R Shams

Government of Western Australia

Assessment Of Hydrogeology And Water Quality Inputs To Yalgorup Lakes

HYDROGEOLOGY REPORT NUMBER HR90

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WATER AND RIVERS COMMISSION

ASSESSMENT OF HYDROGEOLOGY AND WATER QUALITY INPUTS TO YALGORUP LAKES

BY

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Hydrogeology Report NO. HR90

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Cover picture showing thrombolite reef in Lake Clifton

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BACKGROUND

The Yalgorup Lakes (Fig. 1), within the Yalgorup National Park, are located some 100 km south of Perth within the coastal belt. The Yalgorup Lakes, as part of the Peel-Yalgorup wetland system, are recognised under the Ramsar Convention as wetlands of international importance. Two of the largest lakes in the park are Lake Clifton and Lake Preston. The northernmost lake, Lake Clifton, is of particular significance for the living thrombolite reefs along its northeastern shore and is, therefore, an important wetland of Australia. Microbialites are defined as organosedimentary deposits formed from interaction between benthic microbial communities and detrital or chemical sediments. The Lake Clifton microbialites, exhibiting a clotted internal structure, are classified as thrombolites. Studies of the thrombolites indicate that a source of low salinity, alkaline groundwater, and low nutrient status is essential for their survival and that this condition prevails at Lake Clifton.

In recent years, there has been increasing pressure to develop the land around the lakes for horticulture and residential properties. Development would involve clearing of vegetation from the land inducing soil erosion, causing an increase in groundwater recharge, promoting an increase in groundwater withdrawal, and possibly increasing soil nutrients. The watertable configuration would then alter and water quality may deteriorate, thus posing a threat to the ecology of the lakes and to the continued growth of the thrombolites.

Yalgorup National Park occupies a major portion of the land to the north and west of the lakes, and a small area to the east of the lakes. The rest of the area is privately owned. Current landuse is adversely affecting the water resources of the region. A nutrient plume within the groundwater has been identified under land development southeast of Lake Preston, and algal blooms have appeared in the lakes, indicating increasing nutrient input to the lakes.

Development proposals, therefore, warrant a clear understanding of the hydrogeology of the area, including detailed investigations of the watertable configuration, groundwater throughflow, groundwater recharge, water balance, groundwater quality, nutrient fluxes to the lakes, and interaction between lake and groundwater.

The objectives of this investigation are to:

- establish the watertable configuration,
- assess the availability of fresh water,
- determine the groundwater flow pattern between Harvey Estuary and Lake Clifton,
- assess the impact of landuse on groundwater quality, and
- determine the relative degree of nutrient input to the lakes from groundwater.

The results of this investigation will provide scientific information that will assist Government in making decisions for natural resources management, water resources allocation, and the formulation of land development and catchment management strategies. Moreover, local communities will benefit by gaining awareness of the beneficial use of resources and the environment, and an understanding of the importance of appropriate landuse practices.

This investigation was funded by the Commonwealth Government National Landcare Program (NLP) and by the Water Authority of Western Australia (WAWA). The Groundwater Resource Appraisal Section of the Water and Rivers Commission (WRC) (formerly part of the Hydrogeology Branch of the Geological Survey of Western Australia (GSWA)), carried out the hydrogeological investigation, provided technical assistance on hydrogeological issues and prepared this report. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) provided professional advice. The Department of Conservation and Land Management (CALM) carried out a study of nutrient inputs to the lakes from surface water (funded by WAWA), and provided field assistance. Agriculture Western Australia (Ag WA) investigated the impacts of horticulture on nutrient enrichment of the groundwater. Local Government agencies, the Mandurah City Council, Harvey and Waroona Shire Councils, and the local community also provided support.

This report is a supporting document to the final NLP report.

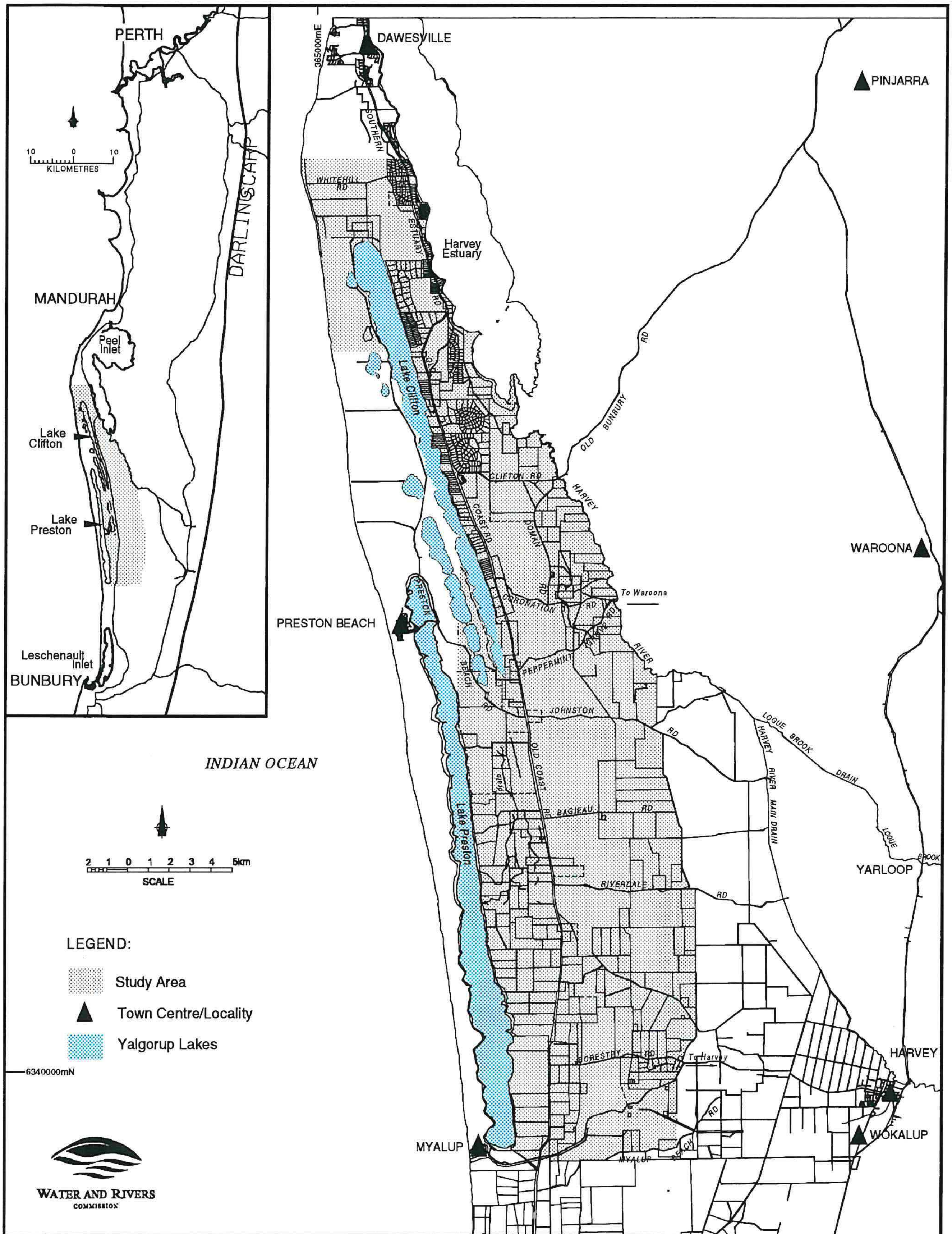

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Figure 1 - Yalgorup Lakes area

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YALGORUP LAKES

Location

The investigation area, comprising the Yalgorup Lakes and the surrounding area of about 150 km^2, is between Mandurah and Bunbury. It lies within Australian Map Grid (AMG) ^{63}82000 N and ^{63}30000 N on the Swan Coastal Plain. The area is bounded to the north by White Hill Road, and to the south by the southern tip of Lake Preston. In the north, the eastern boundary of the area coincides with the western shore of Harvey Estuary and Harvey River. In the south, the eastern boundary is 6 km east of Lake Preston. The western boundary coincides with the coastline in the north and the eastern shore of Lake Preston in the south (Fig. 1).

Climate

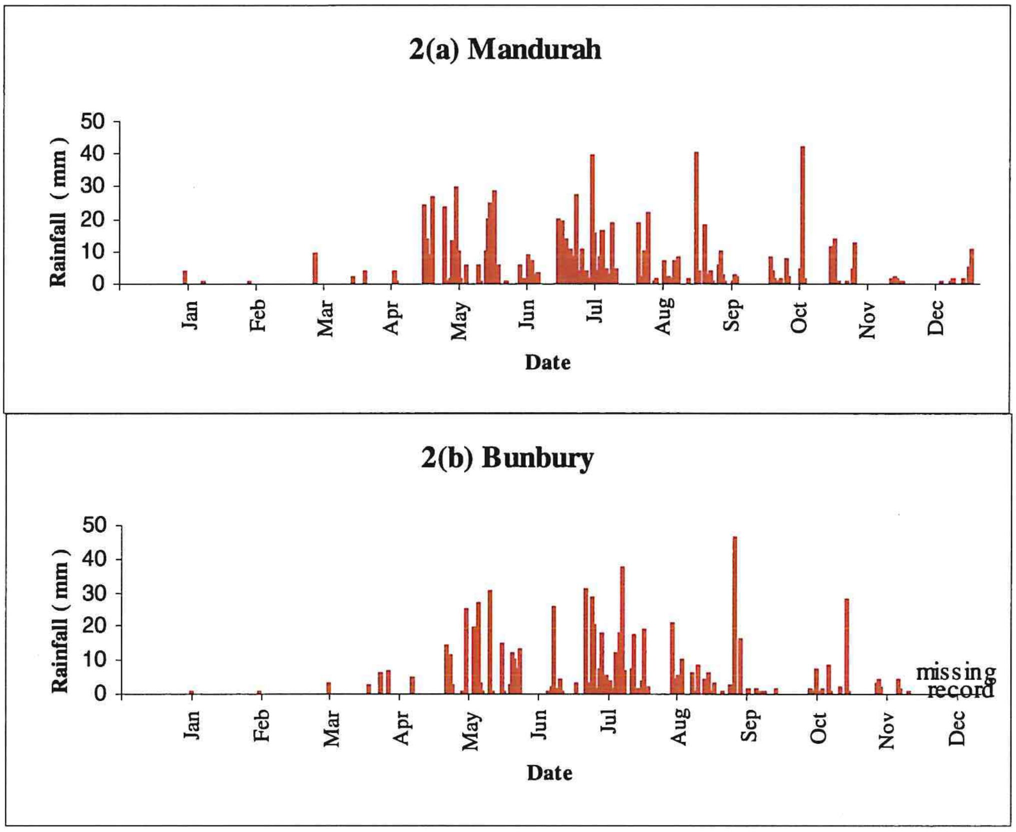
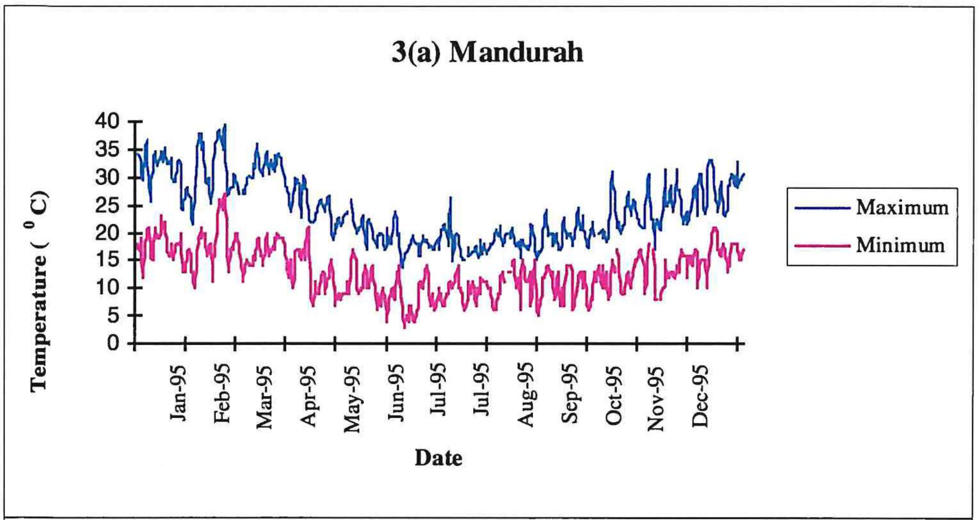


Figure 2. Rainfall, 1995.

The climate of the region is Mediterranean in type, with cool wet winters and warm to hot, dry summers. Meteorological data (Figs 2, 3 and 4) were collected at Mandurah, Bunbury, and Wokalup (Fig. 1) by the Bureau of Meteorology. Rainfall recorded at Mandurah and Bunbury for 1995 was 882 mm and 716 mm respectively, and the total open pan evaporation recorded at Wokalup in 1993 was 1681 mm.



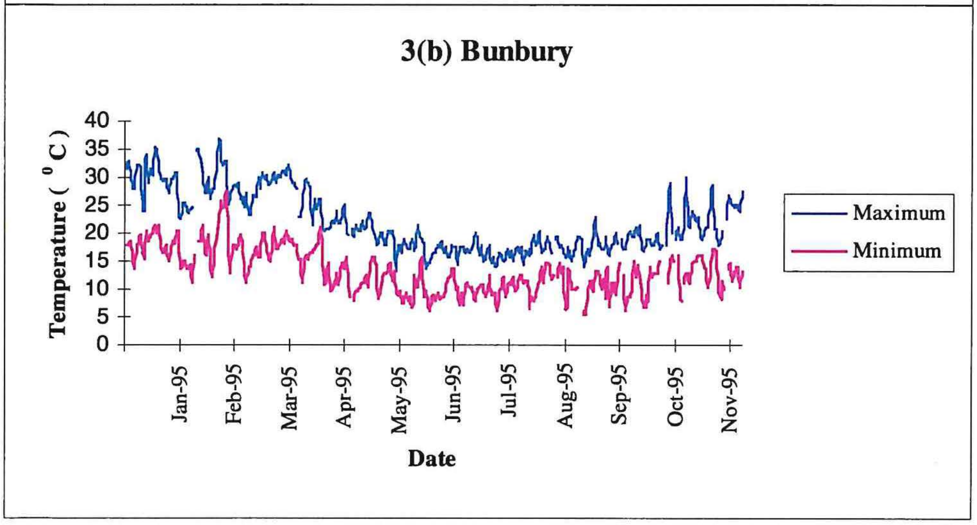


Figure 3. Maximum–minimum temperature, 1995.

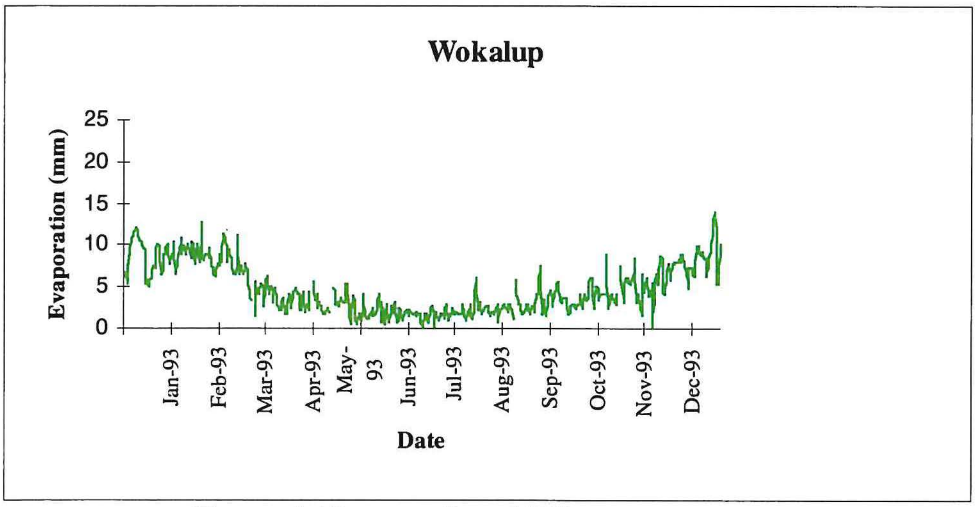


Figure 4. Evaporation, 1993.

Geomorphology and topography

The topography of the area consists of gently undulating limestone hills and elongated lakes known as the Yalgorup Lake system (Fig. 5). The geomorphic elements are as described by McArthur and Bettenay (1974). The limestone hills, which form the north–south Spearwood Dune System and attain a maximum elevation of 70 m AHD (Australian Height Datum), slope gradually westward to the parallel lake system. In the northern area, the crest of the hills lies 2 km east of Lake Clifton and overlooks Harvey Estuary to the east. In the south the crest lies 5 km east of Lake Preston, and abuts the Bassendean Dune System to the east. The Bassendean Dunes are eolian deposits of Bassendean Sand that form a gently undulating sandplain topography reaching 30 m AHD. Low-lying terraces that are subject to seasonal inundation fringe the lakes.

Landuse

There is a wide range of landuses in the area (Fig. 6) including National Parks, logging in State Forests, quarries, irrigated horticulture, pasture and rural residential. A significant horticultural industry has developed in the southern part of the area, to the east of Lake Preston on the Spearwood Dunes. A variety of vegetables are grown on a commercial scale. On the eastern shore of Lake Clifton, this industry is on a smaller scale and over a much smaller area than that of the Lake Preston area. There are other forms of horticulture in the area including small orchards, minor turf farms and nurseries, and cattle and sheep graze on land adjacent to Lake Preston. Cleared rural residential blocks, ranging in sizes from 2–10 ha, exist between Lake Clifton and Harvey Estuary and along the entire eastern shore of Lake Clifton. The native forest to the north and west of Lake Clifton and that on several disconnected land blocks east of the lake, and the chain of lakes, are all vested with CALM as part of Yalgorup National Park. The eastern part of the study area contains State Forest pine plantation (CALM estate) and is logged periodically. Several quarries are operated within the State Forest, government land and private properties.

Vegetation

Yalgorup National Park contains various stands of native vegetation, ranging from forests, woodlands, and heaths to herbfields. Some of the more common plants are tuart, peppermint, jarrah, marri, banksia, sheoak and acacia. Others, such as flooded gum, paperbark, saltwater paperbark, rushes and sedges fringe the margins of the lakes (CALM, 1995). Irrigated crops consist of potatoes, carrots, onions, celery, cabbages, cauliflower, broccoli, grapes and citrus fruit.

Drains and rivers

The Harvey River main drain carries excess runoff from Harvey River to the Harvey River diversion drain, which discharges into the ocean near Myalup (Fig. 7). These man-made channels drain the low-lying area east of Lake Preston and alleviate waterlogging. A network of drains constructed in the eastern part connects the Harvey River in the north to Wellesley River in the south (Fig. 7). A few drains

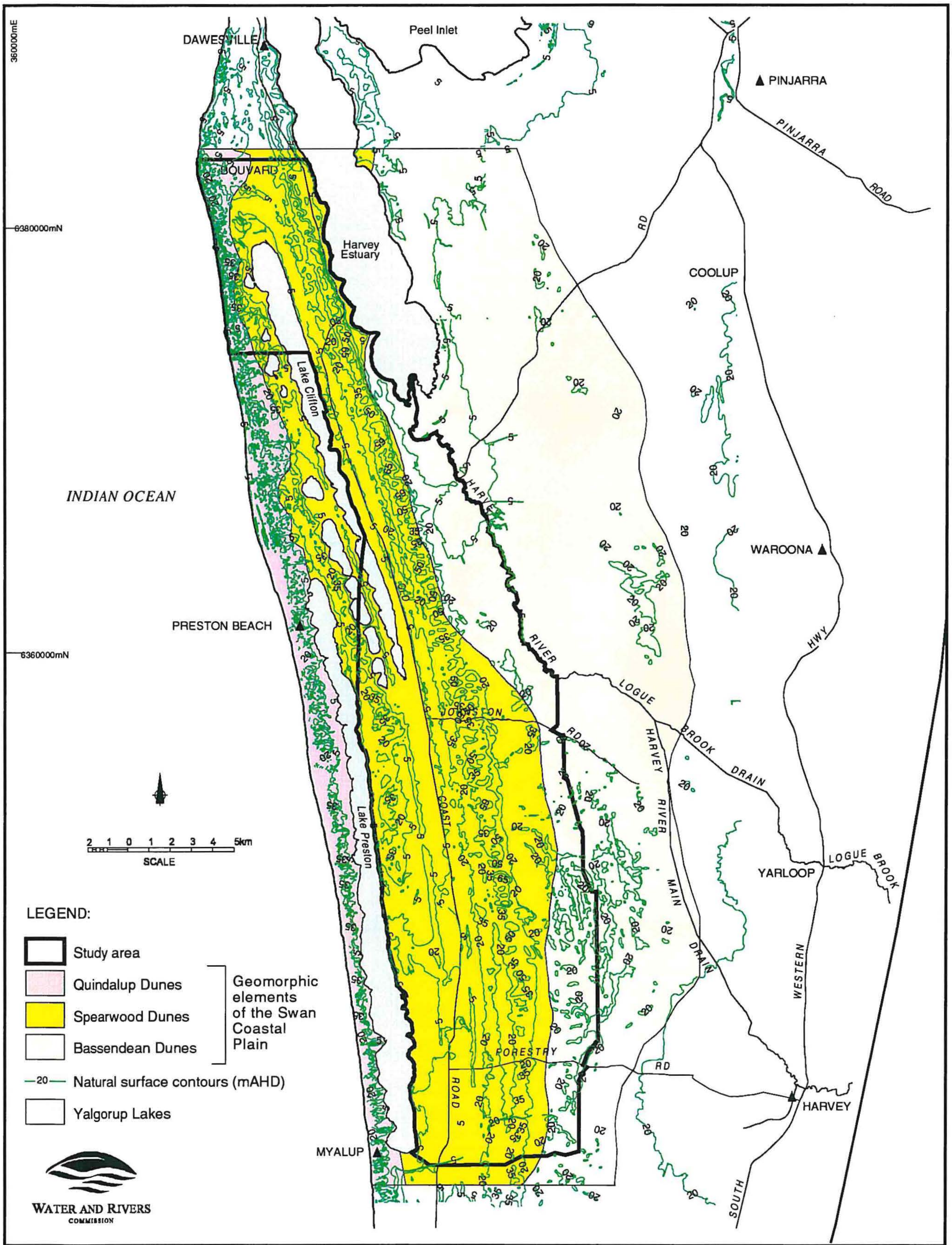


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Figure 5. Geomorphology and topography

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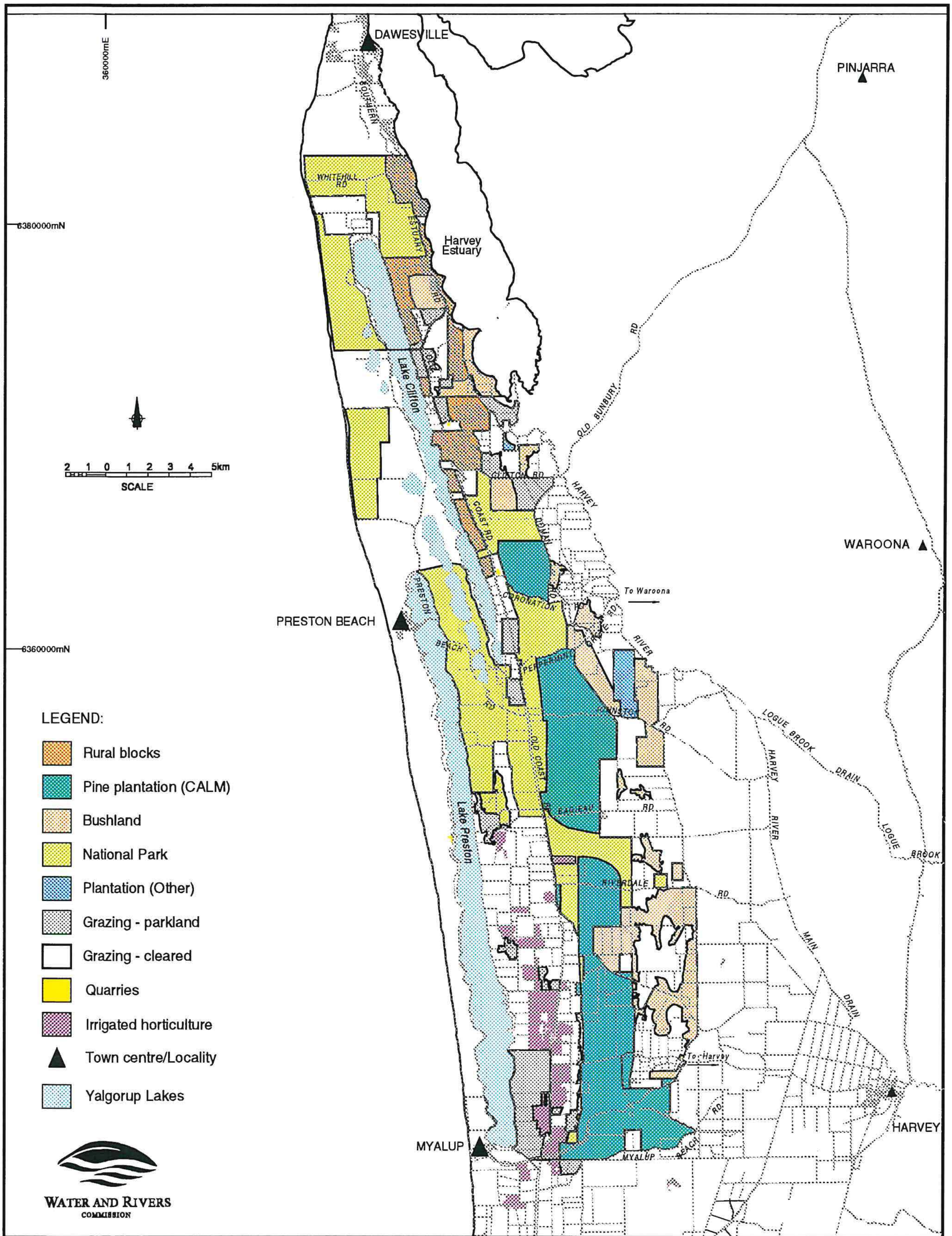

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Figure 6. Landuse

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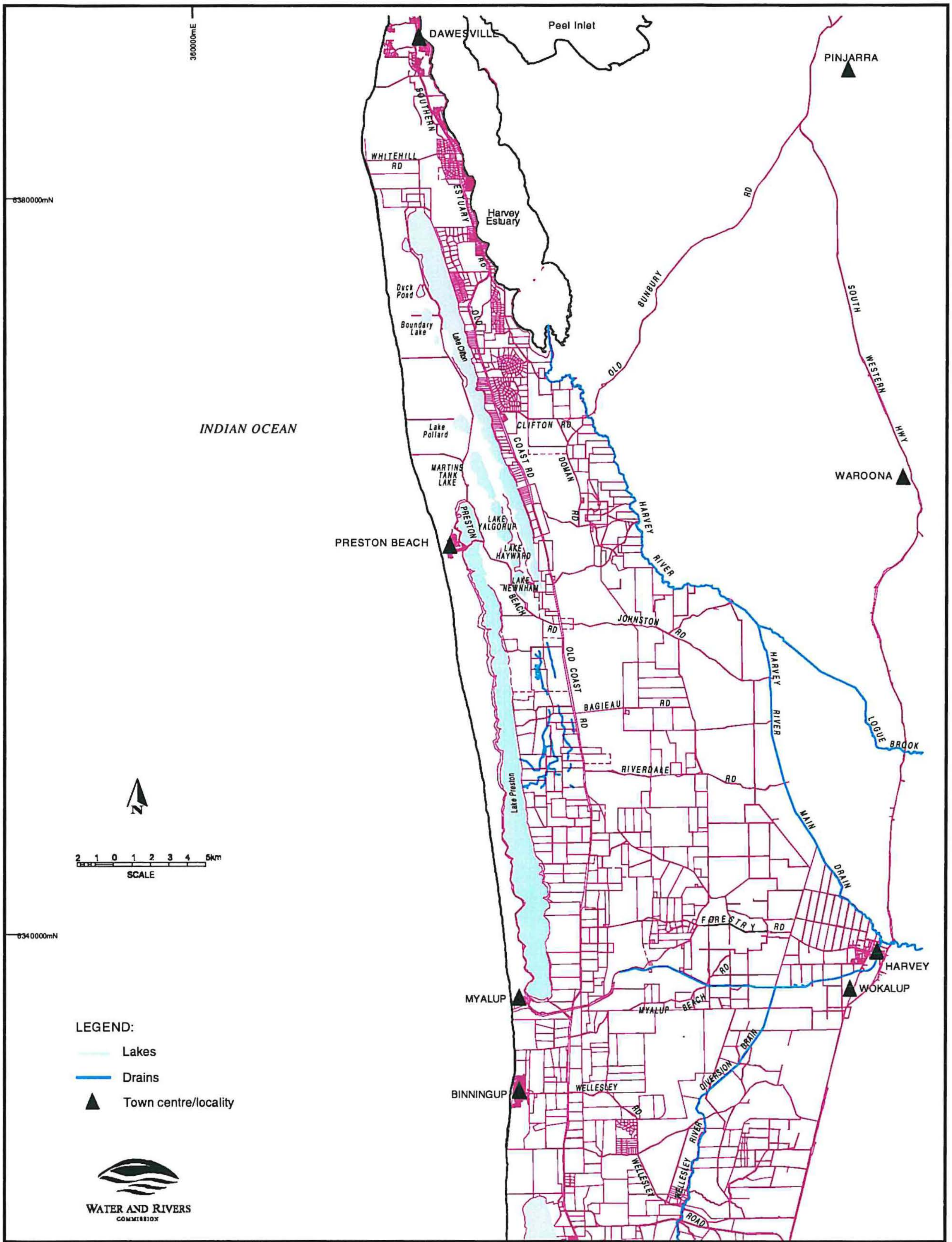

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adjacent to Lake Preston (Fig. 7) concentrate surface runoff from horticulture and pasture land and discharge into the lake.

