithology 2	Lithology 3
UC1	20045964	470713	6202104	220	0.00	9.50	Nil	Possible Cz	clay	loam	ironstone
					9.50	19.10		Weathered Precambrian	quartz	clay	feldspar
UC2	20045967	470364	6200942	200	0.00	8.00	Nil	Possible Cz	sand	gravel	ironstone
UC3	20045969	470101	6200247	200	0.00	8.00	Nil	Possible Cz	sand	clay	ironstone
UC4	20045970	469535	6199870	200	0.00	1.20	Nil	Cainozoic	clay	sand	(none)
					1.20	14.00		Possible Weathered Precambrian	clay	quartz	feldspar
UC5	20045968	471416	6201481	200	0.00	8.00	Nil	Possible Cz	sand	clayey	gravel
UC6	20045966	469685	6201544	200	0.00	4.50	Nil	Possible Cz	clay	sandy	iron staining
					4.50	26.00		Possible Weathered Precambrian	clay	water	quartz
					26.00	35.00		Weathered Precambrian	quartz	water	rock
UC7	20045965	468843	6202402	210	0.00	11.1	Nil	Possible Cz	clay	loam	ironstone
					11.1	12.59		Possible Weathered Precambrian	quartz	feldspar	(none)
					12.59	12.6		Weathered Precambrian	quartz	feldspar	(none)
UC8	20045995	468605	6196027	190	0.00	8.00	Nil	Possible Cz	sand	clay	ironstone
UC9	20045994	468376	6194933	180	0.00	8.00	Nil	Possible Cz	coarse sand	hardpan	sand
UC10	20045993	469475	6194740	190	0.00	11.00	Nil	Possible Cz	sand	ironstone	peat
PM1A	20045997	472039	6188948	180	0.00	3.00		Quaternary	clay	sand	(none)
(~PM1)					3.00	9.00		Pallinup Siltstone	clay	sand	(none)
					9.00	41.00	171.00	Werillup Formation	sand	clay	(none)
					41.00	44.00		Weathered ?age Gneiss	clay	quartz	biotite
PM2	20045972	467969	6200690	200	0.00	4.00		Quaternary	clay	ferricrete	(none)
					4.00	6.00		Tertiary Laterite			
					6.00	18.00		Weathered ?age Granite	clay	rock	weathered
PM3	20045998	473397	6195237	195	0.00	5.00		Quaternary (or Tl)	clay	(none)	(none)
					5.00	19.00		Pallinup Siltstone			
					19.00	51.00	176.00	Werillup Formation	sand	silt, silty	clay
PM4	20045973	476927	6200043	210	0.00	0.55		Tertiary Laterite	clay	sand	ferricrete
					0.50	11.00		Pallinup Siltstone			
					11.00	42.00	199.00	Werillup Formation	sand	clay	silt, silty
PM5	20045909	483026	6202647	220	0.00	1.50		Quaternary	clay	sand	peat
					1.50	2.00		Tertiary Laterite			
					2.00	10.50		Pallinup Siltstone			
					10.50	24.50	209.50	Werillup Formation			
					24.50	39.00		Weathered Archaean Gneiss	clay	feldspar	quartz
PM10	20045942	479107	6193904	215	0.00	5.00		Tertiary Laterite	clay	sand	(none)
					5.00	14.00		Pallinup Siltstone	silt, silty	sand	clay
					14.00	39.00	201.00	Werillup Formation			
					39.00	54.00		Weathered ?age Gneiss	clay	(none)	(none)
PM12	20045908	481594	6201091	220	0.00	3.00		Tertiary Laterite	clay	sand	ferricrete
					3.00	24.00		Pallinup Siltstone			
					24.00	34.00	196.00	Werillup Formation			
					34.00	39.00		Weathered Archaean Granite	rock	weathered	clay
LM1		475399	6196048	215	0.00	16.00		Tertiary Laterite & Pallinup			
					16.00	33.00	199.00	Werillup Formation lignitic			
					33.00	62.00		Werillup Formation sand			