Lakes

The Yalgorup Lakes, part of the internationally recognised Peel–Yalgorup wetland system, comprise two major lakes, Lake Clifton and Lake Preston separated by a string of smaller lakes.

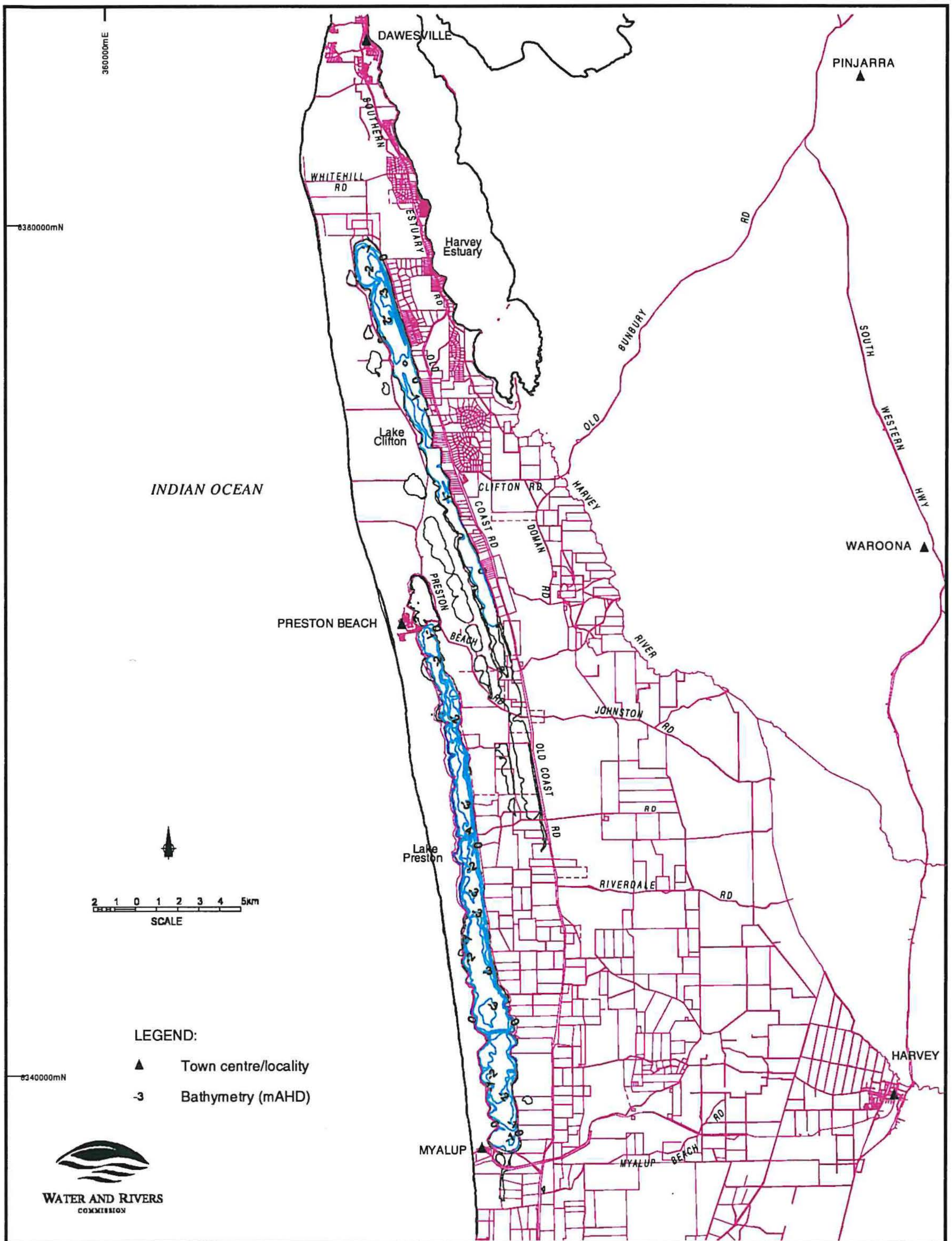
Lake Clifton (Fig. 7) is the farthest inland. The northern end being deeper (Table 1) than the southern end (Fig. 8) and during summer the southern half dries up leaving a much smaller area of water (Commander, 1988). The most spectacular feature associated with this lake is the living thrombolites occurring as a 30 m wide platform along the eastern shore of the lake. They exist in a 14 km length from the north end of the lake, between 50 and 100 m from high water mark in the shallow water zone. Along a part of this margin, the thrombolites form a reef. The survival of thrombolite is attributed to the inflow of low salinity, alkaline water along the zone of groundwater discharge (Moore, 1993).

Table 1. Morphology of the lakes

Lake	*Maximum area of water* km^2	*Length* *km*	*Width* *km*	*Maximum depth* *m*
Clifton	17.8	21.5	1.5	3
Preston	29.6	27.5	2.0	3

Lake Preston (Fig. 7) is the largest lake (Table 1) and is closest to the coast. The lake is divided by a causeway at the northern end and has maximum depth (Table 1) at the southern end (Fig. 8).

Seven smaller lakes lie between Lake Clifton and Lake Preston (Fig. 7). They are, from the north, Boundary, Pollard, Martins Tank, Yalgorup, Hayward, North Newnham and South Newnham Lakes. Other minor wetlands near Boundary Lake are Swan Pond, Duck Pond and Lindas Lagoon.



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*	INITIAL	DATE	Figure 8. Bathymetry of Lake Clifton and Lake Preston	MAP INDEX
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PREVIOUS INVESTIGATIONS

The geology and hydrogeology of the superficial formations between Pinjarra and Bunbury have been described by Deeney (1989a) and more locally by Commander (1988) in the area of the coastal lakes. Sanders (1974) and Wharton (1980) have also discussed the hydrogeology of the area.

As part of the groundwater resource evaluation drilling program of the Perth Basin, the Harvey drilling project (Deeney, 1989b) consisted of an east–west transect of bores near Waroona. The results of other investigations by the GSWA are contained in reports by Commander (1975, 1984).

George and Furness (1979) investigated the relationship between soil salinity and hydrogeology in the Harvey–Waroona area, and descriptions of geomorphology and soils are included in publications by McArthur and Bartle (1980) and McArthur and Bettenay (1974). The history of natural vegetation has been reported by Gough and Portlock (1995).

Extensive work has been carried out on the thrombolites of Lake Clifton by Moore (1993), and the environmental status of Yalgorup lakes is discussed by Burne and Moore (1987). Water chemistry, stable isotopes, nutrient status, lake-bottom sediments and aspects of lake–groundwater interaction have been addressed in the reports of Moore (1987), Moore and Turner (1988) and Rosen et al. (1992).

WAWA (1989) produced a groundwater management review for the South West Coastal Groundwater Area. Soil capability and land resources of the region were discussed by Environmental Capability (1993). Some of the more recent reports on the region are the management plan for Yalgorup National Park (CALM, 1995), draft environmental criteria for Lake Clifton landuse proposal (Environmental Protection Authority, 1995) and draft Coastal and Lakelands Planning Strategy (Ministry of Planning, 1995).

INVESTIGATIONS

The investigations include drilling of bores, and monitoring for water level and water quality variations of groundwater. Monitoring bores were drilled at selected sites for hydrogeological data collection. Privately owned bores were inspected in areas that were not covered by the monitoring bores. Shallow bores were installed along the eastern shore of Lake Clifton and Lake Preston to monitor the quality of groundwater seepage into the lakes. All the bores were surveyed to AHD and AMG coordinates, and have been registered on State Water Resources Information System (SWRIS) database.

Selection of transects and monitoring of bore sites

Four east–west transects (Fig. 9, Table 2) were selected following lines of bores of the Lake Clifton Project (Commander, 1988). Bore sites were selected considering the following aspects:

- areas of proposed rural development,
- landuse,
- bore construction (drilled depth, slotted interval, internal diameter) of existing monitoring bores that meet the monitoring requirements of this study; or have scope for modification to required specifications, and
- accessibility of sites.

The Y1 transect coincides with Line-A of the Lake Clifton Project, and is in natural bushland. Bores were installed to monitor waterlevel and water quality variations of the groundwater under conditions unaffected by development.

The Y2 transect is parallel to Mount John Road. Bores Y2/1 and Y2/2 are designed to monitor changes in water quality and level on the west side of Lake Clifton, and bores Y2/3 to Y2/6 (along Mount John Road) provide these data between Harvey Estuary and Lake Clifton. The area around Mount John Road is of particular interest because of the thrombolite reef along the lake foreshore at the western end of road, and of increased development.

The Y3 transect coincides with Line-B of the Lake Clifton project. The transect is south of the Harvey Estuary and traverses an area of Yalgorup National Park and rural land. This area was selected because, an area along the eastern shore of Lake Clifton is earmarked for future rural development (Ministry for Planning, 1995).

The Y4 transect coincides with Line-E of the Lake Clifton project, and is parallel to Forestry Road. This transect traverses an area under grazing, horticultural, and logging of pines in the State Forest. The transect is located in an area where groundwater is increasing in salinity due to horticultural activity (WAWA, 1989).

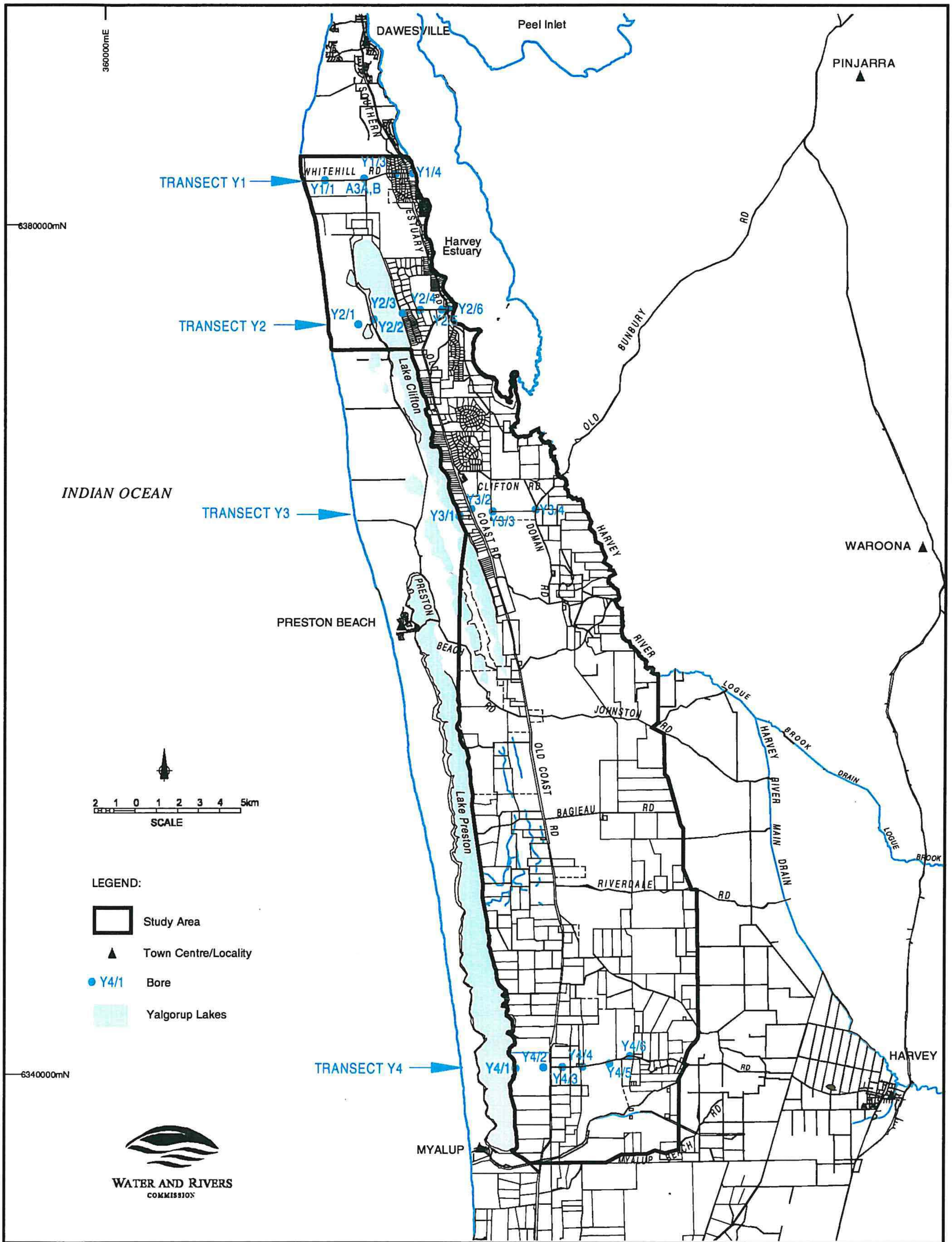

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Figure 9. Location of transect bores

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Table 2. Transects and monitoring bore sites

Transect and site		*Location*	*Total*	*drilled*	*modified*	*Existing site*	*Landuse*
Y1	1/1	White Hill Road (road reserve on northside)	2	1	1	LC site A1	Native bush
	1/2	White Hill Road (road reserve on northside)	2		2	LC site A3	Native bush
	1/3	White Hill Road (road reserve on southside)	2	1	1	LC site A4	Native bush
	1/4	Estuary Road (road reserve), west of Harvey Estuary	2	1	1	LC site A5	rural
Y2	2/1	West of Lake Clifton (within Yalgorup National Park)	2	2			Native bush
	2/2	West shore of Lake Cifton (Yalgorup National Park)	2	2			Native bush
	2/3	East shore of Lake Clifton (west end of Mount John Road)	1			CSIRO 19	Native bush
	2/4	Mount John Road (road reserve on northside)	2	2			Rural zone
	2/5	Mount John Road (road reserve on northside)	2	2			Rural zone
	2/6	Southern Estuary Road (road reserve), west of Harvey Estuary	2	2			Rural zone

Notes: LC = Lake Clifton project.

Table 2. (*contd.*)

Transect and site		*Location*	*Total*	*drilled*	*modified*	*Existing site*	*Landuse*
Y3	3/1	East shore of Lake Clifton (Yalgorup National Park)	2	2			Native bush
	3/2	National Park (east of Old Coast Road)	3	2	1	LC site B4	Native bush
	3/3	National Park (east of Old Coast Road)	3	3		LC site B5	Native bush
	3/4	Doman Road (road reserve), 5 km south of Harvey Estuary	3	2	1	LC site B6	Rural/pasture
Y4	4/1	East shore of Lake Preston (on private property)	2	1	1	LC site E1	Pasture
	4/2	Forestry Road (northside road reserve)	3	1	2	LC site E2	Horticulture
	4/3	Forestry Road (northside road reserve)	3	2	1	LC site E3	Horticulture
	4/4	Forestry Road (northside road reserve)	3	1	2	LC site E4	Pine plantation
	4/5	Forestry Road (northside road reserve)	2	1	1	LC site E5	Pine plantation
	4/6	Forestry Road (northside road reserve)	1	1		LC site E6	Native bush

Notes: LC = Lake Clifton project.

Drilling and establishment of monitoring bores

Twenty-nine multi level bores were established at 18 sites. Drilling and bore construction details are discussed in Shams (1997). During drilling water samples were collected at 1 m intervals and tested for salinity since the entire area is underlain, at depth, by saline groundwater. Drilling was continued until the groundwater salinity reached more than 2000 mg/L. General guidelines for salinity of irrigation water (AWRC, 1988) classifies 1500 mg/L as the upper limit of fresh water, recommended use of which is for most purposes including upper limit for humans. In this investigation, salinity level of 2000 mg/L instead of 1500 mg/L is taken as the upper limit of low-saline water and the interface between low- and high-saline water[1].

Bores are equipped with PVC casing, slotted with 1.5 to 3 m intervals for the intermediate and deeper bores, and 3 to 6 m intervals for watertable bores. The bores requiring modification were cement plugged to required depths. All bores were developed by air lifting until the water was noticeably silt free.

Shallow bores, six on the eastern shore of Lake Clifton and two on the eastern shore of Lake Preston, were established upgradient of the high water mark, (Fig. 10, Appendix 1). The bores were bailed until the water was acceptably silt free.

Fifteen privately owned bores were inspected near Mount John Road, Armstrong Hill Drive and Tuart Grove Avenue (Fig. 11, Appendix 1). The bores are specified with the prefix YPR.

Sampling and monitoring

The objective is to monitor waterlevel and quality variation of groundwater in the bores. Waterlevels are measured at regular intervals to record seasonal fluctuation of the watertable to help determine hydraulic gradient, locate the groundwater divide, direction and velocity of groundwater flow. This information is used to determine the groundwater throughflow, discharge and water balance. Pumped water samples were collected for nutrient and major component analyses to determine the quality of low-saline groundwater, and nutrient flux into the lakes.

Monitoring and sampling was carried out in 44 transect bores, eight lakeside shallow bores, 29 private bores, and 26 GSWA and WAWA bores (Fig. 12, Appendix 1). Of all the bores, water levels were measured at 67 sites (Fig. 13) and bore water samples were collected for quality analyses at 55 sites (Fig. 14) according to the program in Table 3.

Table 3. Monitoring and sampling program

	1995		*1996*					
Monitored	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*
WL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
QL	Yes	No	No	No	No	Yes	No	No

Note: WL= water level; QL= water quality

[1] Low-saline water is all water <2000 mg/L and high-saline water is all water >2000 mg/L.

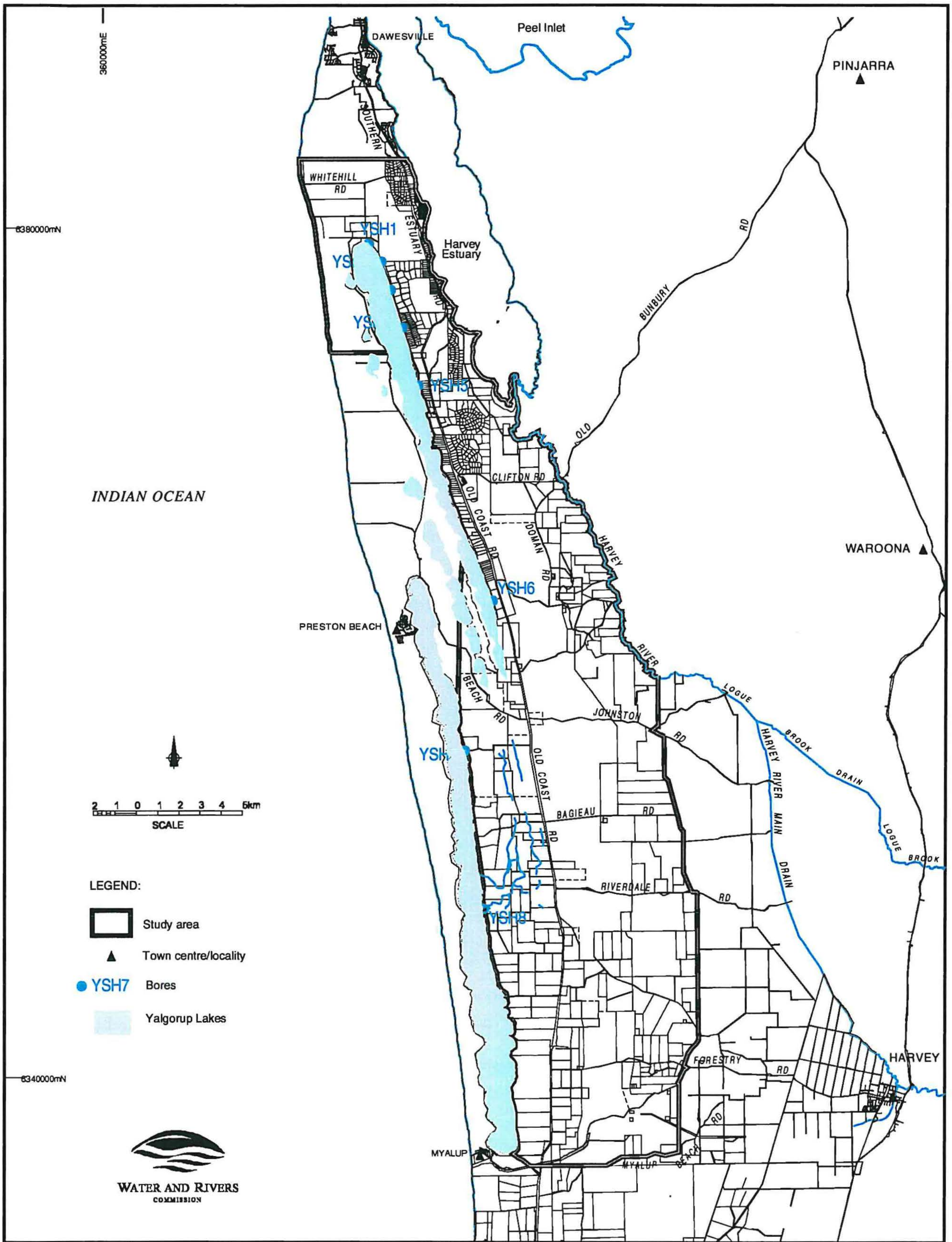

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Figure 10. Location of lakeside shallow bores

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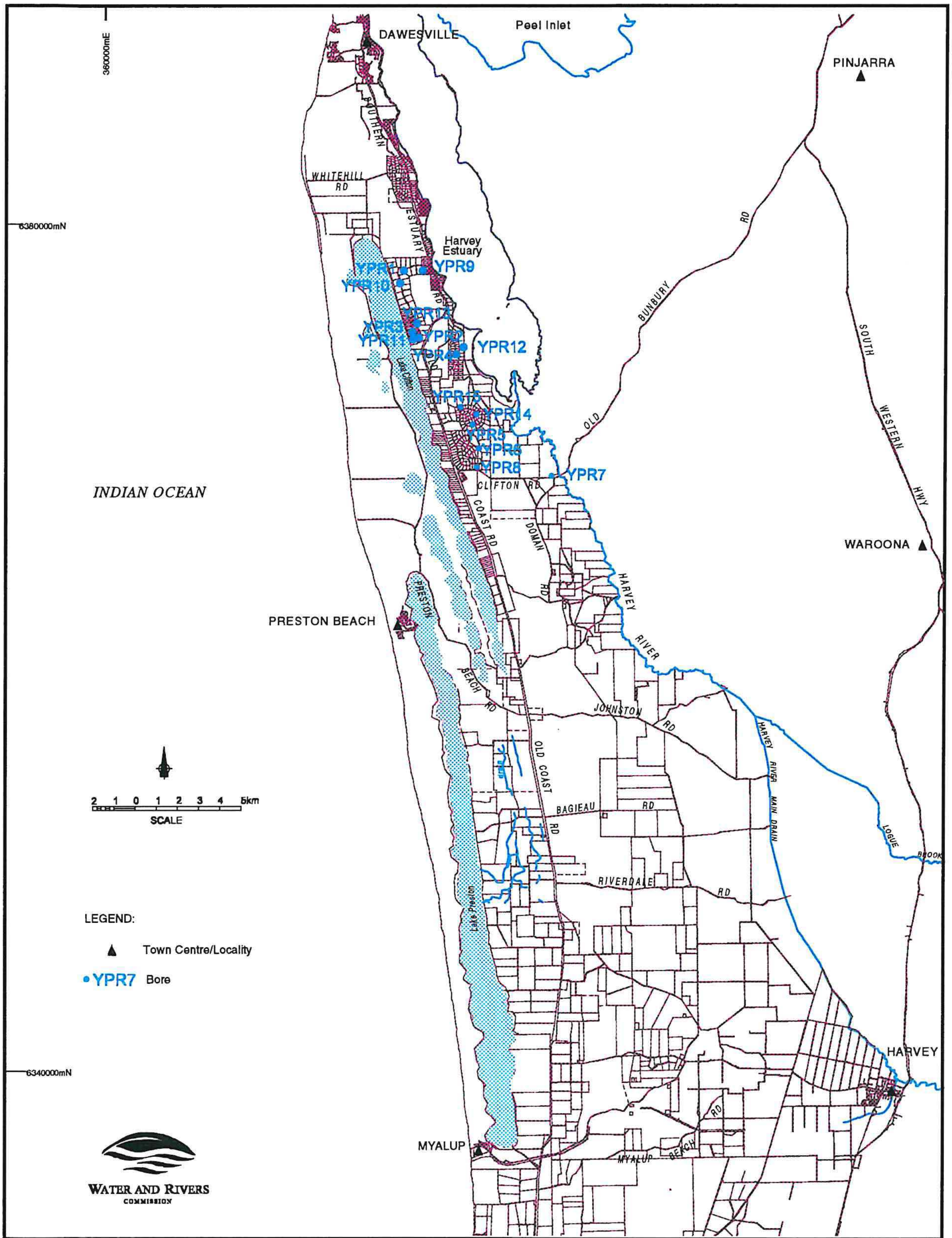

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Figure 11. Location of privately owned bores

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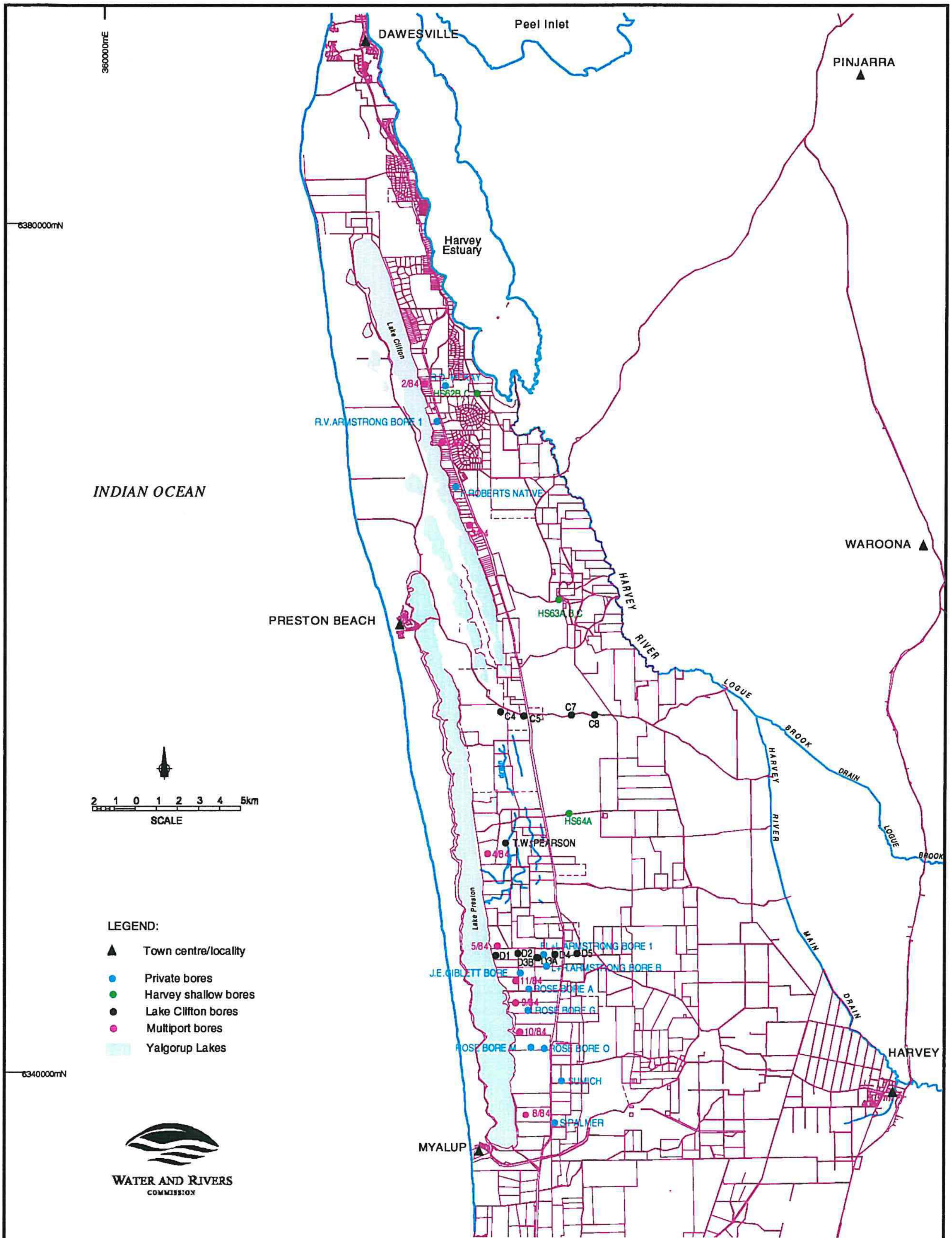

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Figure 12. Location of south-west region bores

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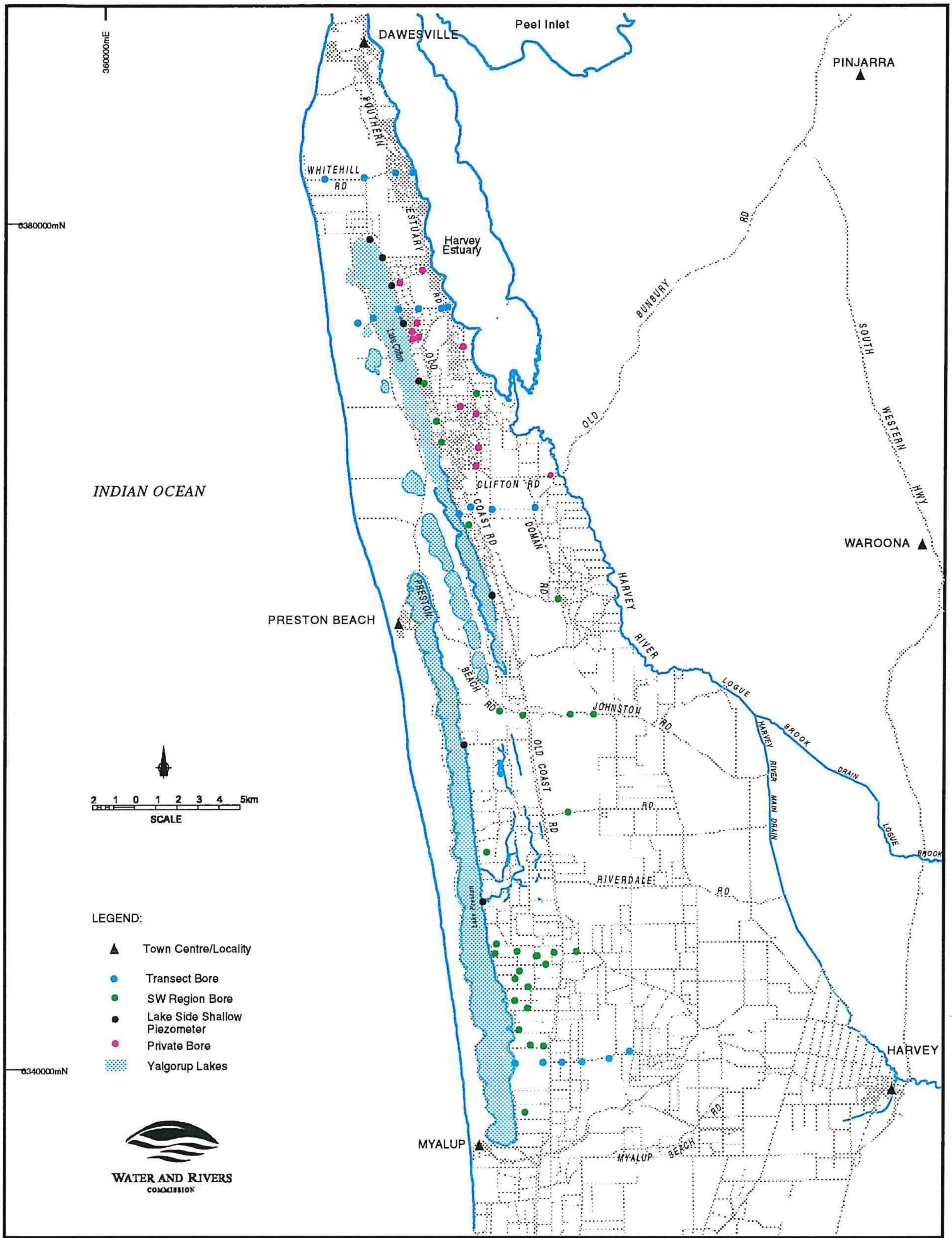

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Figure 13. Location of waterlevel monitoring bores

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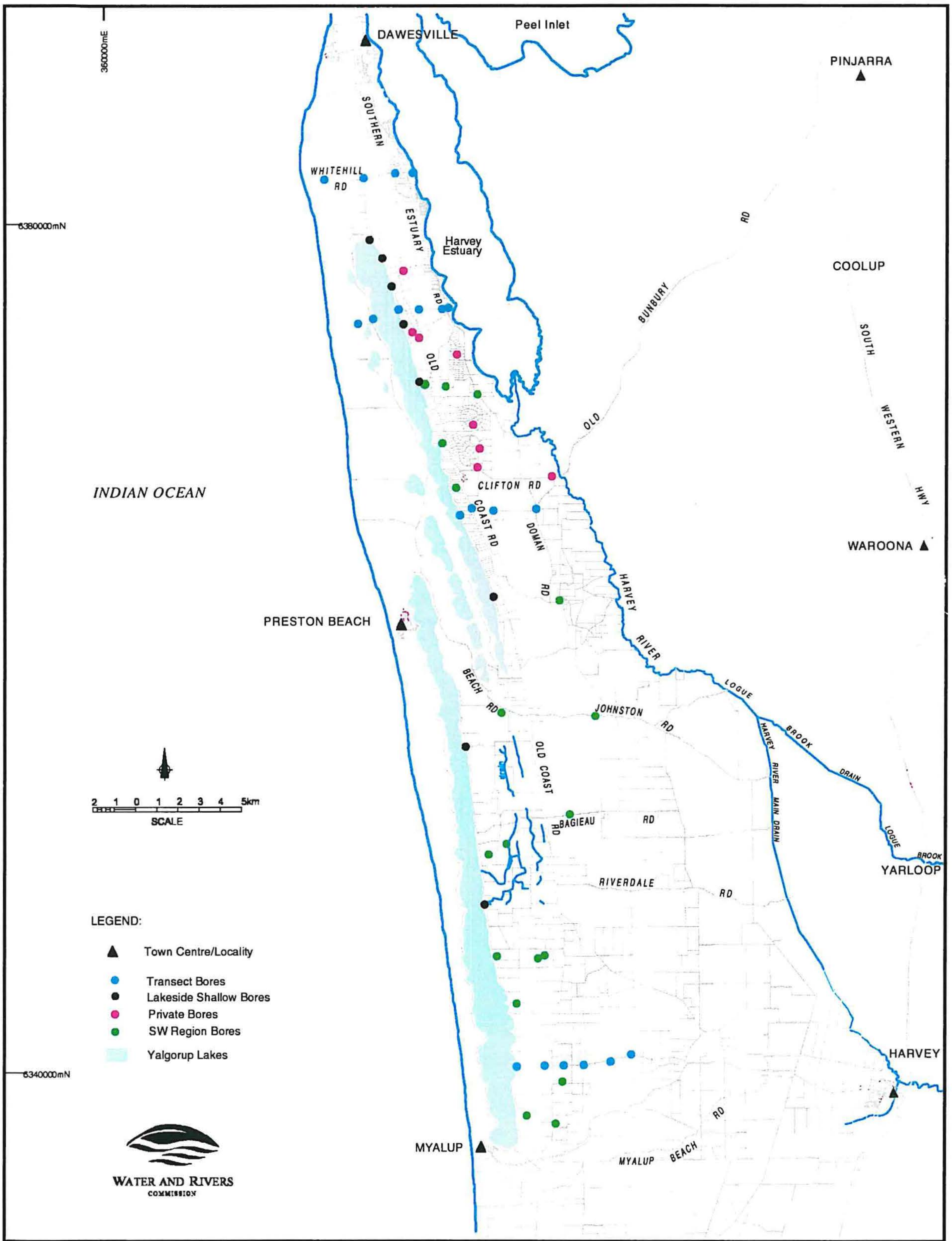

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Figure 14. Location of water quality sampling bores

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At each sampling, field measurement was obtained (Table 4). The first sample was analysed for major-component, and all samples were analysed for-nutrients (Table 4).

Table 4. Water quality parameters

Analysis type	*Parameters*
Field analysis	Dissolved oxygen (DO), redox potential (Eh) alkalinity (pH), electrical conductivity (EC)
Lab analysis	**Major components :** pH, EC, colour, Al, Fe, Mn, Na, K, Ca, Mg, Cl, Si, S, SO_4, CO_3, CO_2, HCO_3, NO_3.
	Nutrients : Total phosphorus Orthophosphate Organic phosphorus Total nitrogen Nitrate + nitrite nitrogen TKN or organic nitrogen Ammonia nitrogen

GEOLOGY

Structural setting

The area is part of the Swan Coastal Plain. It lies in the southern part of the Dandaragan Trough of the Perth Basin, and north of the Harvey Ridge. The Perth Basin was formed by the sagging of Precambrian basement rocks west of the Darling Fault (Fig. 15). On the east of the Darling Fault, Precambrian rocks outcrops on the Yilgarn Craton. In the area, a sedimentary succession some 8000 m thick (Deeney, 1989a) and ranging in age from Silurian to Quaternary was deposited in the Perth Basin, of which the superficial formations extend to a maximum depth of only 70 m. The stratigraphy is discussed in order of deposition to a depth of about 200 m, and the sequence is summarised in Table 5 and shown in sections of Figures 16–19.

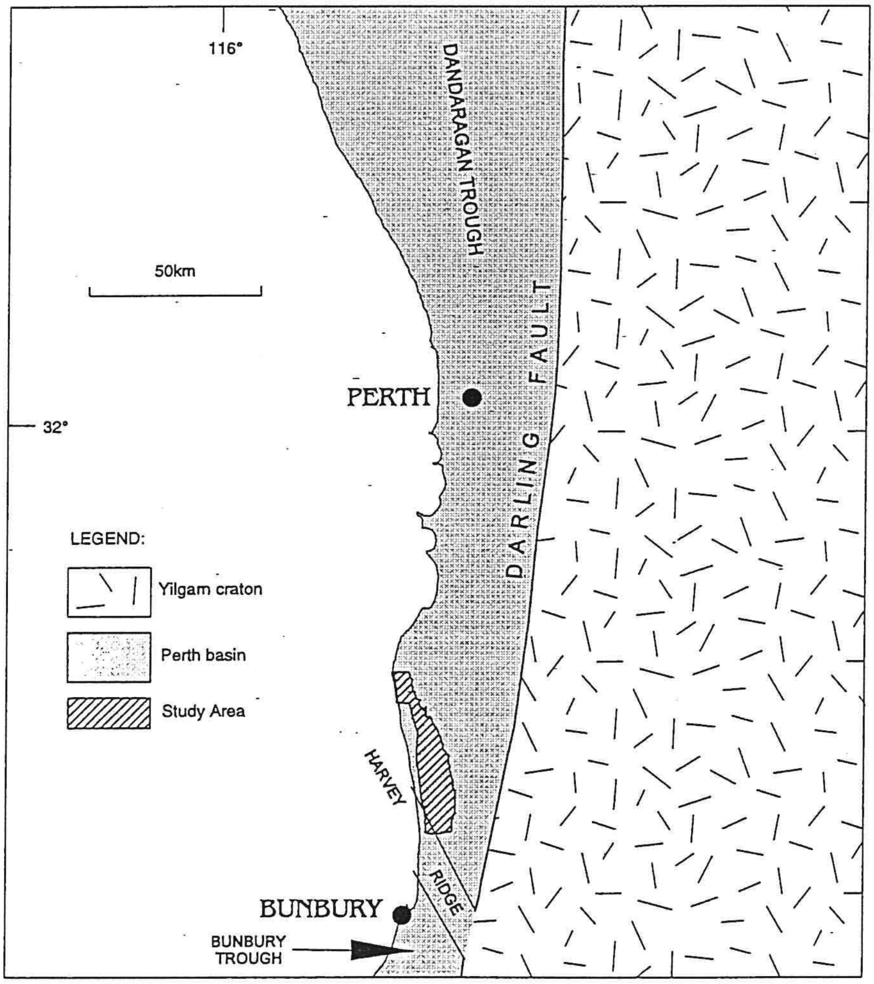

Figure 15. Structural setting (after GSWA, 1990).

Table 5. Stratigraphic sequence.

Age		*Stratigraphy*	*Maximum thickness (m)*	*Lithology*
Cainozoic	Quaternary – Late Tertiary	Safety Bay Sand	10	Shelly sand
		~~	unconformity	~~~~~~~~~~~~~
		Tamala Limestone	70	Limestone; ferruginous sand; fossiliferous, vuggy limestone
		~~	unconformity	~~~~~~~~~~~~~
		Bassendean Sand	32	Sand, silt and clay
		Gnangara Sand	7	Sand, quartz and feldspar pebbles, silt, clay
		~~	unconformity	~~~~~~~~~~~~~
		Ascot Formation	10	Sand, glauconitic clay, abundant fossils
~~	~~~~~~~	~~~~~~~~~	unconformity	~~~~~~~~~~~~~
Mesozoic	Cretaceous	Leederville Formation	175	Interbedded sandstone, siltstone and shale

Stratigraphy

Cretaceous

The **Leederville Formation** is unconformably overlain by the superficial formations. As reported by Deeney (1989b), the top of the formation occurs at approximately -30 m AHD, it is 175 m thick, and thins towards the east and the west. It comprises interbedded sandstones, siltstones and shales. The sandstones are grey, silty, weakly cemented, poorly sorted, and fine- to coarse-grained. The siltstones and shales are dark grey and mottled olive green or brown.

Late Tertiary–Quaternary

The **superficial formations** (collective term) are late Tertiary (Pliocene) to Quaternary in age (Davidson, 1995), and in the area comprise the following sequences in order of deposition.

The **Ascot Formation** (previously known as the Jandakot Beds) lies in the eastern part of the area (Y3/4, Y4/4, Y4/5) and is unconformably overlain by Gnangara Sand. The Ascot Formation consists of moderately cemented, grey to fawn, calcareous sand and clay, with abundant shells and coarse, frosted quartz.

TRANSECT -Y1 (WHITE HILL ROAD)

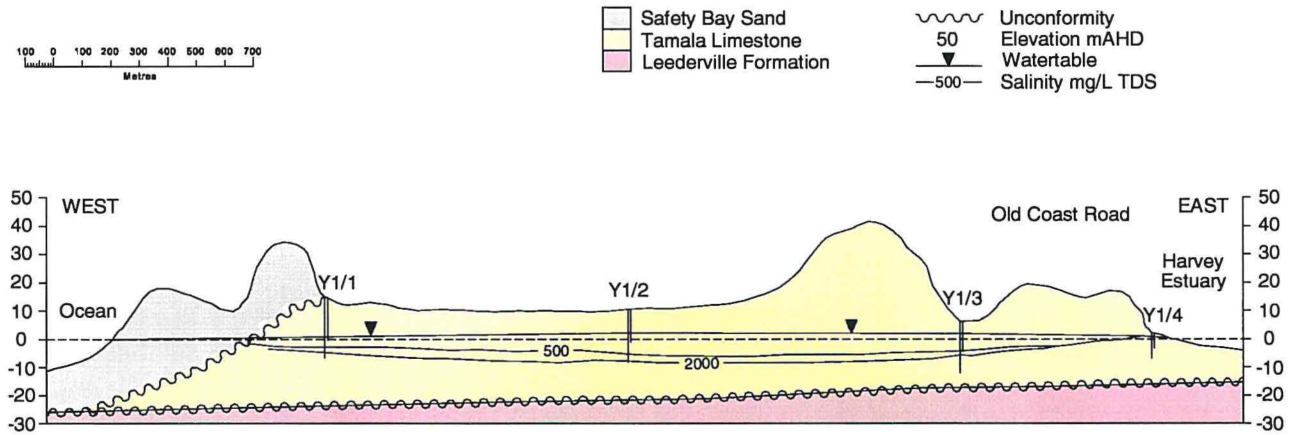

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Figure 16. Geological section of transect Y1

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TRANSECT -Y2 (MOUNT JOHN ROAD)

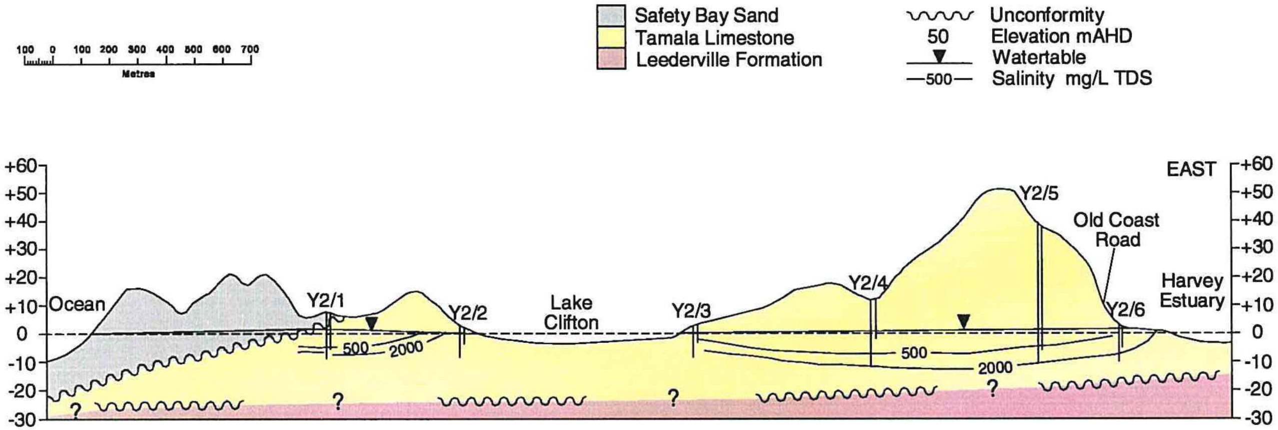

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Figure 17. Geological section of transect Y2

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TRANSECT-Y3 (SOUTH OF OLD BUNBURY ROAD)

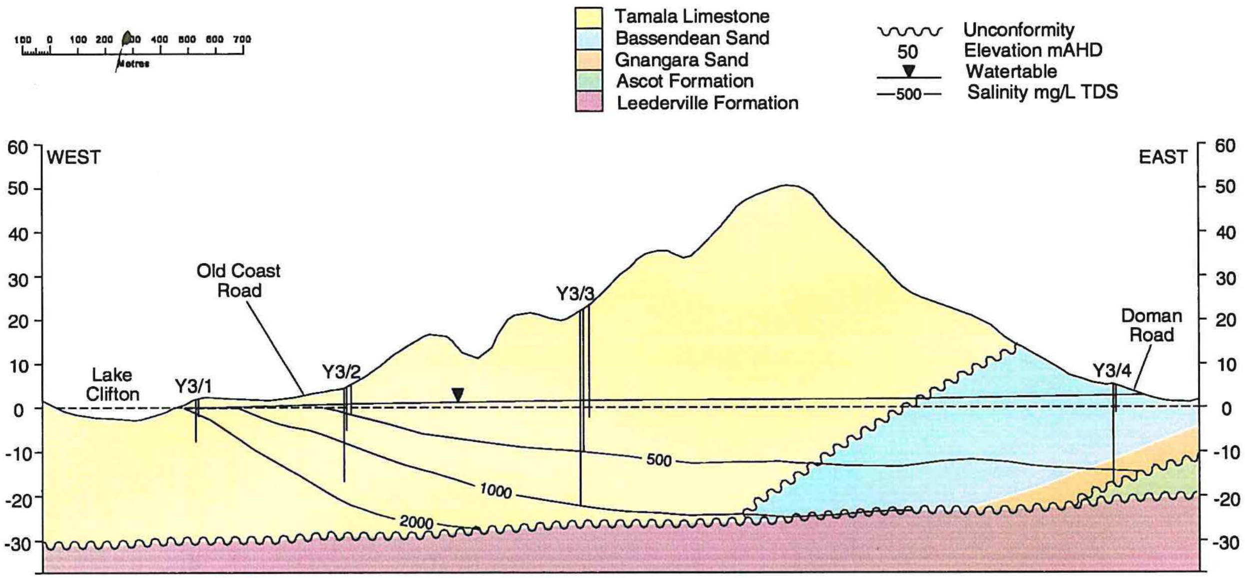

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Figure 18. Geological section of transect Y3

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TRANSECT -Y4 (FORESTRY ROAD)

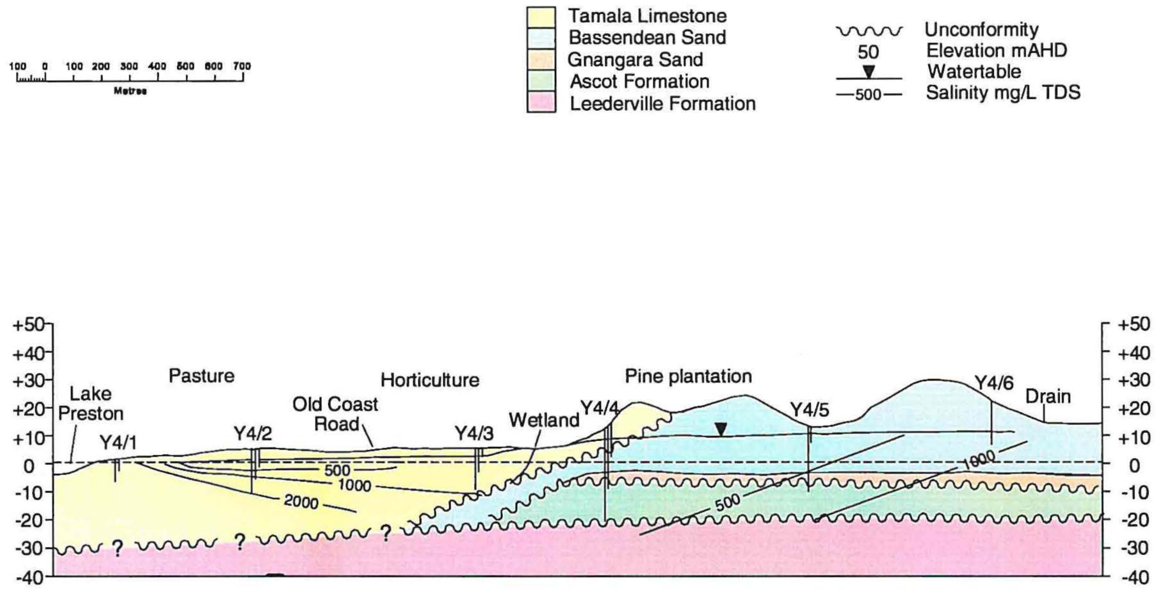

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Figure 19. Geological section of transect Y4

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The **Gnangara Sand,** encountered in the eastern bores Y3/4, Y4/4 and Y4/5, ranges in thickness from 1 to 7 m and is conformably overlain by Bassendean Sand. It consists of dark grey, clayey sand with abundant pebbles and gravel of subrounded to rounded quartz and felspar. There are thin beds of dark grey, poorly sorted clay within the sequence.

The **Bassendean Sand**, which form the land surface in the eastern part of the area (Y3/4, Y4/5, Y4/6) and to the west (Y4/3, Y4/4), is unconformably overlain by the Tamala Limestone in the west. It ranges in thickness from 15 to 20 m and consists of light grey quartz sand that is generally fine- to medium-grained, and subangular to subrounded. It contains some dark, heavy minerals and grey, puggy clay. Near the watertable there is a thin band of highly ferruginized sand, or several bands alternating with grey sand. This layer of limonite-cemented sand is colloquially known as 'coffee rock'.

The **Tamala Limestone** comprises limestone and sand, covers in most of the area and, depending upon topography, has a maximum thickness of 70 m beneath the hills. The limestone is creamy yellowish-grey to white with medium- to coarse-grained frosted quartz. The limestone is fossiliferous, vuggy, friable and well-cemented forming pinnacle structures. In the southern part of the area the formation commonly contains clay. Sand from leached limestone, overlies the limestone and consists of reddish brown to yellow grey frosted quartz of variable grain size and roundness. Near the estuary (Y1/4, Y2/6), Tamala Limestone comprises interbedded clay and clayey sand.

The **Safety Bay Sand** occurs in the western part of the area (Y2/1), west of Lake Clifton, and is about 10 m thick. It unconformably overlies the Tamala Limestone and consists of brown to grey, silty sand and weakly cemented shelly sand, medium-grained subrounded quartz, silt-size heavy minerals, and abundant specks of organic matter.

HYDROGEOLOGY

The hydrogeology of the area is discussed by Deeney (1989a, 1989b) and Commander (1988). The stratigraphic units of the superficial formations are in hydraulic connection and form a regional unconfined aquifer known as the superficial aquifer. The superficial aquifer is recharged from rainfall infiltration. The Leederville aquifer is a major confined aquifer comprising the Cretaceous Leederville Formation. Recharge to the Leederville aquifer in the Yalgorup Lakes area occurs by downward leakage from the superficial aquifer and by groundwater flow from the east.

A groundwater divide exists between the Yalgorup lakes and Harvey Estuary. West of the divide, groundwater flows westward to discharge into the lakes, and east of the divide, groundwater flows eastward to discharge into Harvey Estuary and Harvey River. A groundwater divide also exists to the west of the lakes between the Yalgorup lakes and the ocean. East of the divide, groundwater flows eastward to discharge into the lakes and west of the divide, groundwater flows westward to discharge into the ocean.

In the north a lens of low-saline water (less than 2000 mg/L) overlies high-saline water in the superficial aquifer. In the south, the zone of low-saline water extends to the base of the superficial aquifer. A density boundary represented by 2000 mg/L isohaline contour, and acting as a zone of mixing occurs between the upper low-saline water and the lower high-saline water, and this boundary is known as the saline interface. In the north, the interface is lens-shaped (Figs 16 and 17) lying at 10 m below watertable at the centre of the lens. In the south, the interface is wedge-shaped (Figs 18 and 19) lying at 20–30 m below watertable at its maximum depth. The depth to watertable ranges from 2 to 35 m below ground surface. Near the discharge areas (lakes and estuaries), the low-saline zone thins out and the interface is close to the watertable.

The coastal lakes form an integral part of the groundwater flow-system, where both Lake Clifton and Lake Preston act as groundwater sinks. The salinity in Lake Clifton ranges from 15 000–26 000 mg/L, and in Lake Preston the salinity is lower in the north (8000–20 000 mg/L) and higher in the south (40 000–90 000 mg/L). Both lakes are underlain by hypersaline (>40 000 mg/L) groundwater. The lake waterlevel fluctuates seasonally between 0.85 and -0.1 m AHD in Lake Clifton, and between 0.45 and -0.4 m AHD in Lake Preston. The lake level is a function of rainfall, groundwater discharge and evaporation.

In describing the hydrogeology, reference is made to subareas of the 'South West Coastal Groundwater Area' as defined in WAWA (1989). The following subareas (Fig. 20) fall within the area:

1. northern part of Coastal,
2. White Hills,
3. Island Point,
4. Lake Clifton,
5. Colburra Downs,
6. western part of Harvey, and

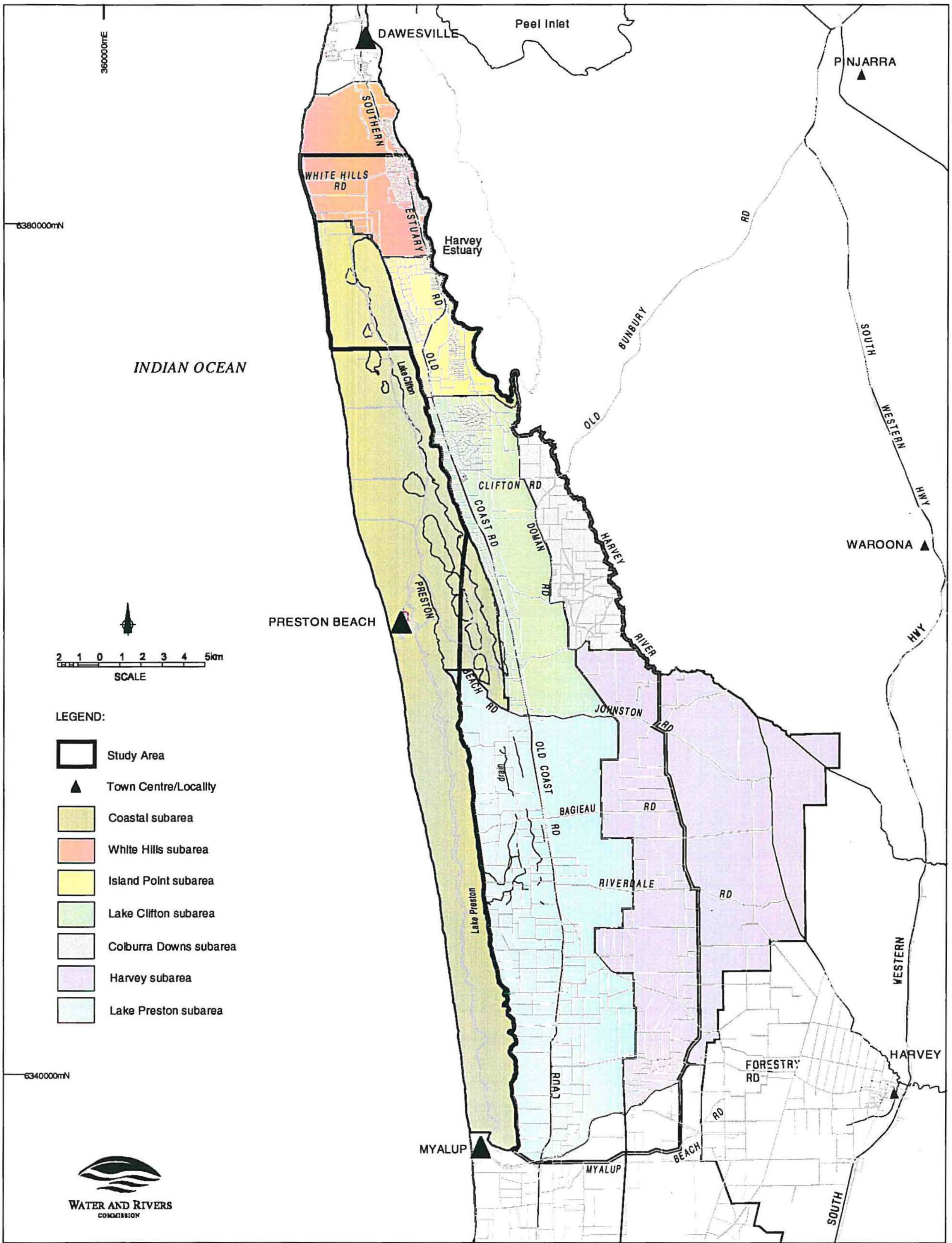

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Figure 20. South west region groundwater subareas

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7. Lake Preston.