					62.00	62.08		Weathered ?age Granite			
LM2		473539	6193638	195	0.00	22.00		Quaternary & Pallinup			
					22.00	26.00	173.00	Werillup Formation lignitic			
					26.00	46.00		Werillup Formation sand			
					46.00	49.30		Werillup Formation clayey			
					49.30	49.50		Weathered ?age ?basalt			
LM3		474939	6189348	180	0.00	2.00		Tertiary Laterite			
					2.00	16.00	<164	Pallinup Siltstone			
					16.00	24.40		Weathered Proterozoic Granite			
					24.40	24.50		Proterozoic Granite			
LM4		470929	6188548	180	0.00	4.00		Tertiary Laterite			
					4.00	20.00		Pallinup Siltstone			
					20.00	33.50	160.00	Werillup Formation lignitic			
					33.50	37.00		Weathered Proterozoic Gneiss			
					37.00	39.00		Proterozoic Gneiss			
LM5		471339	6186348	180	0.00	9.50		Pallinup Siltstone			
					9.50	24.00	170.50	Werillup Formation lignitic			
					24.00	36.70		Weathered Proterozoic Granite			
					36.70	37.00		Proterozoic Granite			
LM6		468689	6189538	180	0.00	11.00		Pallinup Siltstone			
					11.00	46.00	169.00	Werillup Formation lignitic			
					46.00	47.70		Weathered Proterozoic			
					47.70	48.00		Proterozoic ?Schist			
LM7		476939	6194748	210	0.00	3.00		Tertiary Laterite			
					3.00	8.00		Pallinup Siltstone			
					8.00	73.70	202.00	Werillup Formation lignitic			
					73.70	74.00		?age Granite			
LM8		470339	6196448	190	0.00	4.00		Tertiary Laterite			
					4.00	8.00		Pallinup Siltstone			
					8.00	50.00	182.00	Werillup Formation lignitic			
					50.00	53.00		Weathered Archaean Granite			
					53.00	54.00		Archaean Granite			
BL1		476398	6182414	175	0.00	0.80		Quaternary	sand	(none)	(none)
					0.80	5.00		Quaternary or ?Tertiary	clay	sand	(none)
					5.00	10.20	170.00	Werillup Formation	sand	clay	lignite
BL2		476398	6186191	174	0.00	1.10		Quaternary	sandy clay	(none)	(none)
					1.10	5.20		Quaternary or ?Tertiary	clay	(none)	(none)
					5.20	11.00	168.80	Werillup Formation	sand	(none)	(none)
BL3		476398	6184017	174	0.00	0.40		Quaternary (or Tl)	gravel	sand	(none)
					0.40	5.10		Quaternary or ?Tertiary	clay	sand	(none)
					5.10	11.10	168.90	Werillup Formation	sand	clay	(none)
BL4		474764	6182410	175	0.00	2.20		Quaternary	sand	sandy clay	(none)
					2.20	8.20	?172.8	Tertiary or ?Quaternary	clay	ironstone	(none)
					8.20	19.50		Weathered Proterozoic ?Granite	clay	sand	quartz
					19.50	19.80		Proterozoic Granite	rock	(none)	(none)
BL5		474765	6184658	174	0.00	0.60		Quaternary	sand	(none)	(none)
					0.60	7.00	?173.4	Tertiary Laterite	ironstone	clay	gravel
					7.00	20.60		Weathered Proterozoic Gneiss	clay	quartz	sand
BL6		474557	6183826	176	0.00	0.20		Quaternary	sand	(none)	(none)
					0.20	7.40	?175.8	Tertiary Laterite	ironstone	sand	clay
					7.40	26.00		Weathered Proterozoic	clay	sand	quartz
BL7		474355	6183790	185	0.00	0.40		Tertiary Laterite	ironstone	sand	gravel
					0.40	26.00		Weathered Proterozoic ?Granite	clay	sand	quartz