Aquifer material and thickness

This project deals with the superficial aquifer only, the top of which is delineated by the watertable, with the base lying at -20 to -30 m AHD, and sloping gently from east to west. The hydrogeology refers only to the upper low-saline (<2000 mg/L) part of the superficial aquifer.

In the area, the superficial aquifer generally consists of Tamala Limestone. However, for part of Colburra Downs, Lake Preston and Harvey subareas, the Tamala Limestone interfingers with and overlies the older sediments and the aquifer may also include the Bassendean Sand and Gnangara Sand. To the west of Lake Clifton, the superficial aquifer comprises Tamala Limestone and Safety Bay Sand.

The upper part of the aquifer is characterised by sand, calcareous sand, and sandy limestone with pinnacle structures. Adjacent to the lakes and estuary, silt and clay are common in the upper part of the aquifer. At the bottom of the aquifer, the lithology is predominantly limestone and is hard, fossiliferous and vuggy.

In the White Hills and Island Point subareas, the saturated thickness of the low-saline water zone is 10 m, thinning to 1 m some 50 m from the edge of Lake Clifton (Fig. 21). West of Lake Clifton in the Coastal subarea, the low-saline water zone has a maximum thickness of 5 m. In the Lake Clifton and Colburra Downs subareas, the maximum thickness of this zone is 20 m. To the south, in the Lake Preston and Harvey subareas, the thickness of the low-saline water zone reduces from a maximum of 30 m to 10 m within a distance of 5 km, and further to 1 m some 50 m from the edge of the lake (Fig. 21).

Aquifer properties

Aquifer evaluation testing was not carried out as part of this project. Inferences from previous work are made in order to estimate aquifer properties. In areas where hydraulic properties were not evaluated from pump-testing, they have been estimated from lithology.

Aquifer evaluation tests were carried out during a hydrogeological investigation by Groundwater Resource Consultants (1986) at Dawesville Channel, 7 km north of the Yalgorup Lakes (Fig.1). The Tamala Limestone encountered at the White Hills and Island Point subareas is similar to that at Dawesville. Pumping-test results were used to determine the hydraulic properties of sand and limestone within the aquifer at Dawesville, where the calculated hydraulic conductivity ranged between 150 and 200 m/d and the effective porosity (θ) was 0.2. The same hydraulic properties are considered to be applicable to the superficial aquifer in the White Hills, Island Point, and Lake Clifton subareas.

Commander (1988), carried out pumping tests to determine the hydraulic properties of Tamala Limestone. His interpretation of pumping-test data for the Lake Preston

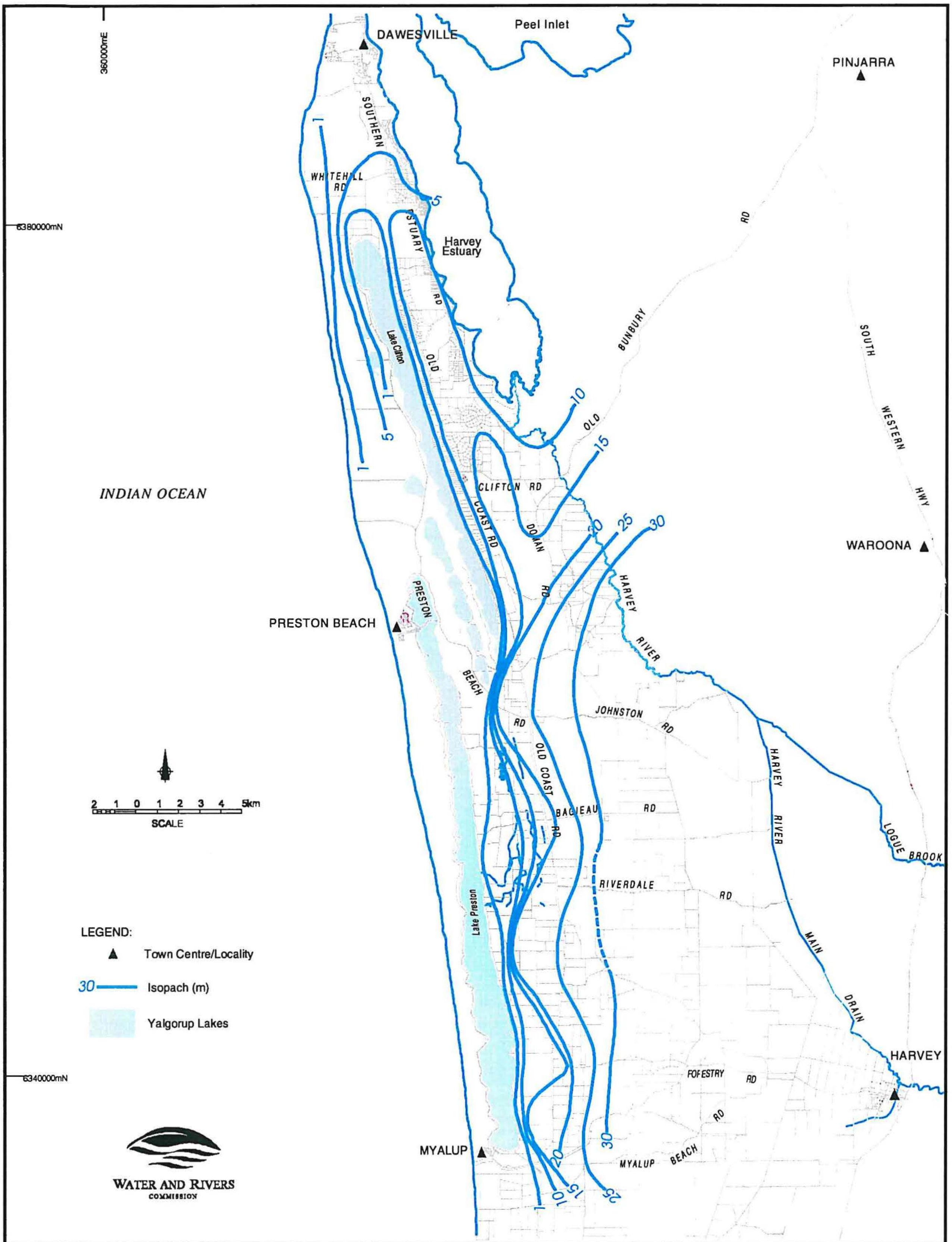

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Figure 21. Isopach of low-saline (<2000mg/L) groundwater in superficial aquifer

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subarea indicates that the hydraulic conductivity ranges from 60 to 80 m/d in the north and from 15 to 40 m/d in the south. These values are used in determining the aquifer properties in the Lake Preston subarea.

The large variation in hydraulic conductivity observed from north (White Hills, Island Point and Lake Clifton subareas) to south (Lake Preston subarea) is due to the cavernous nature of the Tamala Limestone. In the north, the Tamala Limestone comprises mainly hard, well-cemented, vuggy limestone and the hydraulic conductivity is attributed to solution channels and fissures in the limestone. In the south, Tamala Limestone comprises mainly sandy limestone and the hydraulic conductivity is attributed to intergranular porosity.

Groundwater level

The watertable information is based on a monthly monitoring record (Appendix 2) between November 1995 and June 1996 and the watertable contours of November 1995 are shown in Figure 22. The watertable is very close to mean sea level (<1 m AHD) in the White Hills and Island Point subareas. South of Harvey Estuary (Lake Clifton subarea), the watertable reaches a maximum elevation of 3 m AHD at site Y3/4 sloping to less than 1 m AHD at site Y3/3, 3 km east of Lake Clifton. In the Lake Preston subarea, the watertable is at 11 m AHD at the easternmost site (Y4/6) dropping to 1 m AHD about 500 m east of Lake Preston. For all the bores along the shore of the lakes, the watertable is above sea level, except along the northeastern shore of Lake Preston where it falls below sea level over a wide area.

Watertable position has remained relatively unaltered since 1983 (Deeney, 1989a) over most of the region. The watertable rise observed in the Lake Preston subarea near bore Y4/5 is attributed to the clearfelling of pine trees to the north of Forestry Road before 1993 inducing increased recharge.

Groundwater divide

The groundwater divide (Fig. 22) lies 2 km and 4.4 km east of Lake Clifton in the Island Point and Lake Clifton subareas respectively. In the Island Point subarea, there is a westward shift of the groundwater divide in summer. To the west of Lake Clifton, the groundwater divide shifts seasonally and was depicted at about 2 km west of the lake in winter and shifted eastward in summer (GHD Pty Ltd, 1997). In the Lake Preston subarea it is 9.4 km east of Lake Preston (Fig. 22) and on the west of the lake the divide was not delineated due to lack of waterlevel data.

Watertable fluctuation

The watertable fluctuates in elevation less than 0.5 m over most of the area, exceeding 1 m only in areas of intensive horticultural practice in the southern area, where its decline is a reflection of groundwater abstraction. In the rest of the area, the seasonal watertable fluctuation is not influenced by abstraction. Figure 23 shows the watertable fluctuation over a five-month period. The watertable fluctuated between 0.5 and 1.0 m in the area to the south of Lake Clifton. This area is subjected to

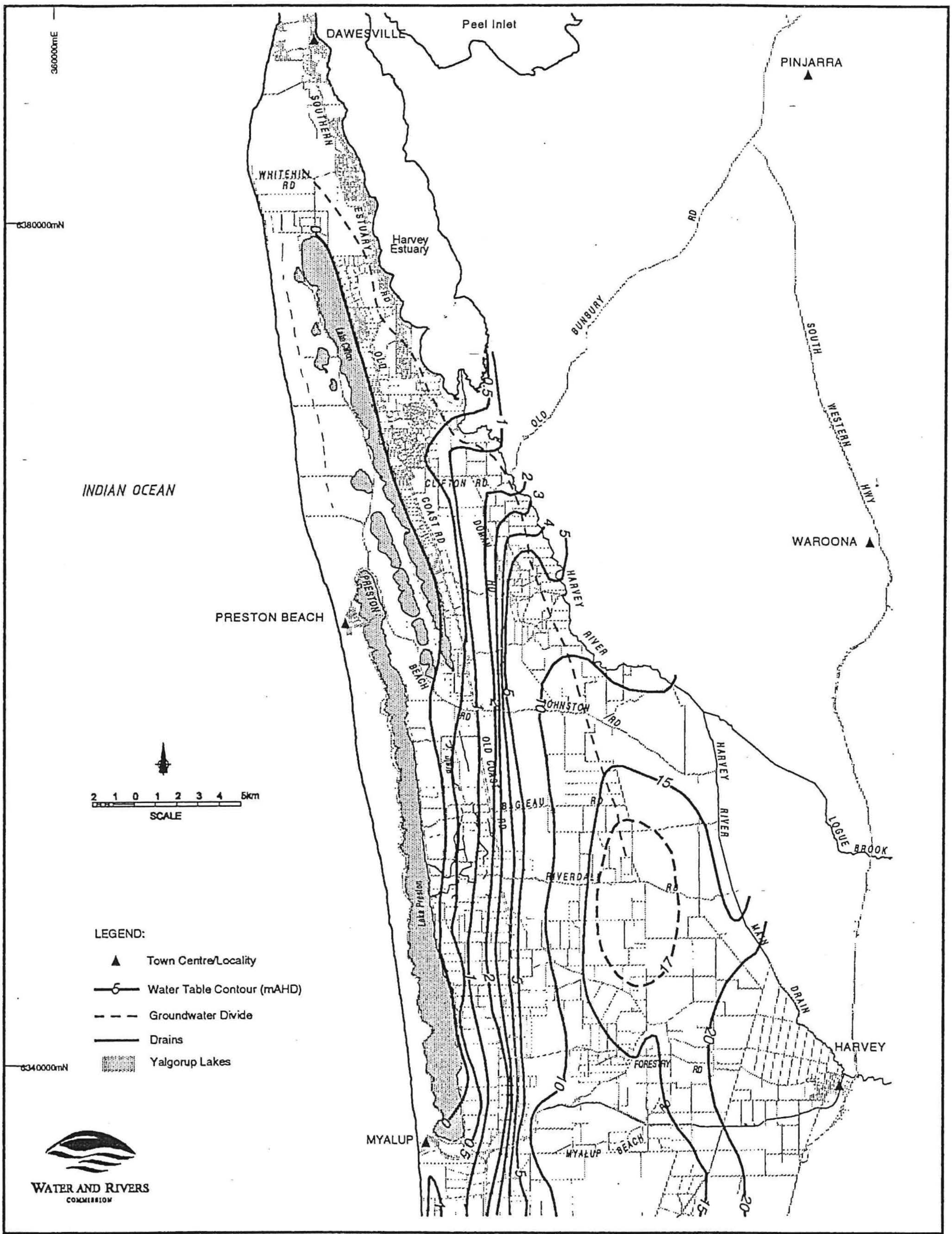

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Figure 22. **Watertable contours (November 1995)**

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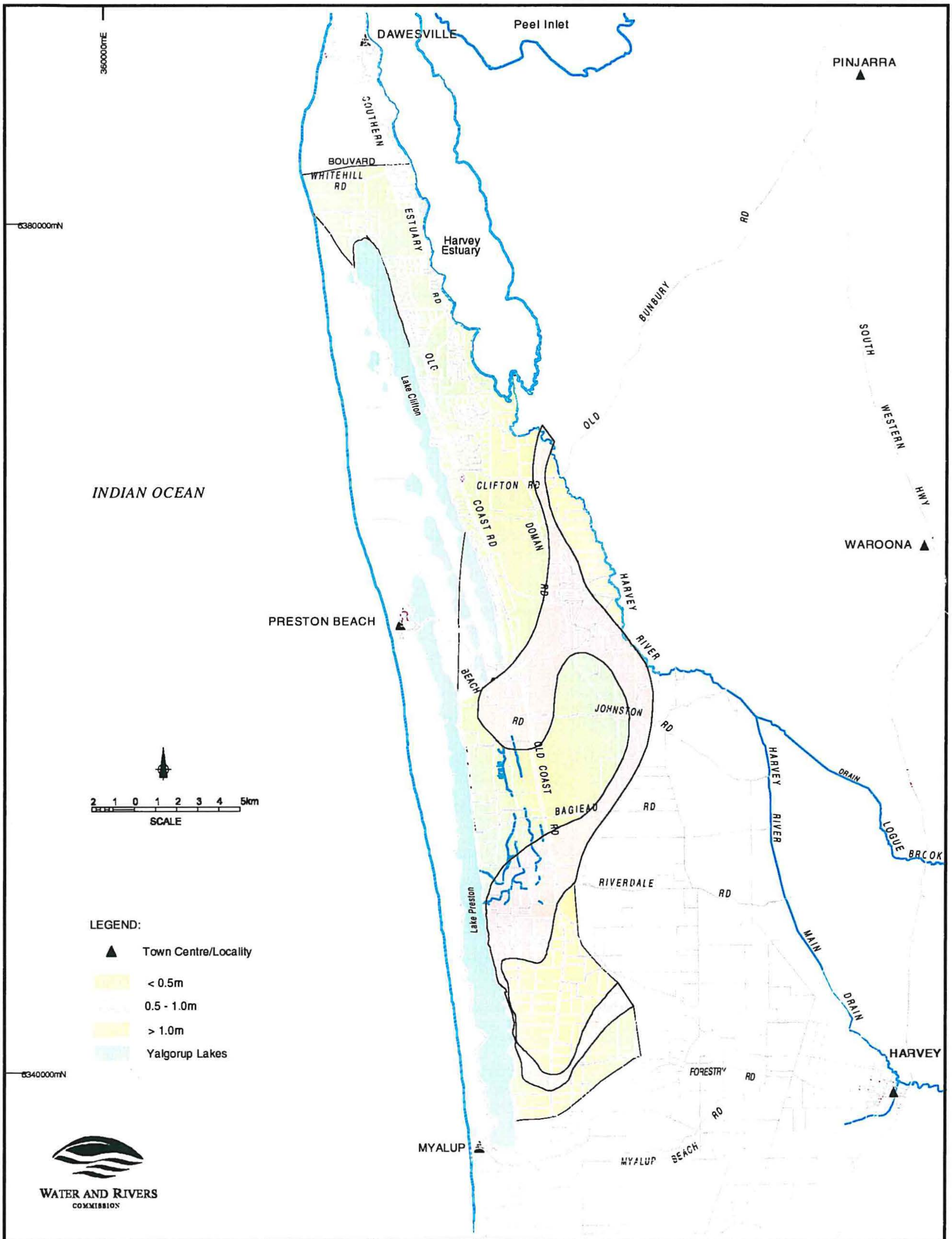

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Figure 23. Seasonal fluctualion in the watertable (Nov95 - Mar96)

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seasonal inundation and watertable was about 1 m below ground in summer. Vegetation in this area are mainly flooded gum and saltwater paperbark (CALM, 1995). Hill *et al*, (1995) mapped the area as dampland type wetland, and evaporation from wetland vegetation was found to be about 109% of annual rainfall (Farrington et al., 1990). High evapotranspiration from this area is, therefore, attributed to relatively pronounced watertable fluctuation. In the pine plantation south of Lake Clifton subarea and east of Old Coast Road (Fig. 6), watertable fluctuated less than 0.5 m (Fig. 23). Significant interception loss and transpiration loss can occur from pine forest (WAWA, 1986). Low seasonal fluctuation of watertable in this area is, therefore, attributed to interception loss and evapotranspiration loss from mature trees (planted in 1960s). Insignificant seasonal variation of the hydrographs and minimal recharge were also observed underneath mature pines from hydrograph analyses of WRC data from pine plantation near Yanchep caves north of Perth.

Monitoring results from nested bores

The monitoring results (Figs. 24–27) indicate that there is generally a variation of hydraulic head with depth.

In the White Hills subarea, at site Y1/1 the waterlevel fluctuated between months, with an increase of 5 cm from November to February and 8 cm increase from March to April (Fig. 24). There is no significant abstraction in the vicinity and this minor variation can be attributed to measurement error or a tidal influence. Such influence may also explain the waterlevel fluctuation in bore Y1/4A (Fig. 24). There is a seasonal shift of the crest of the groundwater mound in this area, it is located at site Y1/2 during the months of November to January and shift westward to site Y1/1 from February to June.

In the Island Point subarea, the nested bores at sites Y2/2 and Y2/6 (Fig. 25) show higher hydraulic head in the deeper bores, indicating groundwater discharge into Lake Clifton and Harvey Estuary, respectively. At site Y2/5A, the watertable fell to -7 cm AHD in April, the seasonal fall increased by licensed abstraction at a property close to the bore. Lowering of the watertable reduces the watertable gradient, thus reducing fresh groundwater discharge to Lake Clifton. If watetable falls below the lake water level (water level was measured at -15 cm AHD about the same time, Fig. 28), then there will be intrusion of saline water from lake into the groundwater.

In Lake Clifton and Colburra Downs subareas, the watertable apparently slopes from site Y3/4 westward toward Lake Clifton (Fig. 26). There is a topographic ridge between Y3/3 and Y3/4, and no bore was drilled here. It is anticipated that waterlevel measurement underneath this ridge might have indicated that the crest of the groundwater mound in this area is under the ridge. Under this circumstance, all groundwater discharge from the west of the mound is to Lake Clifton and from east of mound to Harvey River. Waterlevel in all bores fell below sealevel, at site Y3/1 from March to June and at site Y3/2 from March to May. Sites Y3/1 is on the edge of the lake and Y3/2 is 500 m east from the edge of the lake. Watertable was also measured below sealevel (-2.85 m AHD) in private bores 4 km north of transect Y3. The watertable elevation, as measured in bores YPR14 and YPR15 in Armstrong Hills

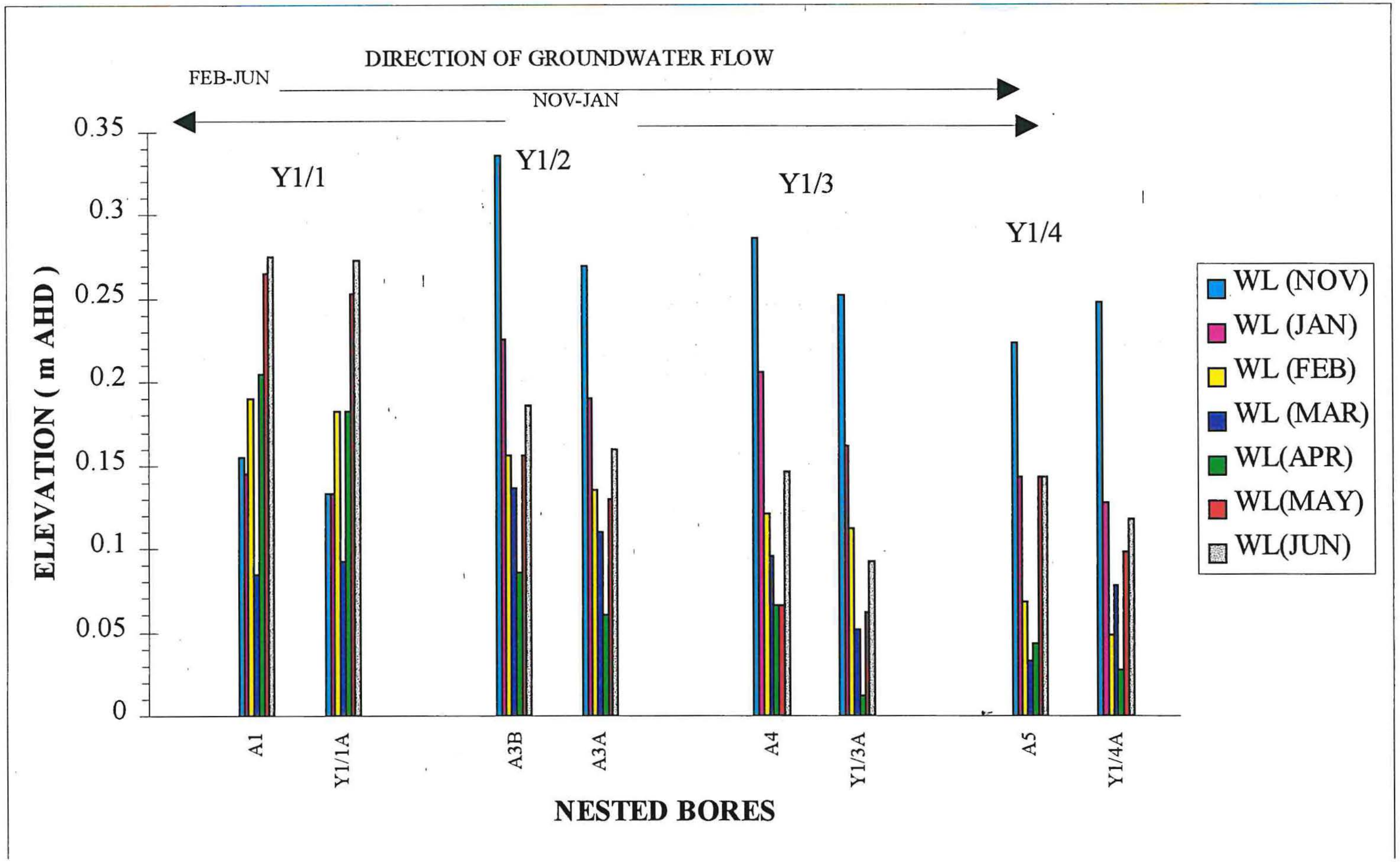

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Figure 24. Waterlevel fluctuation in nested bores of transect Y1 (1995–96)

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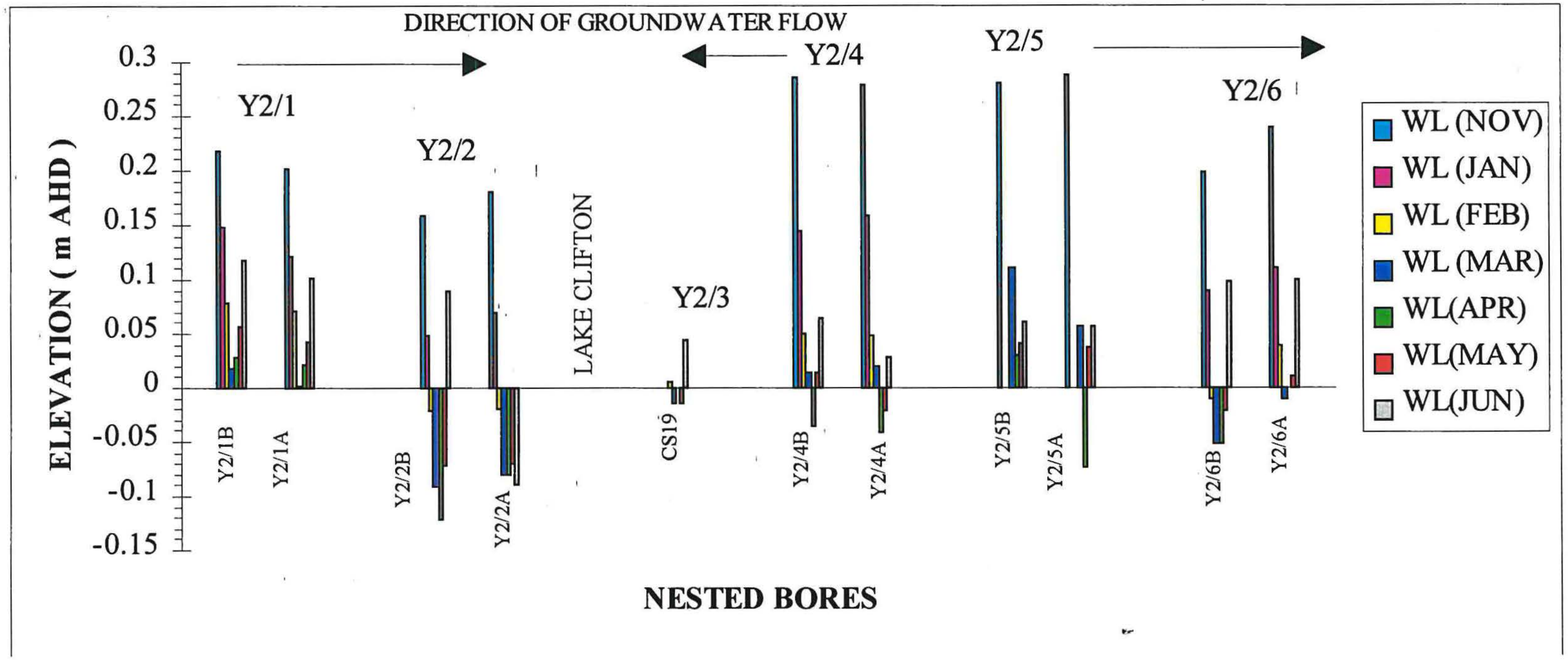