Appendix 3. Details of proposed drilling 2003

Site	Easting	Northing	Elev	Depth-	-To	Top	TYPE	Stratigraphy	Lith 1	Lith 2	Lith 3	Drill	Sample	Comments
1S	485330 MGA	6206170 GDA'94	289 mAHD	0 5 20	5 20 25	**Tpw** **mAHD**	2	Laterite Weathered Archaean Granite Archaean Granite	ironstone clay quartz	clay sand rock	sand gravel (none)	aircore	1 SALT 1	moved 330m S, seep to N **very high**
2E	482740	6204580	235	0 5 25	5 25 30		3 ?1	Possible Cz Weathered Archaean Granite Archaean Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore	1	moved 940m E into catchment to find gw movement in catchment
~~3~~	~~485950~~	~~6204550~~	~~**255**~~	~~0~~ ~~15~~	~~15~~ ~~20~~		~~1~~ ~~?3 ?4~~	Weathered Archaean Granite Archaean Granite	clay quartz	sand rock	ironstone (none)	aircore	~~1~~	**abandoned, very high, ?dry**
4C	472310	6203580	215	0 15	15 20		1 ?3	Weathered Archaean Granite Archaean Granite	clay quartz	sand rock	ironstone (none)	aircore	1	outside catchment for WL ?thin Czs on weathered bedrock
5C	474520	6203340	205	0 5 25	5 25 30		3 ?4	Cz Weathered Archaean Granite Archaean Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore auger1	1 ?2&3	outside catchment for WL ?second shallow bore
6C	476900	6203040	210	0 5 25	5 25 30		3 ?4	Cz Weathered Archaean Granite Archaean Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore auger2	1 ?2&3	outside catchment for WL ?second shallow bore
7S	479670	6201970	215	0 5 25	5 25 30		3 ?4	Cz Weathered Archaean Granite Archaean Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore auger3	1 ?2&3	moved 390m S, outside catchment for WL ?second shallow bore
8C	485980	6201550	225	0 15	15 20		1 ?2	Weathered Archaean Granite Archaean Granite	clay quartz	sand rock	ironstone (none)	aircore	1	moderately high in catchment salt springs in area
9	487800	6202400	**242**	0 5 20	5 20 25		2	Laterite Weathered Archaean Granite Archaean Granite	ironstone clay quartz	clay sand rock	sand gravel (none)	aircore	1	**high in catchment, ?dry, not visited** **move N (or NW) to TYPE 3**
10S	474250	6200070	205	0 5 40 44	5 40 44 45	210	4 ?5	Quaternary Tp & Tpw Weathered Archaean Granite Archaean Granite	sand sand clay quartz	clay lignite sand rock	ferricrete clay (none)	aircore auger4	1 2&3 SALT 2	moved 400m SSW, ?mid channel second shallow bore SAND PROBLEM 1
11C	483840	6200200	215	0 5 40 44	5 40 44 45	210	4	Quaternary Tp & Tpw Weathered Archaean Granite Archaean Granite	sand sand clay quartz	clay lignite sand rock	ferricrete clay (none)	aircore auger5	1 2&3	not in mid channel second shallow bore SAND PROBLEM 2
12C	487200	6200190	225	0 5 40 44	5 40 44 45	220	4	Quaternary Tp & Tpw Weathered Archaean Granite Archaean Granite	sand sand clay quartz	clay lignite sand rock	ferricrete clay (none)	aircore auger6	1 2&3	not in mid channel second shallow bore SAND PROBLEM 3 near drainage divide, check for bedrock
13N	472200	6200590	205	0 5 40 44	5 40 44 45	210	4 ?5?3	Quaternary Tp & Tpw Weathered Archaean Granite Archaean Granite	sand sand clay quartz	clay lignite sand rock	ferricrete clay (none)	aircore auger7	1 2&3	extra site 1750m N of 13 second shallow bore SAND PROBLEM 4 Cz thickness uncertain, ?palaeochannel
13S	472210	6198270	200	0 15	15 20		1	Weathered Archaean Granite Archaean Granite	clay quartz	sand rock	ironstone (none)	aircore	1	moved 580m S
14	479100	6198600	210	0 5 40 44	5 40 44 45	213	4	Quaternary Tp & Tpw Weathered Archaean Granite Archaean Granite	sand sand clay quartz	clay lignite sand rock	ferricrete clay (none)	aircore auger8	1 2&3	not in mid channel, **not visited** second shallow bore SAND PROBLEM 5