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COMP	R.S.	6/96	Figure 25. Waterlevel fluctuation in nested bores of transect Y2 (1995–96)
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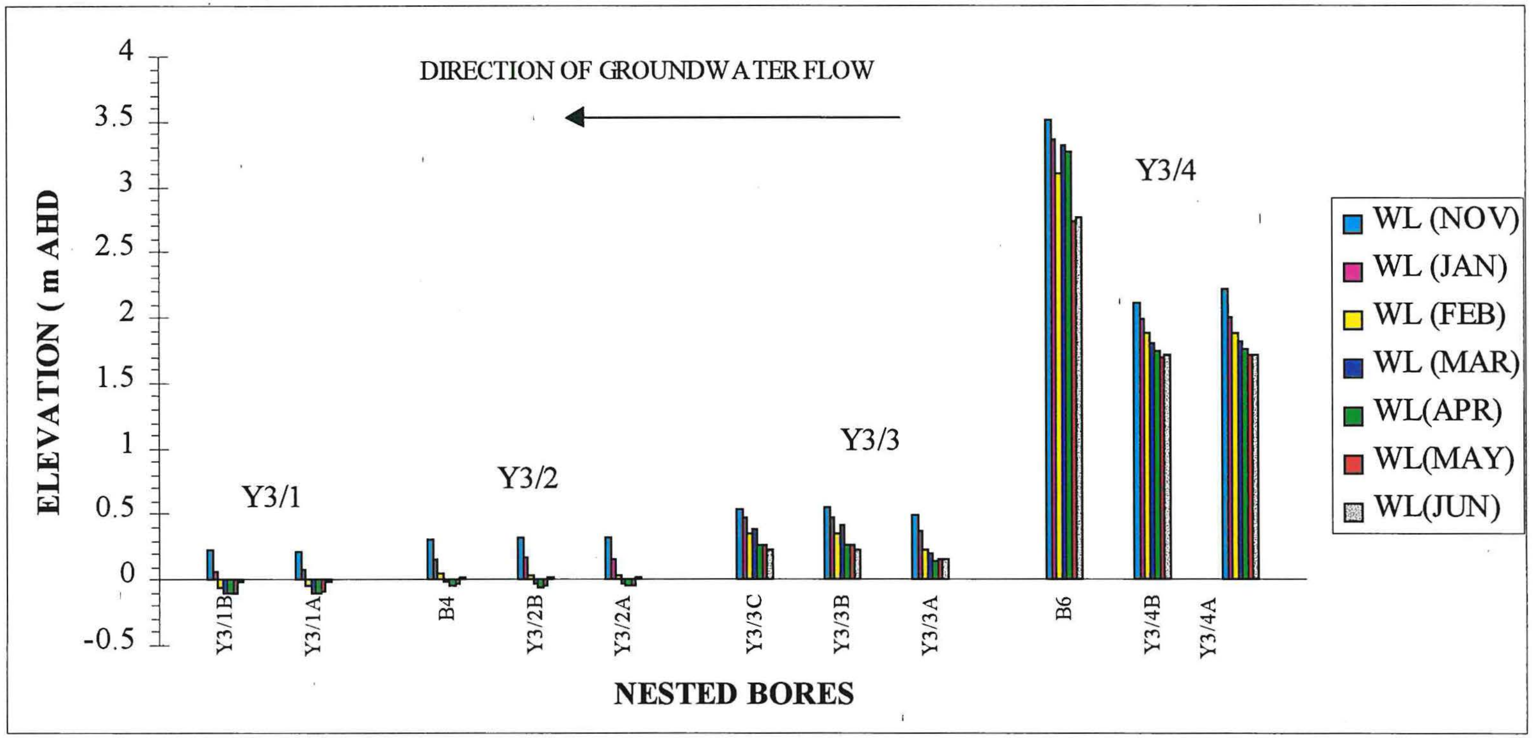

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COMP	R.S.	6/96	Figure 26. Waterlevel fluctuation in nested bores of transect Y3 (1995–96)
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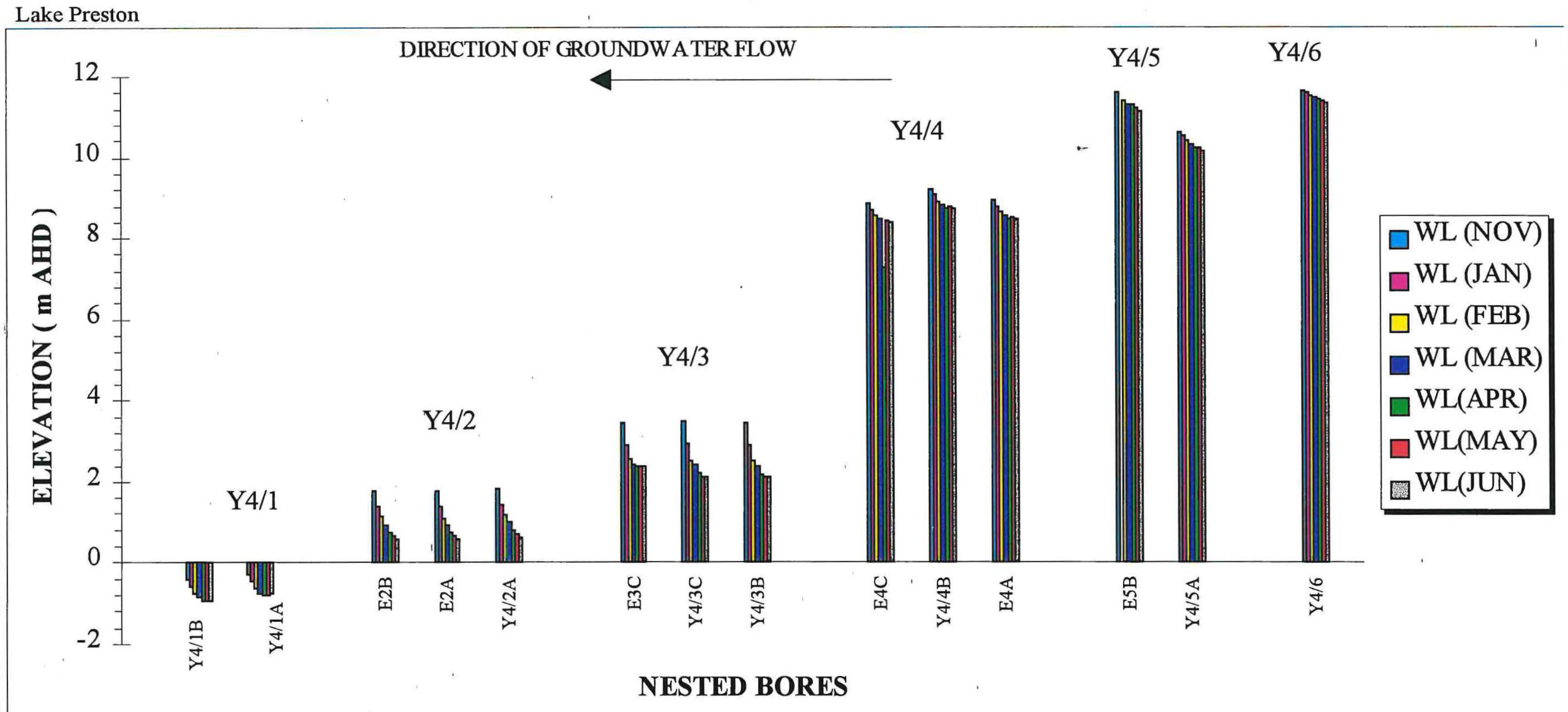

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Figure 27. Waterlevel fluctuation in nested bores of transect Y4 (1995–96)

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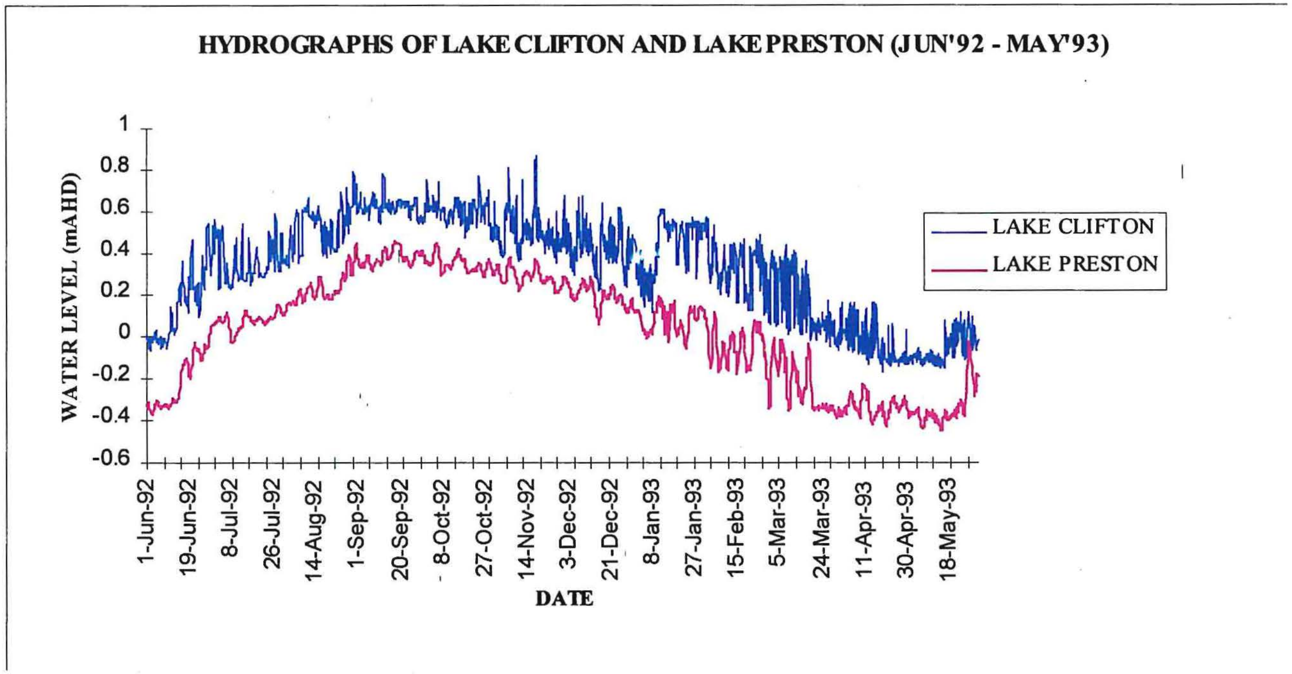

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Figure 28. Hydrograph of Lake Clifton and Lake Preston (Source:CSIRO)

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area, results from the combined effect of abstraction and evapotranspiration by large trees.

Watertable elevation indicate that the intermediate bore Y4/4B (Fig. 27) in Lake Preston subarea has a higher head than that in either the shallow bore (E4C) or the deeper bore (E4A). Site Y4/4 is within the regional groundwater flow environment, which is from east to west. However, due to the groundwater discharge into a wetland on the west (Fig. 19), upward flow from the intermediate part of the aquifer (bore Y4/4B) is observed at this site.

Watertable gradient and groundwater velocity

The watertable gradient calculated from measured groundwater levels indicates a very low gradient in the Island Point and Lake Clifton subareas. Low hydraulic gradient is attributed to the high hydraulic conductivity (150-200 m/d) of the cavernous Tamala Limestone in the north, compared to the relatively low hydraulic conductivity (5-80 m/d) in the Lake Preston subarea. In the eastern part, at the boundary between the Tamala Limestone and Bassendean Sand, the hydraulic gradient is steeper due to the change in lithology and hydraulic conductivities. Hydraulic gradient is relatively steep in the Lake Preston subarea compared with that in the northern subareas.

Groundwater velocity is calculated as follows:

$$V = (Ki/\theta) \times 365 \qquad (1)$$

where,
- V = linear velocity (m/year)
- K = hydraulic conductivity (m/d)
- i = hydraulic gradient (dimensionless)
- θ = effective porosity (dimensionless and assumed equivalent to specific yield)
- 365 = days in year

Based on estimated hydraulic conductivity and measured hydraulic gradient at the watertable, the groundwater velocity at the watertable (Table 6) is calculated near the groundwater divide and near the lakes for each of the subareas. The estimated velocities indicate that groundwater velocity at the watertable is slowest in the Island Point subarea, and faster near the groundwater divide than near the lakes in Lake Clifton, Colburra Downs and Lake Preston subareas. Faster flow of groundwater at the watertable near the groundwater divide in Lake Clifton, Golburra Downs and Lake Preston subarea is attributed to steeper watertable gradient, the result of extensively cleared land in these areas which increased recharge and watertable rise.

Table 6. Estimated groundwater velocity at the watertable

Parameter	*Groundwater divide*	*Near lake*
	Island Point subarea	
K (m/d)	200	200
i	.0001	.0001
θ	0.2	0.2
V (m/yr)	36	36
	Lake Clifton and Colburra Downs subareas	
K (m/d)	200	200
i	.001	.0004
θ	0.2	0.2
V (m/yr)	365	146
	Lake Preston subarea	
K (m/d)	40	40
i	.003	.0019
θ	0.2	0.2
V (m/yr)	219	138

Water quality

One of the major objectives of this project is to identify those land practices that lead to deterioration of groundwater quality and that, in turn, will be detrimental to the survival of microbialites in Lake Clifton. It is critical for their survival that there be sufficient nutrients (nitrogen and phosphorus), a constant source of carbonate and bicarbonate ions, and availability of light (Moore, 1993). However, high nutrient levels in the water encourage algal growth, limiting light penetration and thereby restrict microbialite formation.

The various sources of nitrogen as a nutrient are the atmosphere, native vegetation, animal excreta, and organic and inorganic fertilizers. Nitrates found in soil and water result from the activities of nitrifying bacteria in the presence of dissolved oxygen at a pH of 7–8. Being soluble, they leach to the watertable. However, denitrification occurs under anoxic conditions in the presence of dissolved organic carbon and low concentration of dissolved oxygen (DO). The Bassendean Sand is known to favour denitrification due to its low redox potential and high dissolved organic carbon content (Pionke et al., 1990).

Phosphorus as a nutrient may be derived from phosphatic nodules in the soil and mostly from fertiliser application where it exists as inorganic orthophosphate. Phosphorus is easily retained by soil, relatively more by clay than by sand. The presence of iron and aluminium increases phosphorus retention in soil and phosphorus may not, therefore, be readily leached to the groundwater. Compared with Bassendean Sand, Tamala Limestone contains higher iron and calcium carbonate. This increases the phosphorus sorption capability of Tamala Limestone (McPharlin et al., 1990).

Salinity

Over most of the area, the groundwater at the watertable is fresh with a salinity mostly less than 500 mg/L (Fig. 29). The salinity does, however, increase with depth but for much of the area remains ≤ 2000 mg/L to the base of the superficial aquifer. The low-saline water forms a lens (≤ 10 m thick) in the White Hills and Island Point subareas. In this area the deep groundwater (>10 m below watertable) has salinities in excess of 5000 mg/L and can be as high as 20 000 mg/L (Commander, 1988). The water within Lake Clifton ranged from 31 000 mg/L at the end of the dry season (May) to 14 000 mg/L at the end of the wet season (November) in 1991 (Rosen et al., 1996), while the groundwater salinity beneath the lake, is 40 000 mg/L.

The groundwater beneath the western edge of the estuary (bore Y1/4, Fig. 9) has a salinity of 30 000 mg/L (Commander, 1988) and beneath the eastern edge 32 000 mg/L, at a depth of 12 m below the watertable (Sadgrove and Deeney, 1989). This would suggest groundwater salinities in excess of 30 000 mg/L below the estuary. Figure 30 is a schematic presentation of the shallow groundwater salinity in the Island Point subarea.

The groundwater salinities at the watertable was greater than 1000 mg/L near the shore of Lake Clifton (Fig. 29). South of Lake Clifton and to the east of Lake Preston, groundwater beneath a large area has a salinity of about 2000 mg/L, and the salinity in Lake Preston was 55 000 mg/L in 1991–1992 (Rosen et al, 1996). Watertable elevation in this area (site YSH7, Fig. 9) is lower than the waterlevel in Lake Preston for most of the year causing migration of saline water into the aquifer.

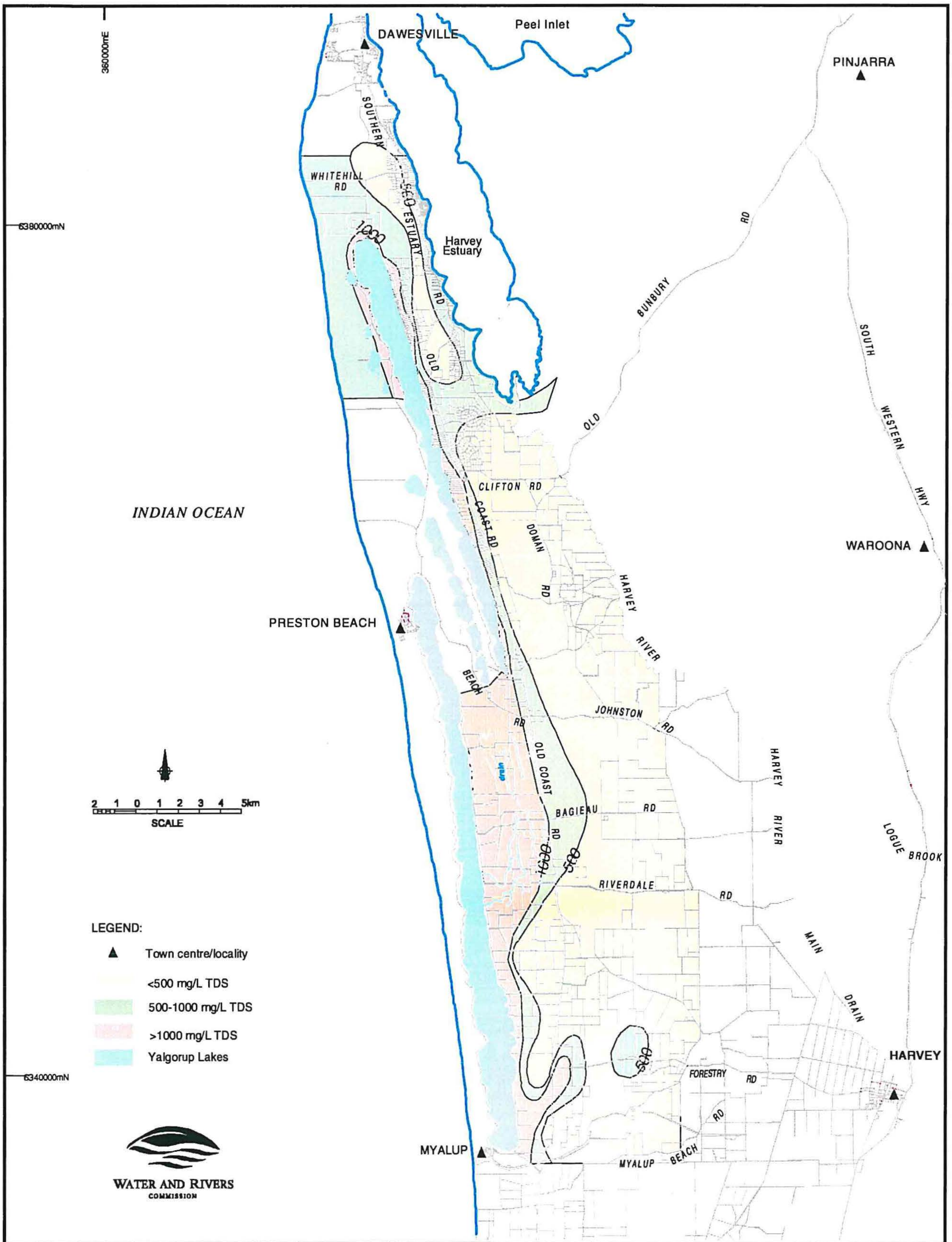
Chloride

Figure 31 shows groundwater chloride concentration in the area. The shifting of isochlor line inland in the southern part of Lake Preston subarea is the result of salt recycled through irrigation water under horticulture land (Commander, 1982). In the Island Point subarea a zone, of lower chloride concentration remain between the Lake Clifton and Harvey Estuary with higher concentration inland from the water bodies. A zone of low chloride groundwater also occurs in White Hills subarea between the ocean and Harvey Estuary with higher concentration inland from the water bodies

Nutrient concentration

The nutrients examined were, organic and inorganic compounds of nitrogen and phosphorus. The nutrient concentrations (Appendix 3) of bore water is compared with guideline level. The guideline level is an indication of concentration values for nutrients at or above which eutrophication by nutrient enrichment in lakes, estuaries, and embayments have been known to occur. There is no guideline level of nutrient concentration in groundwater for eutrophication, therefore, guideline levels for lakes and reservoirs is used.

Total nitrogen: Total nitrogen comprises nitrate+nitrite nitrogen, ammonia nitrogen and organic nitrogen. The guideline level for total nitrogen (TN) is 0.1–0.5 mg/L



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COMP	R.S.	6/96	Figure 29. Salinity at water table (1995-96)	MAP INDEX
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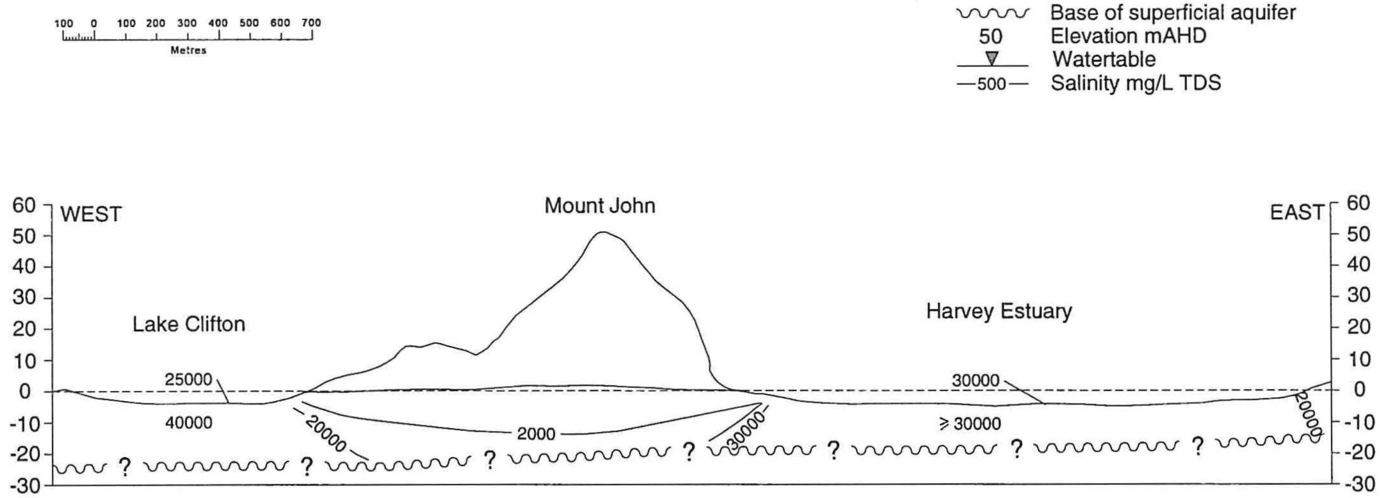

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Figure 30. Schematic representation of the relationship of lake, groundwater and estuary in Island Point subarea

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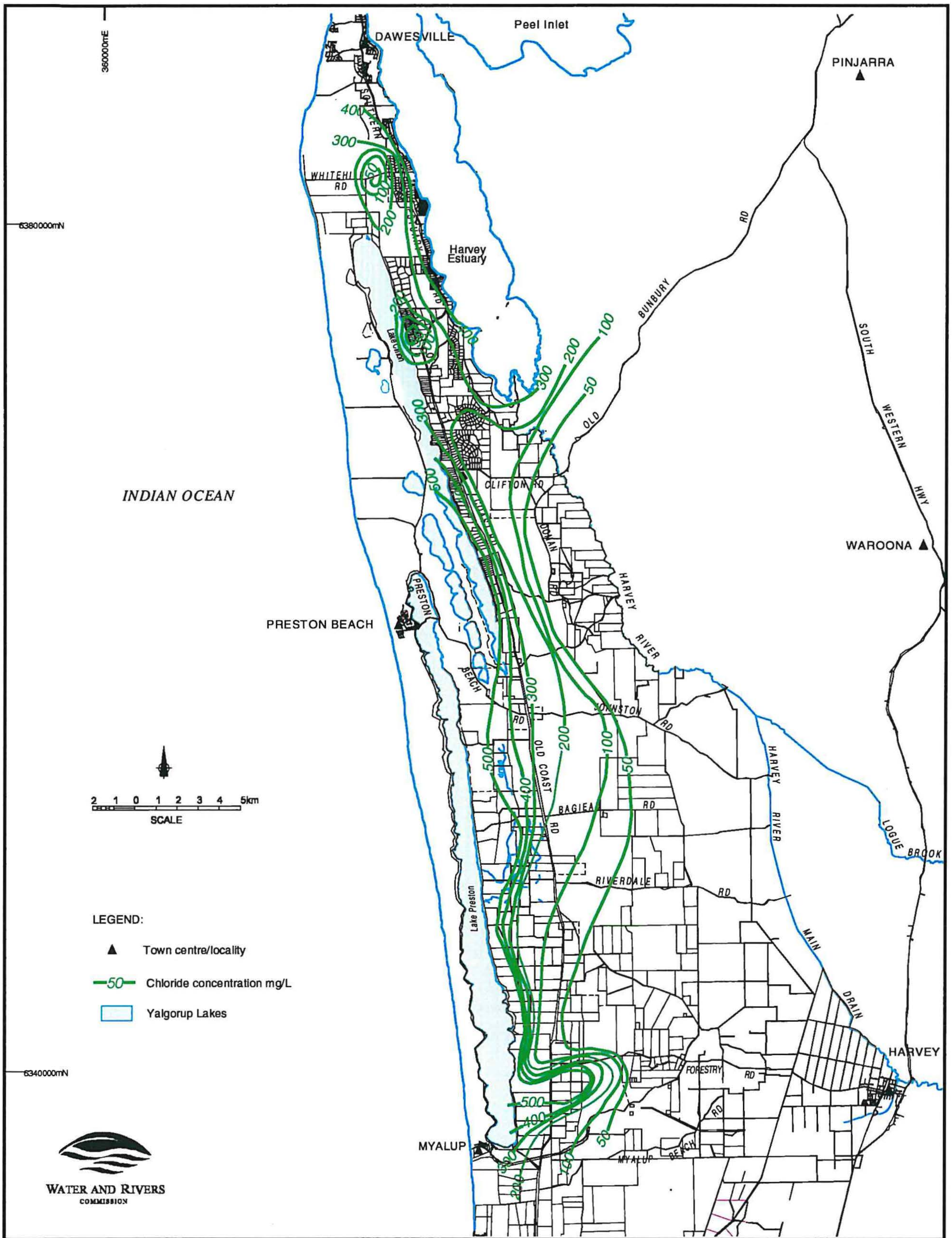

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Figure 31. Chloride concentration at watertable (1995-96)

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(Terry and George, 1995). Regional distribution of total nitrogen concentration at the watertable (Fig. 32) indicates that over most of the region the limit is exceeded. Organic nitrogen is the dominant fraction of the total nitrogen in majority of the bores, and it occurs naturally. However, concentration in excess of 10 mg/L TN has been identified in several bores east of the Lake Preston (Fig. 33b), where nitrate+nitrite nitrogen was the dominant fraction. These anomalies are associated to local contamination from horticultural activity and cattle grazing. Nitrate+nitrite nitrogen was the dominant fraction of TN in several bores of the Island Point and Lake Clifton subareas (Fig.33a). Elevated level (up to 6.0 mg/L TN) was found in shallow groundwater (lake side shallow bores) within National Park area where organic nitrogen was the dominant constituent. The concentration of total nitrogen in the lakes (Table 7) exceeds the guideline level.

Table 7. Total nitrogen in the lakes (after Rosen *et al.*, 1996)

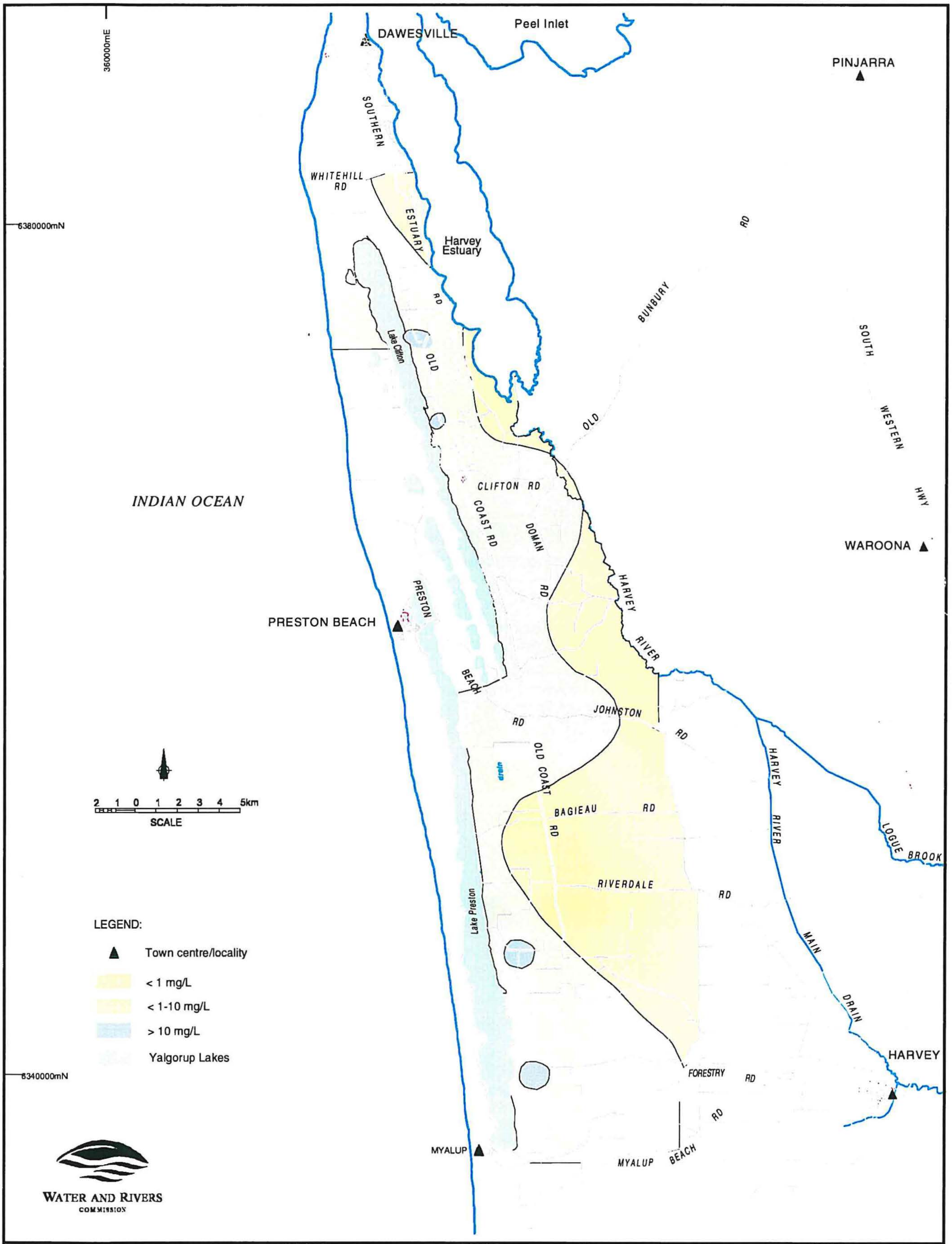
Date	*Lake Clifton (mg/L)*	*Lake Preston (mg/L)*
May 1992	2.87	3.81
September 1992	1.72	0.89

Nitrate+nitrite nitrogen: Bore water was analysed for nitrate+nitrite nitrogen (Appendix 3), the guideline level for this is not available. Therefore the nitrate nitrogen guideline is used for comparison. The guideline level of nitrate nitrogen for eutrophication in lakes is 0.25 mg/L (Terry and George, 1995).

In the Island Point subarea, concentrations in some of the bore water sampled exceed the guideline level and are higher than those in the Harvey Estuary (<0.01 mg/L in summer and 0.3 mg/L in winter of 1995–96 reported by Peel Inlet Management Authority). Bore Y2/5, near Lot 46, Mount John Road (Fig. 9), has groundwater with 1.7 to 2.0 mg/L of nitrate+nitrite nitrogen. The landuse is flower production, and fertiliser is considered to be the source of nutrients in the groundwater, although the details of fertiliser application are unknown. The source of 9 mg/L nitrate+nitrite nitrogen concentration in the groundwater at sites YPR2 and YPR3 (Fig. 11) is probably sewage. Concentrations of 2.7 mg/L nitrate+nitrite nitrogen in bore RD McKay is probably due to grazing activity, with a reduction in level observed at the end of summer (April). Reduction is probably due to throughflow and absence of recharge in summer, which prevented additional flux of nutrient to the watertable.

In the Lake Clifton subarea (Fig. 34), nitrate+nitrite nitrogen concentrations are generally below the guideline level. However, elevated levels (about 2.0 mg/L) were found in bores of the Tuart Grove area (YPR6, YPR8), and sewage pollution may be the cause. Concentrations of 1.2 mg/L nitrate+nitrite nitrogen in bore F Roberts Native (horticulture) probably reflect landuse (Fig. 12). A reduction in the level was observed at the end of summer.

On the west of Lake Clifton, the nitrate+nitrite nitrogen concentration of 1.1 mg/L (Y2/1B, Appendix 3) in the upper 5 m of the aquifer under the National Park is due to nitrogen-fixing by vegetation (especially *Acacia*). Concentration of 3-6 mg/L



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*	INITIAL	DATE	
COMP	R.S.	6/96	**Figure 32. Total nitrogen concentration at watertable (1995-96)**
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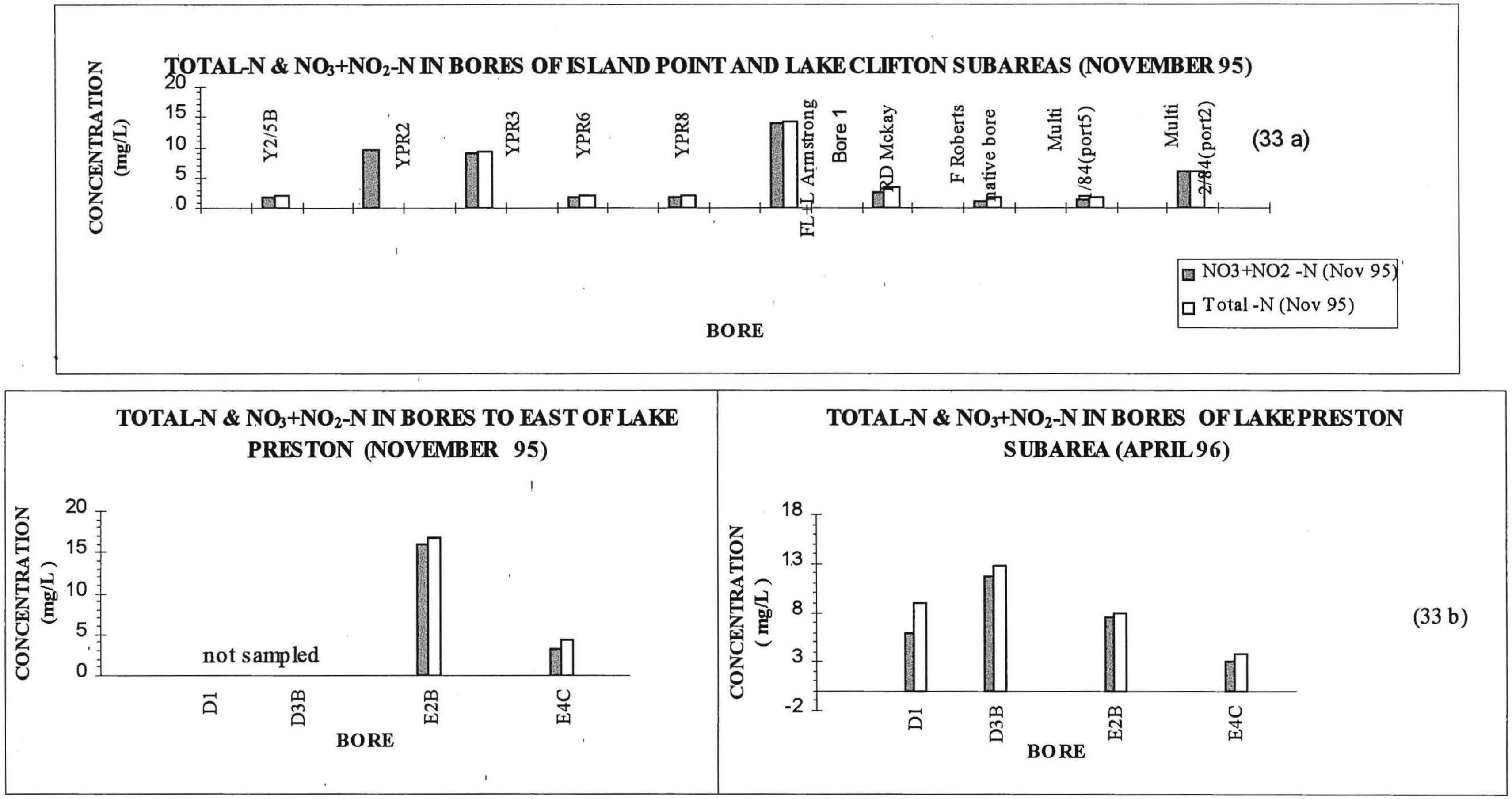

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Figure 33. Bores showing elevated levels of nitrate+nitrite nitrogen concentration at watertable

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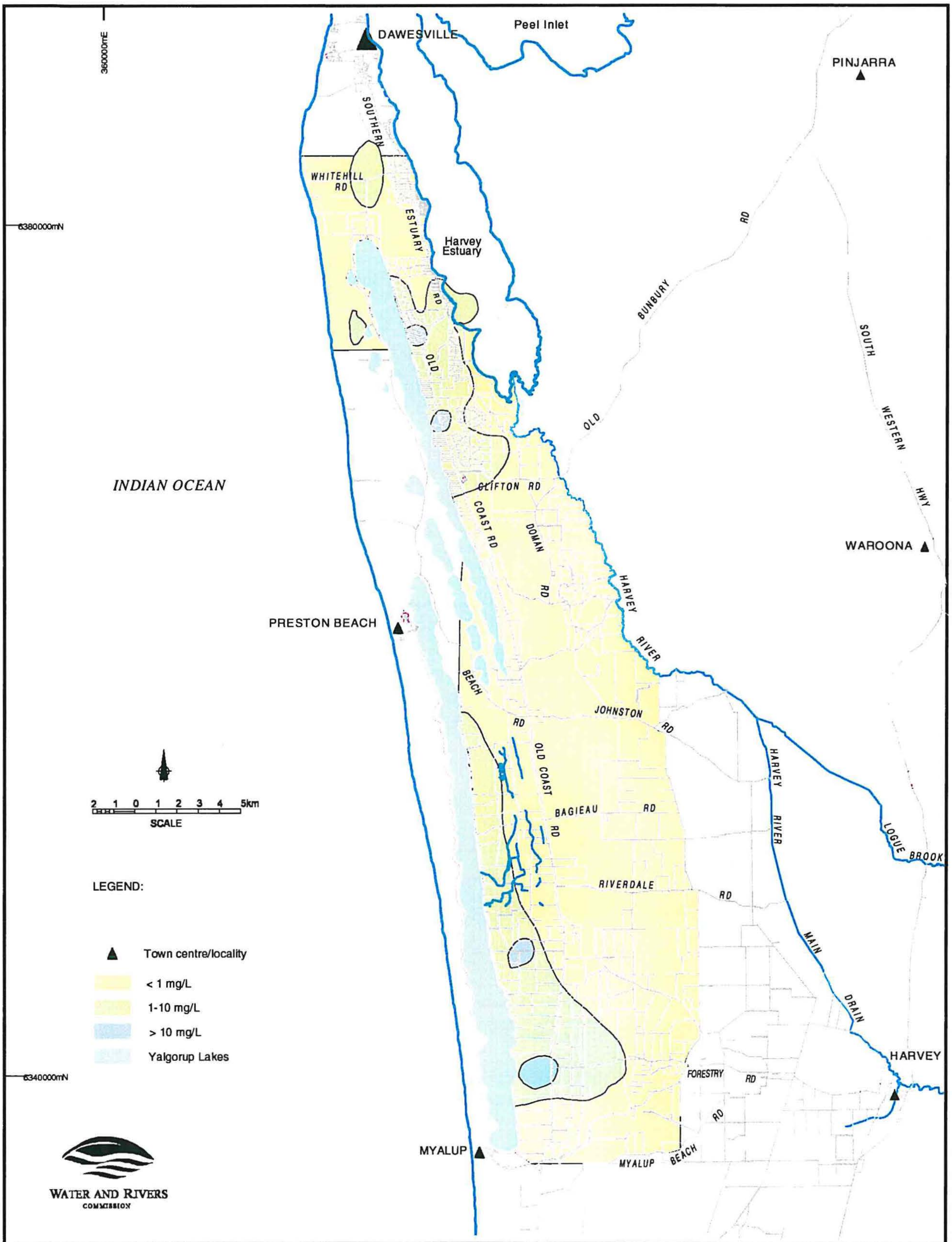

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Figure 34. Nitrate + nitrite nitrogen concentration at watertable (1995-96)

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nitrate+nitrite nitrogen detected in multiport bore 2/84, down gradient of a market garden (Lot 6, Old Coast Rd), is possibly due to the leaching of applied fertiliser.

In Lake Preston subarea, where irrigated horticulture and pastoral activities are practised, the guideline levels of nitrate+nitrite nitrogen concentration in groundwater are exceeded. Elevated concentration has been found in deep bore D3A (8 mg/L) and shallow bore D3B (11 mg/L) at the same site (Fig. 12), in bore FL+L Armstrong 1 (12–14 mg/L) and in bore D1 (6 mg/L) where horticulture is the main activity. Elevated concentration of 7–16 mg/L nitrate+nitrite nitrogen detected in the upper 3 m of the aquifer in bore E2B, located within grazing land (Fig. 12) is probably due to the activity of grazing. Fertiliser application is almost certainly responsible for a nitrate+nitrite nitrogen concentration of 3 mg/L in bore E4C, down gradient of a pine plantation. The source of this nutrient contamination will be identified by CALM research currently tracking nutrients in the soil profile beneath pine plantations.

The lake water was tested for nitrate nitrogen, shown in Table 8, and was well below the guideline limit.

Table 8. Nitrate nitrogen concentration in the lakes (after Rosen *et al.*, 1996)

Date	*Lake Clifton (mg/L)*	*Lake Preston (mg/L)*
July–August 1992	0.043	0.042
March–May 1992	<0.001	<0.001

Organic nitrogen: No guideline limit has been reported for organic nitrogen with regard to eutrophication in lakes. But high organic nitrogen, which contributes to the high total nitrogen, was detected in a number of bores in the area. Several of these bores (Fig. 35a) are located within the National Park where decaying vegetation produces organic nitrogen. Organic nitrogen is usually the dominant fraction of total nitrogen in a wetland or swamp environment (Davis et al., 1993), and higher concentration in groundwater on the down hydraulic gradient side is therefore expected, as is the case with bores E3C and B6 (Fig. 35b). Groundwater sampled from bores at the base of superficial aquifer, mainly in the Lake Preston subarea and one in Lake Clifton subarea, revealed high organic nitrogen (Fig. 35c), and is probably influenced by groundwater originating further east. In the lakes, organic nitrogen concentrations (Table. 9) are relatively high and contribute to the total nitrogen concentration in lake water.

Table 9. Organic nitrogen concentration in the lakes (after Rosen *et al.*, 1996)

Date	*Lake Clifton (mg/L)*	*Lake Preston (mg/L)*
May 1992	2.82	3.10
September 1992	1.61	0.19

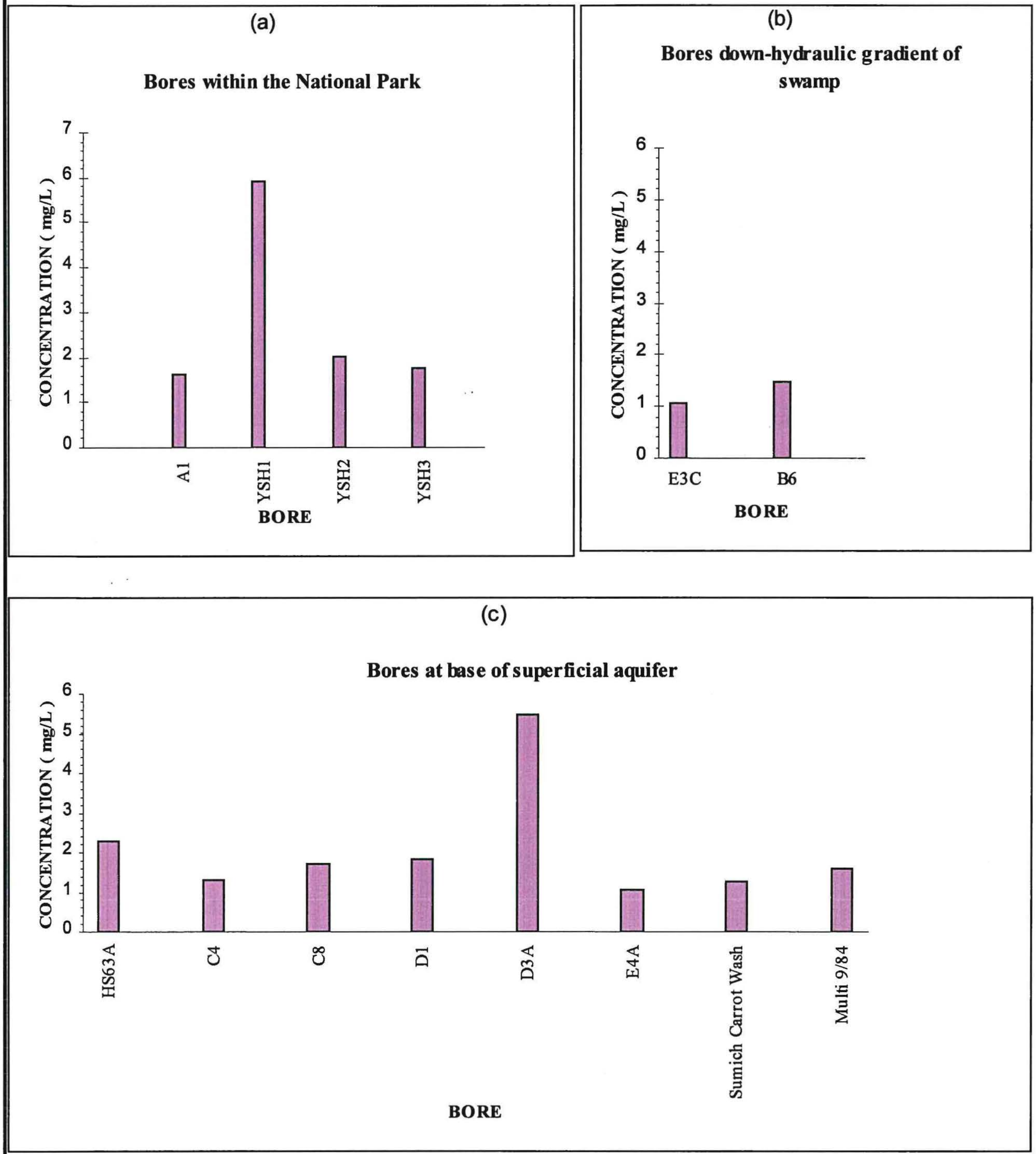

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Figure 35. Bores showing elevated organic nitrogen concentration

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Ammonia nitrogen: The guideline limit for ammonia nitrogen in coastal lakes is less than 0.005 mg/L (Australian and New Zealand Environment and Conservation Council (ANZECC), 1992). Groundwater in a few bores has ammonia nitrogen concentrations below this limit, however, most of the groundwater is between 0.005 and 0.5 mg/L, and some between 1 and 2 mg/L. Groundwater with ammonia nitrogen concentrations of 1 to 2 mg/L in bores D1, Y4/1, multiports 8/84 and 9/84 is in intensively grazed land (Fig. 36) adjacent to Lake Preston. These are deep bores, and shallow bores at these sites have ammonia nitrogen concentration between 0.2 and 0.7 mg/L. The ammonia nitrogen concentration at these sites is attributed to animal excreta.

In the lakes (Table 10), the high winter concentrations of ammonia nitrogen are probably due to input from surface runoff. Lake Preston has a higher concentration than Lake Clifton because the eastern shore of Lake Preston is more extensively used for grazing. Comparison of the various forms of nitrogen concentration in the lake water (Fig. 37) indicates that organic nitrogen is the major form in both the lakes. However, in Lake Preston ammonia becomes the dominant form of nitrogen during September.

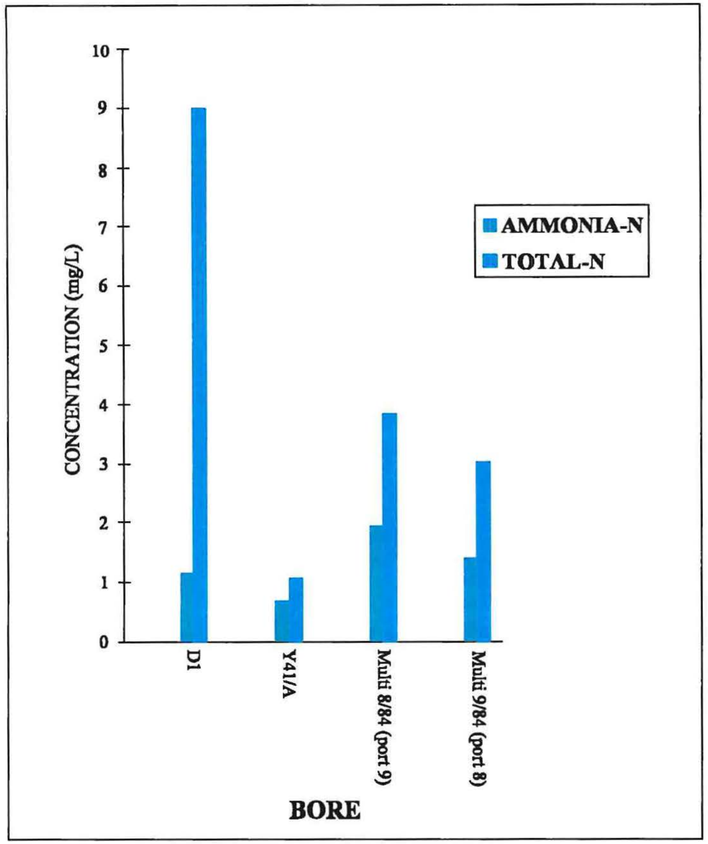
Table 10. Ammonia nitrogen concentration in the lakes (after Rosen *et al.*, 1996)

Date	*Lake Clifton (mg/L)*	*Lake Preston (mg/L)*
June–July 1992	0.13 (July 92)	0.8 (June 92)
November 1992	<0.01 (Nov 92)	0.01 (Nov 92)

Groundwater enriched in total nitrogen mainly occurs near the watertable. However few anomalies occur. In Island Point subarea, nitrate+nitrite nitrogen concentration at the watertable (Y2/5B) was 1–2 mg/L. Similar concentration (2.5 to 4 mg/L) was found in the deep groundwater on the down hydraulic gradient side (bores Y2/4A and CS18; Fig. 38). Higher concentration of ammonia nitrogen (Appendix 3) in deeper groundwater, compared to the shallow groundwater within the grazing land of Lake Preston subarea (Fig. 36), is probably due to the rapid migration of ammonia nitrogen rich water from the watertable to the bottom of the aquifer. These are the only sites in the area where migration of a nitrogen plume to the bottom of the aquifer is identified.

Total phosphorus: Total phosphorus as a nutrient comprises ortho-phosphate and organic phosphorus. The guideline levels of total phosphorus for eutrophication in water bodies is 0.005–0.05 mg/L (Terry and George, 1995). Generally, organic phosphorus greatly exceeds ortho-phosphate concentration in the area. Regional distribution of total phosphorus at the watertable (Fig. 39) indicates that, concentration is below the guideline limit in the Island Point subarea, groundwater from a few bores in the Lake Clifton subarea exceeded the limit, and groundwater from most bores in the Lake Preston subarea exceeded the guideline limit.

Groundwater sampled from bores that are screened at the bottom of the superficial aquifer indicated elevated ortho-phosphate concentration (exceeding guideline limit



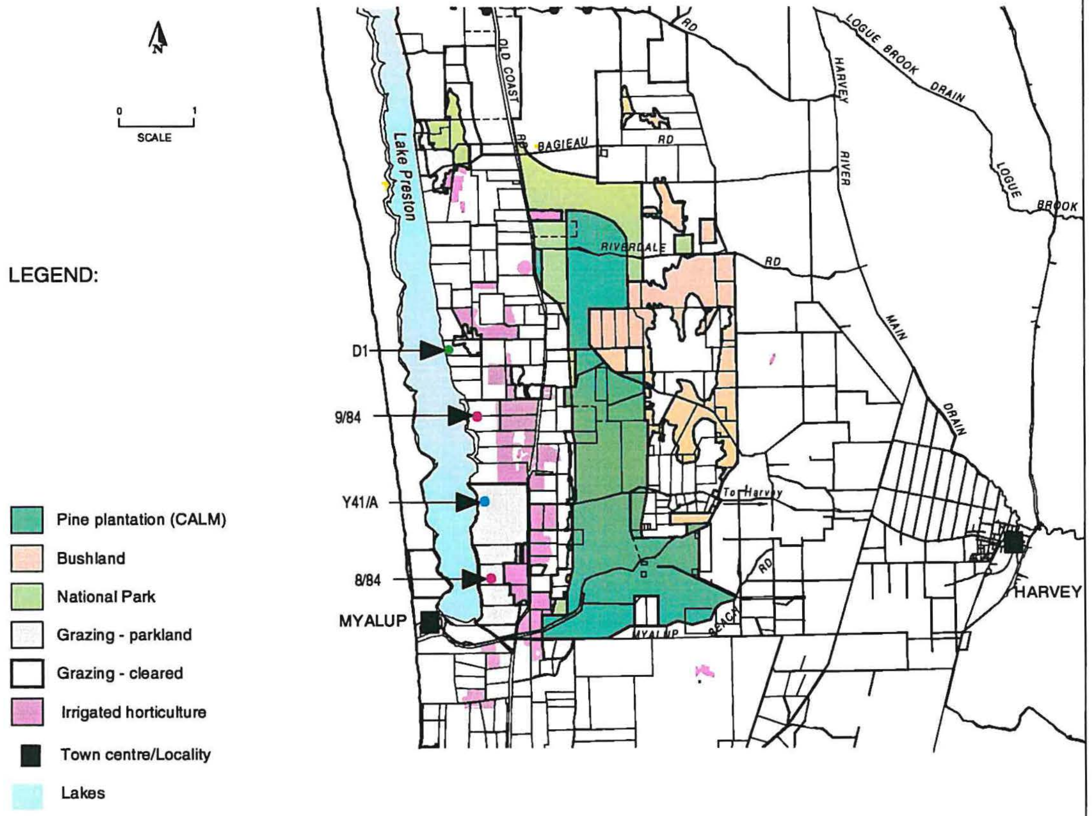


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Figure 36. Ammonia nitrogen concentration in bores of Lake Preston subarea

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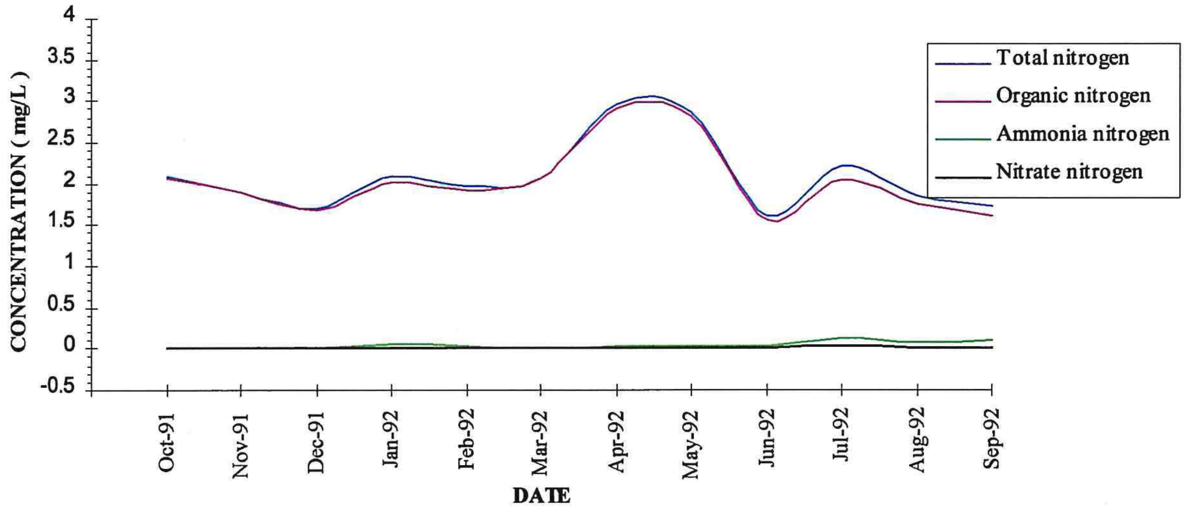
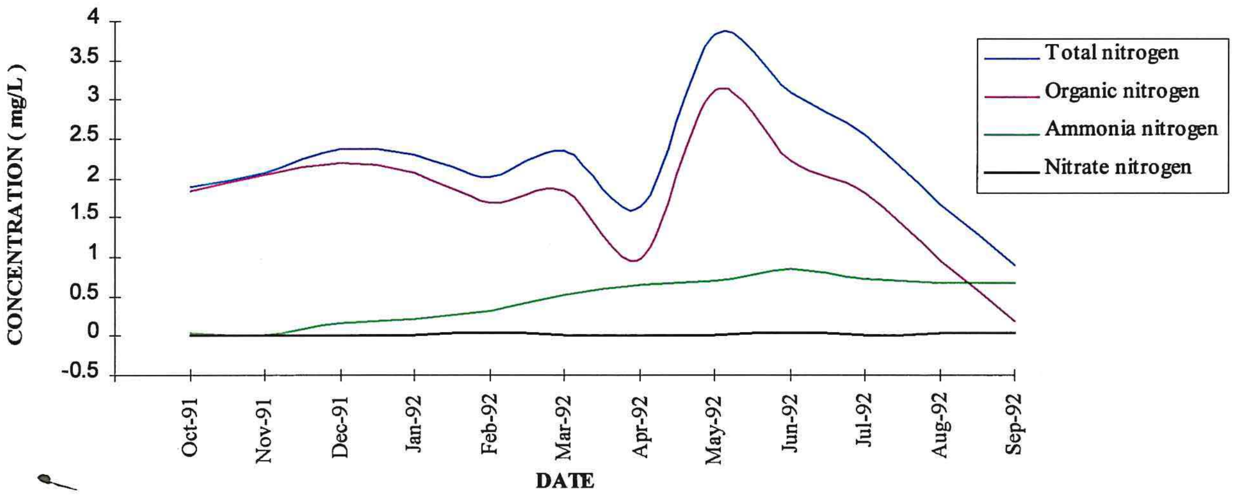
LAKE CLIFTON