15	480800	6199150	215	0 5 40 44	5 40 44 45	213	4	Quaternary Tp & Tpw Weathered Archaean Granite Archaean Granite	sand sand clay quartz	clay lignite sand rock	ferricrete clay (none)	aircore auger9	1 2&3	not in mid channel, **not visited** second shallow bore SAND PROBLEM 6
16N	485460	6199380	222	0 5 40 44	5 40 44 45	218	4 ?3	Quaternary Tp & Tpw Weathered Archaean Granite Archaean Granite	sand sand clay quartz	clay lignite sand rock	ferricrete clay (none)	aircore auger10	1 2&3	moved 680m N second shallow bore, ?perched WL SAND PROBLEM 7
17NE	472530	6197320	205	0 15	15 20		1 ?2	Weathered Archaean Granite Archaean Granite	clay quartz	sand rock	ironstone (none)	aircore	1	moved 180m NE to midslope
18W	474360	6196470	200	0 15	15 20		1 ?3	Weathered Archaean Granite Archaean Granite	clay quartz	sand rock	ironstone (none)	aircore	1	moved 250m W from divide to midslope ?Cz determine geology
19N	476920	6197480	210	0 5 25	5 25 30		3 ?4	Cz Weathered Gneiss Gneiss	clay clay clay	sand sand rock	ironstone ferricrete (none)	aircore auger11	1 ?2&3	moved 140m N to T-junction **+300m past** ?second shallow bore 300m N moves from TYPE 1 to 3
20	487900	6195450	245	0 5 20	5 20 25		2	Laterite Weathered Archaean Granite Archaean Granite	ironstone clay quartz	clay sand rock	sand gravel (none)	aircore	1	outside catchment, **not visited** bore in corner has 2m head, lignites to NW will give WL to Yarnup
21NE	488690	6196240	225	0 5 25	5 25 30		3 ?4	Cz Weathered Archaean Granite Archaean Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore auger12	1 ?2&3	moved 2330m NE just on Tertiary seds ?second shallow bore
22W	481670	6193820	230	0 5 25	5 25 30		3	Cz Weathered Archaean Granite Archaean Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore auger13	1 ?2&3	moved 530m W ?second shallow bore ?window to p/channel, ?fault, ?hydrogeology
23N	479950	6192860	225	0 5 20	5 20 25		2 ?3	Laterite Weathered Archaean Granite Archaean Granite	ironstone clay quartz	clay sand rock	sand gravel (none)	aircore auger14	1 ?2&3	moved 460m N to clay flats, ?hydrogeology ?second shallow bore
24E	474340	6191070	195	0 5 25	5 25 30		3	Cz Weathered Archaean Granite Archaean Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore auger15	1 ?2&3	moved 490m N ?second shallow bore
25SE	479370	6189390	225	0 5 25	5 25 30		3	Cz Weathered Archaean Granite Archaean Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore auger16	1 ?2&3	moved 660m SE, wet heath on clay ?second shallow bore determine (hydro)geology
26S	485150	6188030	210	0 5 20	5 20 25		2	Laterite Weathered Proterozoic Granite Proterozoic Granite	ironstone clay clay	clay sand rock	sand gravel (none)	aircore	1	moved 270m S, heath on clay
27N	483920	6187160	198	0 5 25	5 25 30		3	Cz Weathered Proterozoic Granite Proterozoic Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore auger17	1 ?2&3	moved 360m N, heath on clay ?second shallow bore
28N	485140	6187020	201	0 5 25	5 25 30		3	Cz Weathered Proterozoic Granite Proterozoic Granite	clay clay quartz	sand sand rock	ironstone gravel (none)	aircore auger18	1 ?2&3	moved 220m N, near heath on clay ?second shallow bore
29	478000	6181000	181	0 5 40 44	5 40 44 45	176	4 ?5	Quaternary Tp & Tpw Weathered Proterozoic Granite Proterozoic Granite	sand sand clay quartz	clay lignite sand rock	ferricrete clay gravel (none)	aircore auger19	1 2&3	?mid channel, **not visited** second shallow bore SAND PROBLEM 8 **MS & IW to discuss**
TOTALS				190+915		8	29							