LAKE PRESTON



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*	INITIAL	DATE	Figure 37. Different forms of nitrogen concentration in lake water	MAP INDEX
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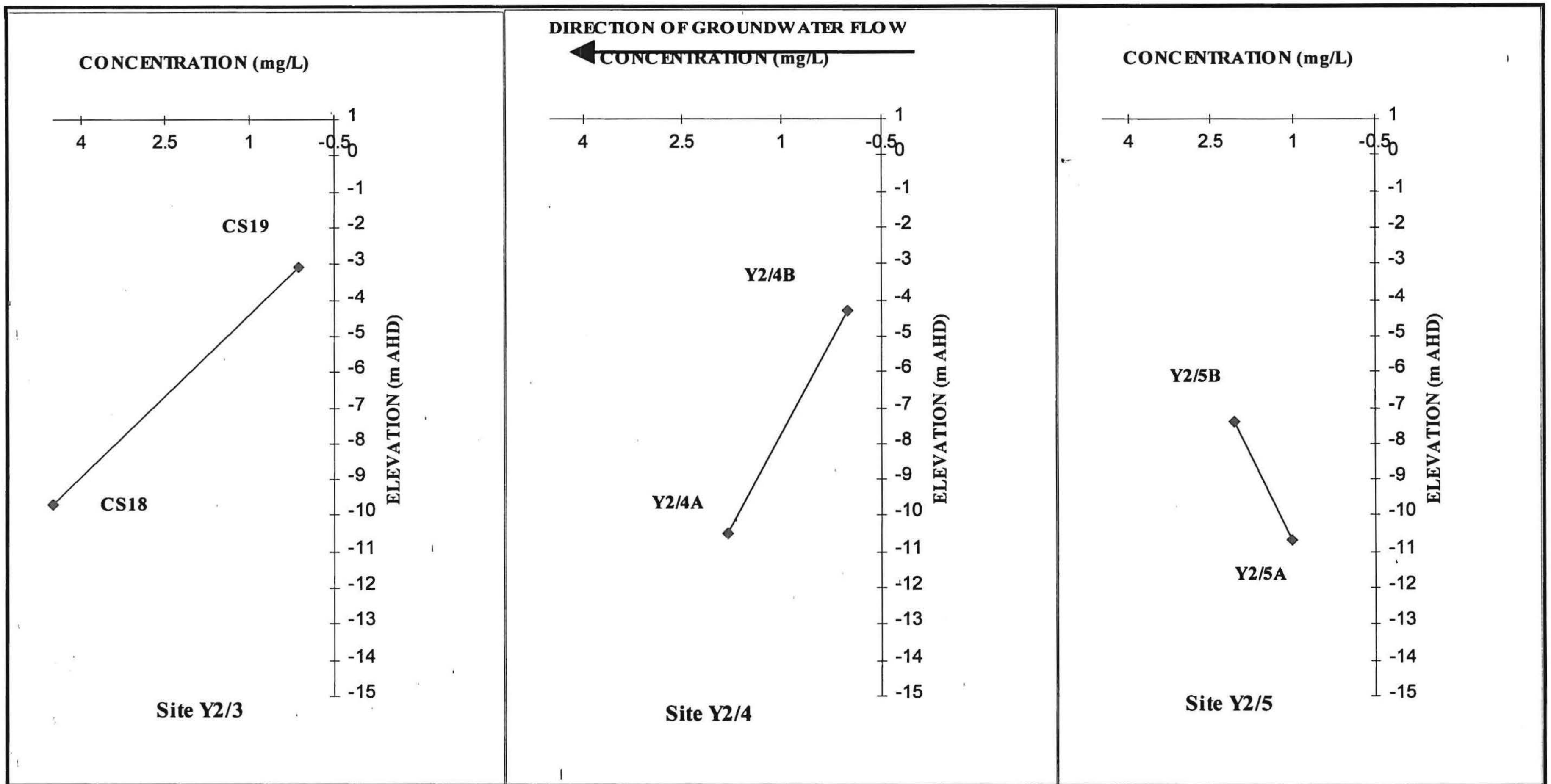

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Figure 38. Nitrate+nitrite nitrogen concentration in nested bores of transect Y2

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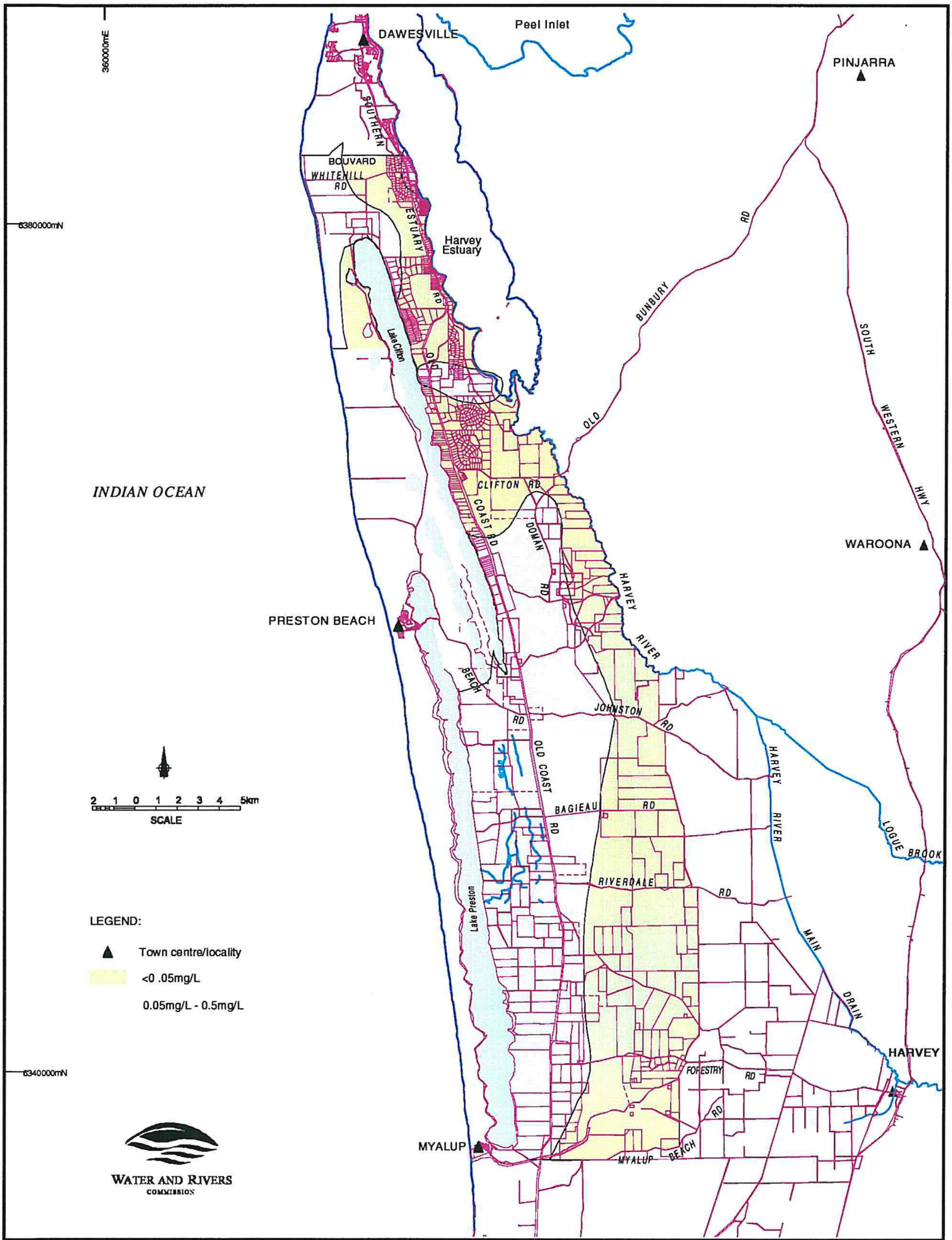

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Figure 39. Total phosphorus concentration at watertable (1995-96)

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0.01 mg/L, ANZECC, 1992). These relatively elevated concentrations were, 0.12 mg/L ortho-phosphate in April 1996 in bore RD Mckay, 0.12–0.2 mg/L ortho-phosphate in bore Y3/4A, 0.21 mg/L ortho-phosphate in deep bore of multiport 9/84 and 0.13 mg/L ortho-phosphate in bore D3A (Fig. 40). The source of phosphorus concentration in the bore water at these sites may be naturally occurring from phosphatic minerals, that are thought to incur phosphorus concentration in groundwater (Allen, 1981).

Within Lake Clifton, the concentration of ortho-phosphate ranged from 0.004 to 0.019 mg/L between 1979 and 1988 (Rosen et al., 1996). Concentration of ortho-phosphate in Lake Preston ranged from 0.008 to 0.017 mg/L between October 1991 and September 1992 (Rosen et al., 1996).

The ratio of nitrogen to phosphorus in water is known to influence the type and intensity of nuisance algae growth. In recent years, the nitrogen–phosphorus ratio (N:P) has been used to help define the eutrophic character of water. When N:P is greater than about 20:1, the system is phosphorus limited (high nitrogen concentration) and growth of some algal species will be limited by lack of available phosphorus; when less than about 16:1 the system is nitrogen limited (high phosphorus concentration) and growth of some algal species is limited by lack of available nitrogen. The N:P ratio in the shallow groundwater was in the range of 16:1 – 20:1 in about 30% of bores (total number of bores about 45). This indicates a relative balance between the two nutrients for these bores, whereas for the remainder, recorded levels indicate that the shallow groundwater could be eutrophic. The nitrogen–phosphorus ratio in about 10% of the bores is less than 16:1 indicating increasing phosphorus concentration in groundwater. Water in the Lake Clifton has highest concentration of nitrogen and lowest concentration of phosphorus. Rosen et al. (1996) concluded that the nutrient discharge to Lake Clifton via groundwater was not sufficient to noticeably change the concentrations of the lake. However, the fact that macroalgae *Cladophora* has been observed (Rosen *et al*, 1996) in the lake indicates that phosphorus is available for their growth, and that the phosphorus may have discharged into the lake by groundwater.

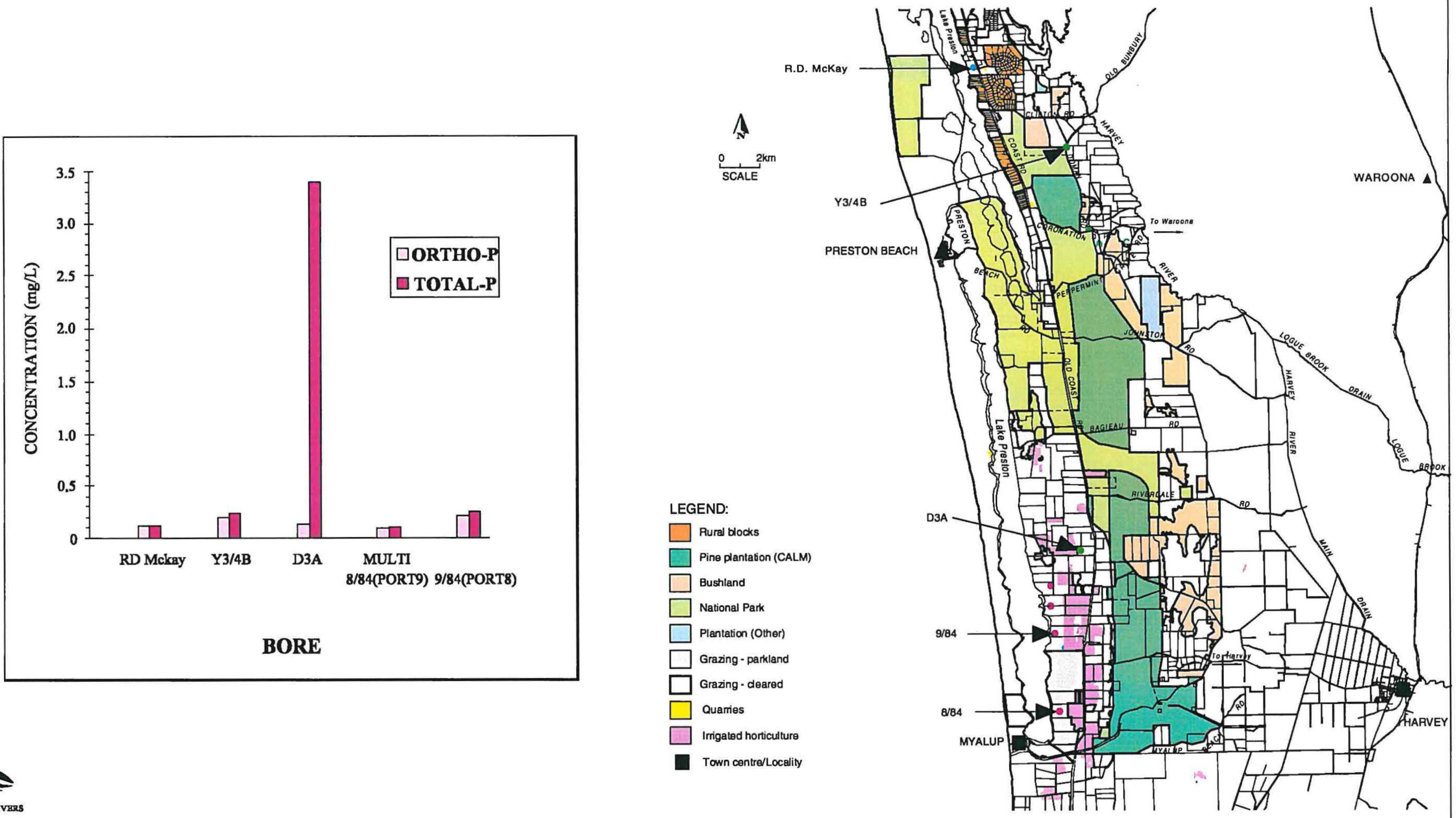

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Figure 40. Bores with ortho-phosphate concentration exceeding guideline level

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WATER BALANCE

The water balance equates all water entering the flow system to all that that leaves the system.

Inflow and outflow

Input to groundwater is mainly by recharge from rainfall with some return of abstracted groundwater in areas where irrigation is practised. Output from the groundwater flow system includes discharge into lakes from all subareas, discharge into the ocean and Harvey Estuary from White Hills and Island Point subareas only. Where the watertable lies at shallow depth, groundwater is lost by evapotranspiration from vegetation. In the southern part of the area, losses from the flow system also result from abstraction and leakage to the Leederville Formation.

The lakes act as groundwater sinks and output is by evaporation. Although in Lake Preston some transference of water with the underlying hypersaline groundwater may take place by diffusion (Commander, 1988), this has been disregarded in the water balance calculation.

The capture zones of the lakes are the areas from which groundwater flows to discharge into the lakes. Throughflow to the lakes within the capture zones is calculated both by groundwater hydraulics and by chloride mass balance. There is one sampling and monitoring site west of Lake Clifton, and none west of Lake Preston. Therefore, the extent of the capture zone to the west of the lakes has been estimated. The capture zones to the east of the lakes are better defined. It is assumed that the groundwater component of the lake-water budget contributed from the east and west is proportional to the area of the respective capture zones.

Lake budget

The waterlevel in the lake is maintained by the rain falling on the lake, discharge from groundwater and evaporation from lake surface. Since there is no significant overland flow, the groundwater contribution to the lakes is the difference between the total volume of rain falling on the lakes, evaporation from the lakes and evapotranspiration from the fringing vegetation of the lake. The lake comprises the open water body and the fringing vegetation of the high water mark. Fringing vegetation of the lakes is part of the vegetated buffer zones of the lakes. Buffer zones range in width from 20 m to 600 m (Davies and Lane, 1996), however, only about 50 m of the buffer is within the high water line forming the vegetated fringing area of the lakes (A_{veg}). Wetland type vegetation occurs in the fringing area, from where evapotranspiration (E_{veg}) may be equivalent to 107% of annual rainfall (Farrington et al, 1990). The water balance for a lake is calculated as follows:

$$Q_{lake} = E_L - R_L - E_T \qquad (2)$$

with,
$$R_L = R \times A_L$$
$$E_L = E \times A_L$$
$$E_T = E_{veg} \times R \times A_{veg}$$

where, Q_{lake} = groundwater discharge to lake (m^3/yr)
R_L = rainfall over A_L (m^3/yr)
R = rainfall (m/yr)
A_L = lake area (m^2)
E_L = evaporation from A_L (m^3/yr)
E = lake evaporation (m/yr)
E_T = evapotranspiration from fringing vegetation (m^3/yr)
E_{veg} = evapotranspiration rate from fringing vegetation (%)
A_{veg} = vegetated area fringing the lake (m^2)

Throughflow determined by groundwater hydraulics

Groundwater throughflow to the lake is determined by analysis of groundwater flownet (Fig. 41). Groundwater flowlines, representing the direction of groundwater flow, for convenience are drawn perpendicular to the watertable contours. Areas between flowlines are referred to as flow-channels, and the areas between each watertable contour and bounding flowlines are termed flownet cells. Flow-channels are defined for each of Lake Clifton and Lake Preston, and these represent the capture zones for the lakes (Fig. 41).

Groundwater throughflow discharges into the lakes from the full thickness of the aquifer, and is calculated at the discharging end of the flownet that is near the lake, using Darcy's equation, as follows:

$$Q_{Darcy} = K \times i \times b \times \ell \qquad (3)$$

where, Q_{Darcy} = volume of water flowing across a length of the aquifer (m^3/yr)
ℓ = length of the aquifer across which the groundwater discharges into lake (m)
b = saturated thickness of aquifer (m)
K = hydraulic conductivity (m/d)
i = hydraulic gradient (dimensionless)

For each flow channel, hydraulic gradient (i) at the watertable is measured at the discharging end of the flownet that is near the lake (Table 4) and width (ℓ) of flow-channel is the length of the discharging end of the flownet. An average thickness (b) of the superficial aquifer is used in the calculation of throughflow from each channel.

Throughflow calculation using chloride mass balance

It is assumed that all the chloride in the groundwater originates from rainfall (Davidson, 1995). The chloride concentration in rainfall (including dryfall) over the area is 14 mg/L (Hingston and Gailitis, 1976). The ratio of chloride concentration in rainfall to that in groundwater is a measure of the rainfall contributing to actual recharge and is defined as a percentage:

$$R_{chg} = (Cl_r / Cl_g) \times 100 \qquad (4)$$

where, R_{chg} = percentage of rainfall recharge
Cl_r = concentration of chloride in rainfall (mg/L)
Cl_g = concentration of chloride in groundwater (mg/L).

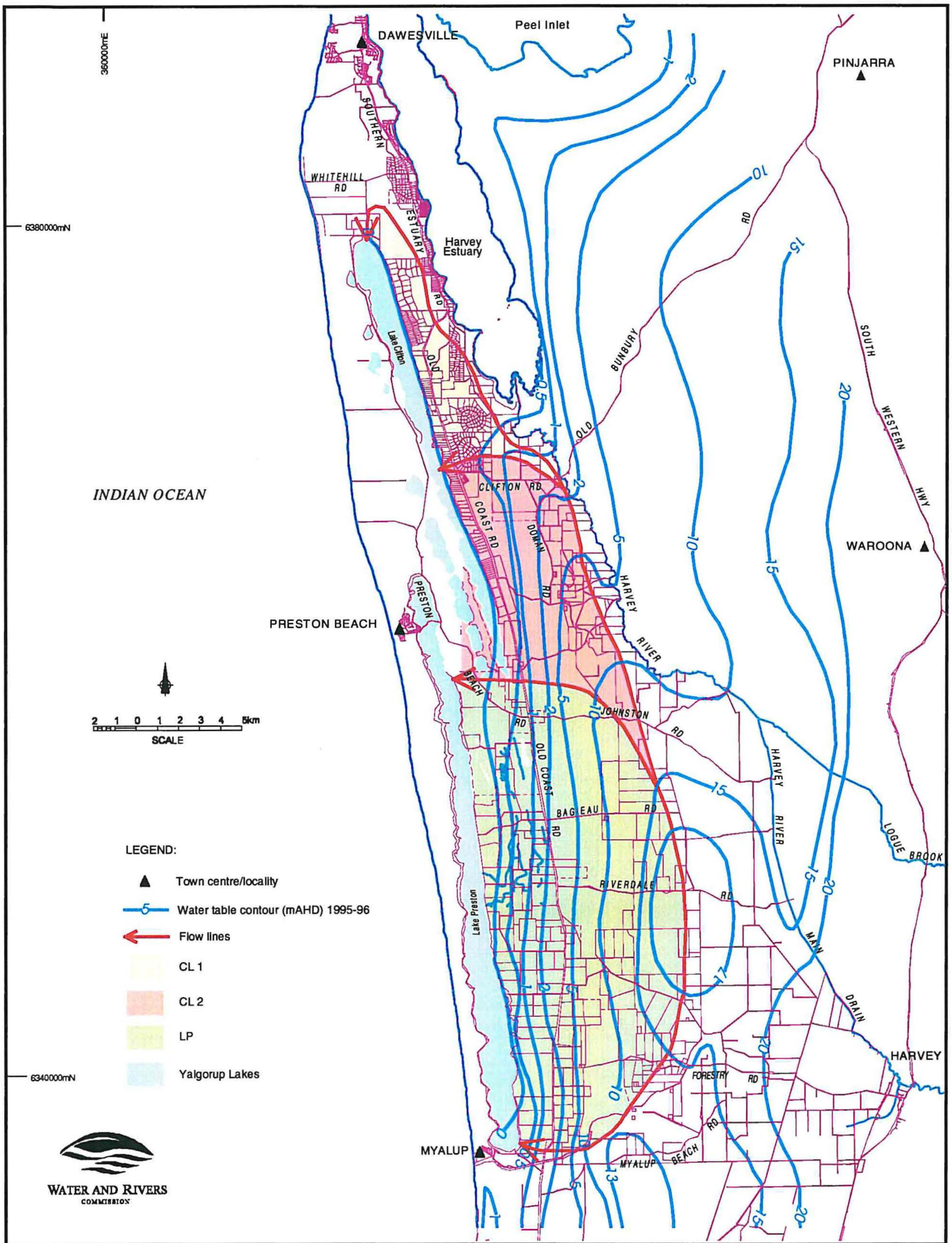

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Figure 41. Superficial aquifer groundwater flownets

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Total recharge (R_{ech}) over the capture zone area of the lakes is

$$R_{ech} = R_{chg} \times R \times A_G \qquad (5)$$

However, part of the total recharge contributes to abstraction (Abs) and leakage (Qleak) to the underlying Leederville aquifer and the remaining discharges as groundwater throughflow into lakes.

$$Q_{chloride} = R_{ech} - (Abs + Qleak) \qquad (6)$$

where, $Q_{chloride}$ = groundwater throughflow (m^3/yr) discharge into lakes
R_{ech} = total recharge (m^3/yr)
R_{chg} = percentage of rainfall recharge
R = rainfall (m/yr)
A_G = capture zone area of the lake (m^2)
Abs = total abstraction from capture zone (m^3/yr)
Qleak = total leakage from capture zone (m^3/yr)

Water balance for the lakes were calculated using three different methods Q_{lake}, Q_{Darcy} and $Q_{chloride}$, and these need to be equal.

Water balance for Lake Clifton

Q_{lake},

The capture zone area for Lake Clifton is about 90 km^2 to the east of the lake (Island Point, Lake Clifton and Colburra Downs subareas) and about 40 km^2 to the west. The ratio of capture zone area is 2:1 (east:west), and the lake area is proportioned on this basis. The water balance is calculated for the eastern area of the lake (A_L = 11.8 km^2) and the lake water budget presented in Table 11.

Table 11. Components of Lake Clifton water budget (east)

Component	*Value*
Total lake area (m^2)	17 800 000 [(a)]
Lake area (A_L) fed by groundwater from east (m^2)	11 800 000 [(b)]
Rainfall (R) at Mandurah in 1995 (m/yr)	0.882
Pan evaporation at Wokalup in 1993 (m/yr)	1.681
Pan coefficient	0.93 [(c)]
E (m/yr)	1.5633 [(d)]
R_L (m^3/yr)	10 400 000 [(e)]
E_L (m^3/yr)	18 400 000 [(f)]
A_{veg} (m^2)	1 110 000 [(g)]
E_{veg} (%)	107 [(h)]
E_T (m^3/yr)	1 043 400 [(i)]
Q_{lake} (m^3/yr)	7 000 000 [(j)]

(a) Commander, (1988)
(b) Two-third of total lake area
(c) Hoy and Stephens, (1979)
(d) Pan evaporation × Pan coefficient
(e) R × A_L
(f) E × A_L
(g) vegetated area fringing the lake
(h) 1.07 (Farrington *et al*, 1990)
(i) A_{veg} x E_{vegx} x R
(j) E_L - R_L - E_T

Q_{Darcy}

Groundwater throughflow to the lake from the capture zone is obtained from hydraulic calculations using equation (3). Two flow-channels, CL1 and CL2 are defined within the capture zone of Lake Clifton (Fig. 41 and these correspond approximately to the Island Point subarea, and to the Lake Clifton and Colburra Downs subarea, respectively. Components of the groundwater throughflow (Q_{Darcy}) equation for each of the flow channels and for the total groundwater throughflow to Lake Clifton are shown in Table 12.

Table 12. Components of groundwater throughflow to Lake Clifton

Parameters	*Flow channel*		
	CL1	*CL2*	*Total*
Hydraulic conductivity (K) (m/d)	200	200	
Hydraulic gradient (i)	0.0001	0.0004	
Aquifer thickness (b) (m)	20	20	
Width of flow channel (l) (m)	11 600	10 600	22 200
Throughflow (Q_{Darcy}) (m^3/yr)	1 600 000	6 100 000	7 700 000

Moore (1993) concluded that there is continuous seepage of fresh groundwater into the lakes along the foreshore and that the width of this seepage zone varies, both throughout the length of the foreshore and seasonally. Seepage zone width measured at a single location on the eastern foreshore of the lake is 100–150 m, and seepage rates measured ranged from 343 to 1807 mL/m^2/h or 3.0 to 15.9 m/yr (where 1 mL/m^2/h^1 = .00876 m/yr). Higher seepage rates measured where thrombolites are growing and low rates where they are absent. Seepage flow of 8 325 000 m^3/yr is calculated using seepage rate of 3.0 m/yr, average seepage zone width of 125 m and the length of the seepage zone of 22 200 m. It is apparent that this seepage flow exceeds the calculated throughflow (Q_{Darcy}), the discrepancy being due to lack of accurate data. Much higher seepage flow of 41 625 000 m^3/yr is calculated using seepage rate of 15.9 m/yr. However, the actual annual seepage flow may be less than the calculated flow because of seasonal variation of seepage zone width.

$Q_{chloride}$

Throughflow was also calculated using the chloride mass balance equation (6). For the calculation an average value of chloride for each subarea is used, from the chloride concentration map (Fig. 31). The average chloride concentration in groundwater is considered to be 200 mg/L in flow-channel CL1 and 150 mg/L in flow-channel CL2. Current abstraction rates within the flow channels are obtained from the Water Resources Licensing System (Water and Rivers Commission) database. No leakage is known to occur between the superficial and Leederville aquifers. The components of throughflow calculation using the chloride-balance equation are set out in Table 13.

Table 13. Components of chloride mass balance for Lake Clifton

Parameters	*Flow channel*	
	CL1	*CL2*
$A_G (m^2)$	25×10^6	65×10^6
Cl_r (mg/L)	14	14
Cl_g (mg/L)	200	125
Rchg (%)	7	11.2
RECH (m^3/yr)	1 500 000	6 400 000
Abs (m^3/yr)	366 050	380 800
$Q_{chloride}$ (m^3/yr)	1 100 000	6 000 000
Total $Q_{chloride}$ from both flow channels (m^3/yr)	7 100 000	

Water balance for Lake Preston

$Q_{lake,}$

The northern part of Lake Preston receives groundwater from areas between Lake Clifton and Lake Preston, and the remainder from the Lake Preston subarea. The total area of Lake Preston is 29.6 km^2, and the area in the south fed by groundwater from Lake Preston subarea alone is 25 km^2.

The capture zone area of Lake Preston is about 175 km^2 to the east and estimated at 25 km^2 to the west. The ratio of the capture zones (east:west) is therefore 7:1 and the lake area is proportioned with 22 km^2 of the lake being recharged from east and 3 km^2 from the west. The water balance has been calculated for the eastern area of Lake Preston and details are given in Table 14.