Appendix 4 – Surface water resources (notes by P. Taylor for Hearn in prep.)

Catchments

In hydrological terms the Lake Muir-Unicup catchments are highly complex, encompassing an abundance of wetlands of varying size, character, water quality and landscape position. Some of these, such as Lake Muir itself, are almost exclusively internally draining i.e. they are effectively local sinks, whereas others overflow to downstream wetlands or in some cases into other waterways such as the Frankland or the Tone River. In addition there are numerous constructed channels that drain farming land and divert surface run-off either into wetlands or directly into the Tone river. Subject to rainfall and evaporation and also connectivity with groundwater, the wetlands may be either; permanent or ephemeral; and naturally fresh, naturally saline or seasonally alternating. Depending on their position in the landscape, they may belong to perched groundwater systems that overlie poorly conductive clays or they may be "windows" to deeper, regional groundwater aquifers. For convenience and where obvious distinctions can be made between watersheds, the study area has been divided into a number of (informally named) sub-catchments (Fig. 2). Also shown are the relative size and distribution of the main wetlands within the catchment and their interconnectivity via the major watercourses and constructed drains (Map 1).

Lake Muir Catchment

Lake Muir is the major sink for most of the water in the region and acts as a large shallow evaporating basin which usually dries up to a salt pan in summer. It has been known to overflow very infrequently to the southwest through swamps into the Deep River. There are two main inlets for surface water into the lake; one to the north passes under the Muir Highway bringing water along artificial channels from beyond Red Lake through Cowerup Swamp; the second, on the eastern side of the lake at Mulgarnup Bridge, is fed from the Mulgarnup Swamp complex again assisted by artificial channels. Flows into the Mulgarnup Swamp complex originate from three distinct sources. Rising in Quindinup Nature Reserve, to the south west of Yarnup Swamp is Pindicup Creek, a major watercourse that flows westwards, where it meets Pindicup Lake and then turns south to flow under the Muir Highway into the complex. From the north east, De Campo's creek flows from the hilly country on either side of Unicup Road to the Muir Highway where it is diverted westwards long the road edge until it passes under the highway and through an artificial drain across private property. Further to the east, Noobijup Creek rises in the hilly country on the southern and western sides of Noobijup Road and with the assistance of substantial artificial drainage passes under the Muir Highway into another artificial drain into Byenup Lagoon. Byenup Lagoon itself overflows to the north once sufficiently full (usually each year) into the Mulgarnup Swamp complex. To the south of Byenup lagoon are the fresh water lakes Tordit-Gurrup and Neeranup which in average to wet years overflow into Byenup Lagoon.

Lake Unicup Catchment

Lake Unicup is also a closed system with virtually all the catchment being to the east of the lake. Almost certainly, the lake is a window to the regional groundwater system. The bulk of the flows originate from Kulunilup Nature Reserve and are directed towards the lake along constructed drains under Unicup Road. Since the construction of Unicup Road, outflows from Kulunilup Nature Reserve are restricted to two culverts, the northern one directing flows through a series of constructed drains under Wingebellup Road and ultimately into the Tone River and the other directing flows to Unicup Lake. Anecdotal evidence suggests that the relative contributions of these two diversions have been manipulated historically in order to control the level of water in Unicup Lake for recreational activities. It is not clear whether the flows through the two culverts are ever from discrete sources or whether there is always mixing of inflows to the reserve. Outflows measured from the two culverts in 1999 would suggest that the wetlands fill up first in which case mixing is the likely more scenario.

Kulunilup North Catchment

This catchment is treated separately even though it is most likely in parallel with the Lake Unicup catchment as explained above. It drains the most northerly and elevated areas of the region through a culvert under Bokerup Road. As mentioned above, flows exit Kulunilup under Unicup Road and are then directed through a series of constructed drains to the Tone River.

Kodjinup Catchment

- Mordalup, Little Unicup, Buranganup into Kodjinup NR across Pindicup Rd
- Constructed drainage in Kodjinup NR
- Overflows from SW Unicup rarely
- Exit via drain under Buranganup Rd into Tone

Cobertup Catchment

The only other potential sink is a small, naturally saline wetland in Location No. 12561 to the south of the Muir Highway which appears to be an endpoint for flows originating in the southeast of the catchment and which pass through the Cobertup and Pinticup Swamp complex. Again, anecdotal evidence suggests that this water and also some proportion of flows from Noobijup Creek may historically have flowed out of the catchment into the Frankland River which is located just to the south of this point.

Yarnup Swamp Catchment

The outflow from Yarnup Swamp, in the eastern part of the catchment, is similarly directed into the Frankland River via a series of constructed drains, which loop around to the north of Yarnup.

Previous Hydrological Studies

Wetland Monitoring - J.Lane, CALM, Busselton

Monitoring of six wetlands within the Muir-Unicup catchment as part of a greater study of wetlands of south western Australia was initiated by Jim Lane of CALM (Busselton) and is still on-going. Lake depths at surveyed gauge boards, salinity and pH have been recorded from as early as 1977, originally every two months but in later years only in September and November. The wetlands surveyed were Lake Muir, Lake Unicup, Byenup Lagoon, Poorginup Lagoon, Tordit-Gurrup Lagoon and Yarnup Swamp. Determining trends in salinity levels was complicated by the influence of annual rainfall, in terms of both its magnitude and timing, which affected lagoon gauge levels. In general, high water level equated to low salinity due to dilution effects and conversely, low water levels equated to high salinity due to evaporative concentration. To enable year to year comparisons to be made, September and November water levels were plotted against salinity levels measured at the same time. It is expected that, in a wetland at equilibrium in terms of the salt and water balance, a fairly linear but negative correlation would exist between depth and salinity. Wetlands that begin to experience an increase in salt load due to saline run-off for example would show a deviation from that linear relationship. Similarly, any other sudden change to flow regimes in terms of volume or quality would be reflected in corresponding deviations from the stable relationship. The following figures illustrate this concept for the six wetlands surveyed.

- Lake Muir - The relationship between salinity and depth is not well defined prior to 1990, possibly due to sampling problems. After 1990 however there is a strong negative and linear relationship, indicating no significant changes in the salinity of the lake in the last 7 years.
- Lake Unicup - The relationship between salinity and depth changed significantly after 1987 when the depth was consistently higher without a corresponding reduction in salinity. It changed again after 1991 when salinity increased without a corresponding decrease in depth. The cause of these changes is unknown but may be related to a combination of changes in surface water management and rising water tables. Salinity measured in 1999 was 4 times higher than for the same depth 10 years previously.
- Tordit-Gurrup Lagoon - Correlation between salinity and depth has generally been high, despite the large fluctuations in water level, indicating no long term trends.
- Poorginup - Correlation between salinity and depth has generally been good but note that fluctuations in water level and salinity have been relatively small.
- Byenup Lagoon - No measurable change in the relationship between salinity and depth at Byenup Lagoon was detected since monitoring began in 1978 until 1991. From 1992-99 records indicate a shift in the relationship suggesting an increasing salt load.
- Yarnup Swamp - The relationship between salinity and water level in September at Yarnup Swamp has changed since monitoring began in 1981. For the period 1994 to 1998 the salinity of the swamp was significantly higher (for the same water level) than for the period 1989 to 1993 which in turn was higher than for the period 1981 to 1988. Note also that the lowest recorded water levels in September have also increased over the same period, suggesting that the vegetation of the swamp is subject to longer periods of inundation. The increase in both salinity and inundation at Yarnup Swamp is cause for concern and indicates that management of this reserve and its catchment should be given high priority.

Physico-chemistry, aquatic macroinvertebrates and fish survey - A.W. Storey (for CALM)

In 1996 Andrew Storey was contracted by CALM to "Assess the nature conservation values and physico-chemistry of the Lake Muir peat swamp system". Initially, 15 wetlands were visited three times each (October 1996, January and May 1997) and a range of chemical, physical and biological variables were recorded, including salinity and water level. Another four wetlands were visited in August and September 1997 and a further 8 only once in October 1997.

AgWA/CALM stream monitoring 1999–2000

The aim of this project was to investigate the movement of water and salt through the catchment, specifically to determine major flow paths, flow rates, timing of flows and quantities of salt being transported. A number of sites were selected for spot monitoring (see fig). These were generally culverts and pipes under roadways where accurate dimensions of flow could be obtained. Sites were visited up to 16 times during the year. On each occasion, depth of flow was measured either manually or read from a gauge board, the time taken for water to flow through each culvert (a known length) was recorded and the electrical conductivity of the water was measured using a portable WTW LF318 EC meter. Volumetric flow rates were calculated from depth and velocity data and conductivity values were converted to concentrations of salt (mg/L). This enabled mass flow rates of salt (g/s) to be calculated for each site for each visit. An average value was determined for the year and converted to an annual tonnage by assuming flows over 150 days.

Publication feedback form

The Water and Rivers Commission welcomes feedback to help us to improve the quality and effectiveness of our publications. Your assistance in completing this form would be greatly appreciated.

Please consider each question carefully and rate them on a 1 to 5 scale, where 1 is poor and 5 is excellent (please circle the appropriate number).

How did you rate the quality of information?

1 2 3 4 5

How did you rate the design and presentation of this publication?

1 2 3 4 5

How can it be improved?

1 2 3 4 5

....

How effective did you find the tables and figures in communicating the data?

1 2 3 4 5

How can they be improved?

....

....

....

How did you rate this publication overall?

1 2 3 4 5

If you would like to see this publication in other formats, please specify. (Eg. CD)

....

Please cut along the dotted line on the left and return your completed response to:

Publications Coordinator
Water and Rivers Commission
Level 2, Hyatt Centre
3 Plain Street
East Perth WA 6004
Fax: (08) 9278 0639

WATER AND RIVERS COMMISSION

Hyatt Centre
3 Plain Street
East Perth
Western Australia 6004

Telephone (08) 9278 0300
Facsimile (08) 9278 0301
Website: www.wrc.wa.gov.au