Table 14. Components of Lake Preston water budget

Component	*Value*
Total lake area (m^2)	25 000 000 [a]
Lake area (A_L) fed by groundwater from east (m^2)	21 800 000 [b]
Rainfall at Mandurah in 1995 (R) (m/yr)	0.882
Pan evaporation at Wokalup in 1993 (m/yr)	1.681
Pan coefficient	0.93 [c]
E (m/yr)	1.5633 [d]
R_L (m^3/yr)	19 200 000 [e]
E_L (m^3/yr)	34 000 000 [f]
A_{veg} (m^2)	1 120 000 [g]
E_{veg} (%)	107 [h]
E_T (m^3/yr)	1 057 000 [i]
Q_{lake} (m^3/yr)	13 800 000 [j]

(a) Commander, (1988)
(b) Two-third of total lake area
(c) Hoy and Stephens, (1979)
(d) Pan evaporation × Pan coefficient
(e) $R \times A_L$
(f) $E \times A_L$
(g) vegetated area fringing the lake
(h) 1.07 (Farrington *et al*, 1990)
(i) $A_{veg} \times E_{vegx} \times R$
(j) $E_L - R_L - E_T$

Q_{Darcy}

A single flow-channel, LP, that coincides with the Lake Preston subarea (Fig. 41) represents the capture zone of Lake Preston on the east. Hydraulic gradient of the watertable and width of the flow-channel are measured at the discharge end of the flownet. As the thickness of the superficial aquifer varies between 20 m (at site HS64) in the north and 30 m (at site Y4/4) in the south of the subarea, an average thickness of 25m is used in the calculation of throughflow. Hydraulic conductivity in the Lake Preston subarea varies from north to south and an average of 40 m/d is used in the calculation for this subarea. Components of throughflow calculated using equation (3) are detailed in Table 15.

Table 15. Components of groundwater throughflow to Lake Preston

Parameters	*Flow channel LP*
Hydraulic conductivity (K) (m/d)	40
Hydraulic gradient (i)	0.0019
Aquifer thickness (b) (m)	25
Width of flow channel (ℓ) (m)	22 400
Throughflow (Q_{Darcy}) (m^3/yr)	15 500 000

$Q_{chloride}$

The superficial aquifer in flow channel LP is recharged from rainfall, and chloride concentration in the groundwater is used to calculate the recharge. The two major sources of loss from the superficial aquifer are abstraction and leakage to the Leederville aquifer. Current abstraction rates within the flow channel are obtained from the licensing database and leakage is calculated according to equation (7).

$$Qleak = (k'/b') \times \Delta h \times A_G \quad (7)$$

where, Qleak = leakage from superficial aquifer (m^3/yr)

- k' = vertical hydraulic conductivity of the aquifer within which leakage is occurring (m/d)
- b' = thickness of the aquifer over which the leakage is occurring (m)
- Δh = average of the difference between potentiometric head at the top of Leederville aquifer and the watertable in the superficial aquifer (m)
- A_G = area of the flow channel within which the leakage in occurring (m^2)

Downward leakage (Qleak) is evident from waterlevel records at two sites (HS64 and Y4/4). Downward leakage is calculated for the entire Lake Preston subarea (Table 16).

Table 16. Downward leakage in Lake Preston subarea

Parameter	*Values*
k′ (m/d)	5×10^{-4} (a)
b′ (m)	11
Δh (m)	0.4
A_G (m^2)	175.7×10^6
Qleak (m^3/yr)	1 100 000

(a) Davidson, 1995

Chloride concentration in groundwater within most of the Lake Preston subarea lies between 50 and 100 mg/L, and an average of 75 mg/L was used for the calculation. Components of the chloride mass balance equation are shown in Table 17.

Table 17. Components of chloride mass balance for Lake Preston

Parameter	*Flow channel LP*
A_G (m^2)	175.7×10^6
Cl_r (mg/L)	14
Cl_g (mg/L)	75
Rchg (%)	18.6
RECH (m^3/yr)	28 800 000
Abs (m^3/yr)	11 950 000
Qleak (m^3/yr)	1 100 000
$Q_{chloride}$ (m^3/yr)	15 700 000

The discrepancy observed in the throughflows between those calculated by Darcy's equation and those by the chloride mass balance equation are attributed to the use of approximations for some of the variables.

NUTRIENT FLUX

The mass-flux of nitrogen and phosphorus from groundwater to the lakes are estimated using Darcy's calculation.

Mass-flux is calculated as:

$$M = C \times Q_{Darcy}) \qquad (8)$$

and

$$F = (C \times Q_{Darcy}) / \ell \qquad (9)$$

where, M = total mass of nitrogen or phosphorus discharged from groundwater expressed in tonnes/yr [a]

F = mass-flux of nitrogen or phosphorus per km length of the lake shore expressed in kg/yr/km [b]

C = concentration of nitrogen or phosphorus in groundwater (mg/L)

Q_{Darcy} = volume of water flowing across a width of the aquifer (m^3/yr)

ℓ = length of the aquifer across which the groundwater discharges into lake (km)

The average of total nitrogen concentration in groundwater flowing into Lake Clifton (Fig. 32) is 2.0 mg/L. The concentration of total phosphorus is 0.05 mg/L in flow-channel CL1 and northern half of flow-channel CL2, and greater than 0.05 mg/L in the southern half of flow-channel CL2. Concentration of total nitrogen in groundwater flowing into Lake Preston is 2.0 mg/L in the north and 5.0 mg/L in the south. For the calculation, an intermediate value of 3.5 mg/L is used. Total phosphorus concentration in the Lake Preston subarea is 0.1 mg/L. Table 18 show the nutrient flux for Lakes Clifton and Preston, evaluated using equations (8) and (9).

Table 18. Nutrient flux to Lake Clifton and Lake Preston

	Q_{Darcy} *(m^3/yr)*	*ℓ* *(km)*	*Total N* *(mg/L)*	*Total P*	*Mass N* *(tonnes/yr)*	*Mass P*	*Flux N* *(kg/yr/km)*	*Flux P*
	Lake Clifton							
CL1	1 600 000	11.6	2.0	0.05	3.2	0.08	275.9	6.9
CL2	6 100 000	10.6	2.0	0.05	12.2	0.31	1150.9	28.8
Total	7 700 000	22.2			15.4	0.39		
	Lake Preston							
LP	15 500 000	22.4	3.5	0.1	54.3	1.6	2421.9	69.35

[a] M is conventionally expressed in tonnes/yr, therefore C and Q_{Darcy} are converted accordingly by multiplying with a factor of 10^{-6}.

[b] F is conventionally expressed in kg/yr/km, therefore C and Q_{Darcy} are converted accordingly by multiplying with a factor of 10^{-3}.

CONCLUSIONS

1. Groundwater occurs in a regional, unconfined aquifer of the superficial formations. The superficial aquifer comprises Tamala Limestone in eastern part of White Hills subarea, in Island Point subarea and in the western part of Lake Preston subarea; Tamala Limestone, Bassendean Sand and Gnangara Sand in Colburra Downs subarea, eastern part of Lake Preston subarea and in western part of Harvey subarea; and Tamala Limestone and Safety Bay Sand in western part of White Hills subarea and the Coastal subarea.

2. The position of the groundwater divide around Lake Clifton moves seasonally, and in winter the divide is farthest away from the lake and in summer it moves close to the lakes. The groundwater divide is about 2 to 4 km east of Lake Clifton shore and 9 km east of Lake Preston shore; to the west of Lake Clifton, the groundwater divide is about 2 km west of the lake and to the west of Lake Preston it is less than a kilometre from the lake. The shifting nature of the groundwater divide signifies the reduction of capture zone area of Lake Clifton in summer and therefore the seasonal variation of fresh groundwater discharge to the lake.

3. Most groundwater discharge is to the lakes and to the ocean; in the north, groundwater also discharges to the Harvey Estuary. There is some discharge to the Leederville aquifer in the southern part of the area.

4. The watertable is at approximately sea level in both the White Hills and Island Point subareas. In the Lake Clifton subarea, it ranges from 0 m AHD near the lakes to 5 m AHD near the groundwater divide. In the Lake Preston subarea, the watertable has a minimum level of -0.08 m AHD near the lake, rising to more than 15 m AHD near the groundwater divide. Minimum waterlevel is attained in April–May and maximum in September–November. All bores register a response to winter rainfall within a period of one month from the onset of rain. However, the seasonal effect is obscured by tidal effects in bores close to the coast and estuary in the White Hills and Island Point subareas

5. The hydraulic gradient is very low, especially in the White Hills, Island Point and Lake Clifton subareas; The watertable flattens further in summer due to a combination of reduction in recharge and continued abstraction, thus reducing the freshwater discharge to the lakes.

6. Seasonal fluctuation of the watertable is generally less than 1m, but in areas of large-scale abstraction (e.g. Lake Preston subarea), the fluctuation exceeds 1 m. A rising trend in the watertable is observed in the vicinity of a clearfelled pine plantation. Local decline in watertable (below sealevel), in a rural subdivision of partially cleared native vegetation, is attributed to evapotranspiration and abstraction.

7. Groundwater salinity at the watertable is 250 mg/L, increasing with depth to over 2000 mg/L at the fresh water–saline water contact.

8. Low-saline water (<2000 mg/L) occurs as a lens overlying brackish to saline water. In the northern part of Coastal subarea this lens is 5 m thick; in the White Hills and Island Point subareas it is up to 10 m thick and; in the Lake Clifton and Lake Preston subareas, the freshwater extends to the base of the superficial aquifer.

9. Recharge calculated as percentage of annual rainfall is 7% in Island Point subarea, 11% in Lake Clifton and Colburra Downs subareas, and 18% in Lake Preston subarea.

10. Nitrate+nitrite nitrogen concentrations exceeding the guideline level were detected in several bores in the Island Point subarea, this was traced more than 1 km down gradient of bore Y2/5. Elevated concentrations (about 10 mg/L) recorded in other bores within 1 km of the lake shore is the result of both horticultural practice and posssible sewage pollution. Fertiliser usage in horticultural activities and pastoral activities are considered to be the cause of high nitrate concentration in the groundwater in the southern part of the area. At sites D3A and D3B, nitrate nitrogen rich water has migrated to the bottom of the aquifer. At site Y4/2, nitrate nitrogen rich water occurs in the upper few metres of the aquifer.

11. Ammonia nitrogen concentration exceeding guideline levels was observed in bores located in pastures, adjacent to Lake Preston; elevated concentrations were detected in Lake Preston water during winter.

12. Ortho-phosphate concentrations above guideline level were found in groundwater at the base of the superficial aquifer. Although, nitrate pollution of groundwater has been associated with fertiliser usage, the low phosphorus concentration in the same bore water suggests that phosphorus in fertilisers is probably being adsorbed by the soil.

13. Total nitrogen concentration in the groundwater exceeded the guideline level over most of the area. Generally organic nitrogen constitutes the major form of nitrogen in the groundwater except as described for some areas where nitrate and ammonia are the dominant forms of nitrogen. Except for a few sites, groundwater in the superficial aquifer generally had low phosphorus levels that were below the guideline limit.

14. Groundwater from lakeside shallow bores (YSH1 to YSH8) were low in nitrate nitrogen concentration. Two reasons can be identified. Firstly, water quality was monitored during only two months of the year instead of more frequently. Secondly, the nitrate-rich groundwater occurs only at certain sites and the lakeside shallow bores may not have been suitably located.

15. Groundwater discharge to the eastern part of Lake Clifton is 7.7×10^6 m^3/yr, with an estimated total nitrogen flux of 15 tonnes/yr and total phosphorus flux of 0.4 tonnes/yr to the lake.

16. Groundwater discharge to the eastern part of Lake Preston is $15.5 \times 10^6\,m^3/yr$, with an estimated total nitrogen flux of 54 tonnes/yr and total phosphorus flux of 1.6 tonnes/yr to the lake.

RECOMMENDATIONS

1. Waterlevel monitoring should be continued quarterly for five years in order to define the trend of groundwater head in the area.

2. The lakeside shallow bores should be sampled every two months for one year in order to identify whether the nutrient-rich groundwater is flowing into the lakes.

3. Water quality monitoring for nutrients should be carried out for selected bores twice a year (at end of summer and winter) for the next five years (Appendix 4).

4. The source of high nitrate concentration in two bores (YPR2, YPR3) in the Island Point subarea needs to be determined, and microbiological analysis of bore water is recommended to examine the possibility of sewage pollution.

5. Groundwater from bores in the rural subdivision area should be subjected to microbiological analysis to ascertain the impact of current sewage disposal practice.

6. The pumpage, irrigation details and fertiliser application on the properties of large groundwater users requires monitoring.

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Appendix 1. Bore completion details (Bore location in Figures 9–12).

SWRIS number	*Bore name*	*East*	*North*	*N.S.*	*T.O.C*	*T.D.*	*Slotted depth*	*Slotted interval*	*Casing ID*	*Completion date*	*Stratigraphic unit of screened interval*
		AMG	*AMG*	*mAHD*	*mAHD*	*mbns*	*mbns*	*m*	*mm*		
Transect bores											
G61319500	Y1/1A	370402	6382129	11.173	11.903	18	16.5–18	1.5	50	10/06/95	Tamala Limestone
G61319123	A1	370400	6382150	11.136	11.705	14.1	6–14.1	8.1	40	Amended	Tamala Limestone
G61319125	A3A	372250	6382200		8.63	36	14.8–32.8	18	40	existing	Tamala Limestone
G61319126	A3B	372250	6382200		8.646	15.5	7.5–13.5	6	40	existing	Tamala Limestone
G61319501	Y1/3A	373736	6382429	4.152	4.812	17	15–17	2	50	10/04/95	Tamala Limestone
G61319127	A4	373400	6382300	4.272	4.636	11.3	6–11.3	5.3	40	Amended	Tamala Limestone
G61319502	Y1/4A	374583	6282459	1.078	1.678	9	7.5–9	1.5	50	10/03/95	Tamala Limestone
G61319128	A5	374550	6382450	1.016	1.723	3.95	0–3.95	3.95	40	Amended	Tamala Limestone
G61319503	Y2/1A	371986	6375331	4.419	5.102	15	13–15	2	50	10/07/95	Tamala Limestone
G61319504	Y2/1B	371986	6375329	4.564	5.198	10	4–10	6	50	10/07/95	Tamala Limestone
G61319505	Y2/2A	372694	6375559	0.993	1.62	9	7–9	2	50	10/08/95	Tamala Limestone
G61319506	Y2/2B	372693	6375559	0.979	1.709	5	0–5	5	50	10/08/95	Tamala Limestone
G61319551	CS19	374023	6375646	1.905	2.055	5.3	3.6–5.3	1.7	40		Tamala Limestone
G61319507	Y2/4A	374842	6376005	11.489	12.119	22	20–22	2	50	29/9/95	Tamala Limestone
G61319508	Y2/4B	374844	6376004	11.465	12.135	17	14–17	3	50	29/9/95	Tamala Limestone
G61319509	Y2/5A	375926	6376023	37.157	37.797	48	46–48	2	50	25/9/95	Tamala Limestone
G61319510	Y2/5B	375924	6376022	37.306	37.931	43	38–43	5	50	25/9/95	Tamala Limestone

Appendix 1. (*contd.*)

SWRIS number	*Bore name*	*East*	*North*	*N.S.*	*T.O.C*	*T.D.*	*Slotted depth*	*Slotted interval*	*Casing ID*	*Completion date*	*Stratigraphic unit of screened interval*
		AMG	*AMG*	*mAHD*	*mAHD*	*mbns*	*mbns*	*m*	*mm*		
G61319552	Y2/6A	376225	6376083	1.443	1.94	12	9–11	2	50	9/12/95	Tamala Limestone
G61319553	Y2/6B	376225	6376081	1.382	1.969	6	0–5	5	50	9/12/95	Tamala Limestone
G61319511	Y3/1A	376790	6366312	1.136	1.823	15	10–15	5	50	9/10/95	Tamala Limestone
G61319512	Y3/1B	376789	6366313	1.198	1.833	5	0–5	5	50	9/10/95	Tamala Limestone
G61319513	Y3/2A	377338	6366635	3.534	4.13	20	17–20	3	50	9/08/95	Tamala Limestone
G61319514	Y3/2B	377338	6366633	3.547	4.117	13	11–13	2	50	9/08/95	Tamala Limestone
G61319132	B4	377500	6366400	3.525	4.163	5.8	0–5.8	5.8	40	Amended	Tamala Limestone
G61319515	Y3/3A	378358	6366528	25.387	25.99	43	41–43	2	50	26/8/95	Tamala Limestone
G61319516	Y3/3B	378362	6366529	25.502	26.098	38	35–38	3	50	26/8/95	Tamala Limestone
G61319517	Y3/3C	378365	6366529	25.745	26.406	30	26–30	4	50	26/8/95	Tamala Limestone
G61319518	Y3/4A	380393	6366609	4.701	5.304	18	16.5–18	1.5	50	15/8/95	Gnangara Sand
G61319519	Y3/4B	380393	6366611	4.801	5.344	13	10–13	3	50	15/8/95	Bassendean Sand
G61319134	B6	380350	6366400	4.776	4.458	6.2	0–6.2	6.2	40	Amended	Bassendean Sand
G61319520	Y4/1A	379508	6340314	0.507	1.107	8.5	7–8.5	1.5	50	8/10/95	Tamala Limestone
G61319151	E1B	379600	6340400	0.485	1.14	2	0–2	2	40	Amended	Tamala Limestone
G61319521	Y4/2A	380825	6340354	5.535	6.147	17.5	16–17.5	1.5	50	8/09/95	Tamala Limestone
G61319152	E2A	380550	6340400	5.554	6.142	11.7	10–11.7	1.7	40	Amended	Tamala Limestone
G61319153	E2B	380550	6340400	5.548	6.084	8	0–8	8	40	Amended	Tamala Limestone

Appendix 1. (*contd.*)

SWRIS number	*Bore name*	*East* AMG	*North* AMG	*N.S.* mAHD	*T.O.C* mAHD	*T.D.* mbns	*Slotted depth* mbns	*Slotted interval* m	*Casing ID* mm	*Completion date*	*Stratigraphic unit o screened interval*
G61319522	Y4/3B	381728	6340368	5.965	6.665	16.5	14–15.5	1.5	50	8/03/95	Tamala Limestone
G61319523	Y43C	381729	6340368	6.019	6.659	12	9–12	3	50	8/03/95	Tamala Limestone
G61319156	E3C	381950	6340350	5.896	6.622	3.8	0–3.8	3.8	40	Amended	Tamala Limestone
G61319157	E4A	382800	6340350	16.549	17.339	39	29–39	10	40	existing	Leederville Formation
G61319524	Y4/4B	382677	6340390	16.953	17.533	27	24.5–26	1.5	50	8/04/95	Ascot Formation
G61319159	E4C	382677	6340386	16.64	17.4	13.2	5–13.2	8.2	40	Amended	Bassendean Sand, Gnangara Sand
G61319525	Y4/5A	383951	6340549	12.121	12.751	25	22–25	3	50	8/06/95	Ascot Formation
G61319161	E5B	383750	6340550	13.274	13.903	12.629	0–12.629	12.629	40	Amended	Bassendean Sand
G61319526	Y4/6	384917	6340888	23.474	24.031	17	12–17	5	50	8/11/95	Bassendean Sand
Lakeside shallow bores											
G61319527	YSH1	372532	6379281	0.598	0.898	1	0.4–1	0.6	50	11/01/95	Tamala limestone
G61319528	YSH2	373130	6378420	0.374	0.827	1.86	0.96–1.86	1	40	11/03/95	Tamala limestone
G61319529	YSH3	373568	6377090	0.374	1.074	1.45	0.8–1.45	0.65	50	11/01/95	Tamala limestone
G61319530	YSH4	374123	6375308	0.665	0.98	1.86	1.01–1.86	0.85	40	11/03/95	Tamala limestone
G61319531	YSH5	374865	6372588	0.522	0.892	2.03	1.03–2.03	1	40	11/03/95	Tamala limestone
G61319532	YSH6	378372	6362468	0.713	1.293	2.02	1.09–2.03	0.94	40	11/07/95	Tamala limestone
G61319533	YSH7	377060	6355394	0.166	0.736	1.78	0.84–1.78	0.94	40	11/07/95	Tamala limestone
G61319434	YSH8	377969	6347938	0.074	0.474	1.78	0.84–1.78	0.94	40	11/07/95	Tamala limestone

Appendix 1. *(contd.)*

SWRIS number	*Bore name*	*East*	*North*	*N.S.*	*T.O.C*	*T.D.*	*Slotted depth*	*Slotted interval*	*Casing ID*	*Completion date*	*Stratigraphic unit o screened interval*
		AMG	*AMG*	*mAHD*	*mAHD*	*mbns*	*mbns*	*m*	*mm*		
Inspected private bores											
G61319536	YPR1	374122	6377834	-	-	-	-	-	-	-	-
G61319539	YPR2	374854	6374668	-	9.278	-	-	-	-	-	-
G61319542	YPR3	374541	6374935	-	6.522	-	-	-	-	-	-
G61319543	YPR4	376632	6373880	-	-	-	-	-	-	-	-
G61319543	YPR5	377399	6370566	-	-	-	-	-	-	-	-
G61319547	YPR6	377705	6369448	-	40.615	-	-	-	-	-	-
G61319548	YPR7	381132	6368143	-	3.983	-	-	-	-	-	-
G61319549	YPR8	377605	6368571	-	27.455	-	-	-	-	-	-
G61319535	YPR9	375019	6377832	-	55.794	-	-	-	-	-	-
G61319537	YPR10	373957	6377244	-	8.591	-	-	-	-	-	-
G61319538	YPR11	374567	6374581	-	2.34	-	-	-	-	-	-
G61319540	YPR12	376958	6374218	-	5.232	-	-	-	-	-	-
G61319541	YPR13	374773	6375340	-	13.36	-	-	-	-	-	-
G61319545	YPR14	377586	6371047	-	35.895	-	-	-	-	-	-
G61319546	YPR15	376837	6371386	-	41.881	-	-	-	-	-	-
South-west region bores											
G61319112	Rose bore A	380120	6343925	-	2.67	-	-	-	-	-	-
G61319110	JE Giblett bore C	379710	6344675	-	3.03	-	-	-	-	-	-
G61319107	FL+L Armstrong bore A	-	-	-	-	-	-	-	-	-	-
G61319109	LR Armstrong bore B	380955	6345000	-	4.26	-	-	-	-	-	-
G61319190	RD Mckay	-	-	-	-	-	-	-	-	-	-
G61319192	F Roberts native bore	-	-	-	-	-	-	-	-	-	-
G61319105	RV Armstrong bore I	-	-	-	-	-	-	-	-	-	-
G61319198	S Palmer	381350	6337625	-	-	-	-	-	-	-	-

Appendix 1. (*contd.*)

SWRIS number	*Bore name*	*East*	*North*	*N.S.*	*T.O.C*	*T.D.*	*Slotted depth*	*Slotted interval*	*Casing ID*	*Completion date*	*Stratigraphic unit of screened interval*
		AMG	*AMG*	*mAHD*	*mAHD*	*mbns*	*mbns*	*m*	*mm*		
G61319115	Rose bore M	380225	6341180	-	3.22	-	-	-	-	-	-
G61319114	Rose bore O	380855	6341130	-	3.83	-	-	-	-	-	-
G61319113	Rose bore G	380080	6342920	-	2.96	-	-	-	-	-	-
G61319195	TW Pearson	-	-	-		-	-	-	-	-	-
G61319208	L Sumich & Sons 2C	-	-	-	-	-	-	-	-	-	-
G61319215	L Sumich Carrot Wash	-	-	-	-	-	-	-	-	-	-
G61319144	D1	378550	6345500	1.183	1.911	32	0.5–29.5	29	-	-	-
G61319145	D2	379600	6345600	10.351	10.896	42	16–40	24	-	-	-
G61319146	D3A	380550	6345400	19.431	20.036	45	25–45	20	-	-	-
G61319147	D3B	380500	6345400	19.384	20	26	10–25	15	-	-	-
G61319148	D4	381350	6345550	4.425	5.082	35.5	1–35.5	34.5	-	-	-
G61319138	C4	378750	6357000	0.968	1.455	26	1.5–25.5	24	-	-	-
G61319139	C5	379850	6356800	1.926	2.5	24	0.5–24	23.5	-	-	-
G61319141	C7	382100	6356850	38.849	39.331	61	30.5–60.5	30	-	-	-
G61319142	C8	383200	6356850	14.775	15.446	40	2–40	38	-	-	-
G61330108	HS64A	382000	6352200	16.531	17.533	42	28.5–34.5	7	-	-	-
G61330111	HS64C	382000	6352200	16.527	17.573	28	24.5–27.5	3	-	-	-
G61330110	HS64B	382000	6352200	16.521	17.573	18	12.5–15.5	3	-	-	-
G61330104	HS63A	381500	6362300	7.519	8.316	33	21.5–27.5	6	-	-	-
G61330105	HS63B	381500	6362300	7.504	8.393	21	12.5–18.5	6	-	-	-
G61330107	HS63C	381500	6362300	7.511	8.316	9	2–8	6	-	-	-
G61330102	HS62B	377600	6372000	2.945	3.76	33	16–22	6	-	-	-
G61330103	HS62C	377600	6372000	2.911	3.81	6	1.5–4.5	3	-	-	-

Appendix 1. (*contd.*)

SWRIS number	*Bore name*	*East*	*North*	*N.S.*	*T.O.C*	*T.D.*	*Slotted depth*	*Slotted interval*	*Casing ID*	*Completion date*	*Stratigraphic unit o screened interval*
		AMG	*AMG*	*mAHD*	*mAHD*	*mbns*	*mbns*	*m*	*mm*		
G61319225	Multiport 8/84	379975	6338000	-	3.418	-	-16.412	-	-	-	-
							-22.302	-	-	-	-
G61319227	Multiport 10/84	379690	6341900	-	3.074	-	-11.186	-	-	-	-
							-15.256	-	-	-	-
G61319226	Multiport 9/84	379490	6343275	-	2.442	-	-9.738	-	-	-	-
							-15.188	-	-	-	-
G61319228	Multiport 11/84	379500	6344310	-	2.766	-	-8.074	-	-	-	-
							-13.424	-	-	-	-
G61319222	Multiport 5/84	378620	6345950	-	5.593	-	-5.387	-	-	-	-
							-15.787	-	-	-	-
G61319221	Multiport 4/84	378150	6350300	-	6.174	-	-5.016	-	-	-	-
							-9.466	-	-	-	-
G61319220	Multiport 3/84	377250	6365800	-	2.988	-	-5.482	-	-	-	-
							-14.012	-	-	-	-
G61319218	Multiport 1/84	375950	6369700	-	2.761	-	-11.579	-	-	-	-
							-15.579	-	-	-	-
G61319219	Multiport 2/84	375125	6372475	-	2.882	-	-9.848	-	-	-	-

Appendix II. Waterlevel monitoring data (1995–1996)

Bore name	*WL(Nov)*		*WL(Dec)*		*WL(Jan)*		*WL(Feb)*		*WL(Mar)*		*WL(Apr)*		*WL(May)*		*WL(Jun)*	
	mbtoc	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*
Transect bores																
Y1/1A	11.77	0.133	-	-	11.77	0.133	11.72	0.183	11.81	0.093	11.72	0.183	11.65	0.253	11.63	0.273
A1	11.55	0.155	-	-	11.56	0.145	11.515	0.19	11.62	0.085	11.5	0.205	11.44	0.265	11.43	0.275
A3A	8.36	0.27	-	-	8.44	0.19	8.495	0.135	8.52	0.11	8.57	0.06	8.5	0.13	8.47	0.16
A3B	8.31	0.336	-	-	8.42	0.226	8.49	0.156	8.51	0.136	8.56	0.086	8.49	0.156	8.46	0.186
Y1/3A	4.56	0.252	-	-	4.65	0.162	4.7	0.112	4.76	0.052	4.8	0.012	4.75	0.062	4.72	0.092
A4	4.35	0.286	-	-	4.43	0.206	4.515	0.121	4.54	0.096	4.57	0.066	4.57	0.066	4.49	0.146
Y1/4A	1.43	0.248	-	-	1.55	0.128	1.63	0.048	1.6	0.078	1.65	0.028	1.58	0.098	1.56	0.118
A5	1.5	0.223	-	-	1.58	0.143	1.655	0.068	1.69	0.033	1.68	0.043	1.58	0.143	1.58	0.143
Y21A	4.9	0.202	-	-	4.98	0.122	5.03	0.072	5.1	0.002	5.8	-0.698	5.06	0.042	5	0.102
Y2/1B	4.98	0.218	-	-	5.05	0.148	5.12	0.078	5.18	0.018	5.17	0.028	5.14	0.058	5.08	0.118
Y2/2A	1.44	0.18	-	-	1.55	0.07	1.64	-0.02	1.7	-0.08	1.7	-0.08	1.69	-0.07	1.62	0
Y2/2B	1.55	0.159	-	-	1.66	0.049	1.73	-0.021	1.8	-0.091	1.83	-0.121	1.78	-0.071	1.71	-0.001
CS19	1.83	0.225	-	-	-	-	2.05	0.005	2.07	-0.015	-	-	2.07	-0.015	2.01	0.045
Y2/4A	11.84	0.279	-	-	11.96	0.159	12.07	0.049	12.1	0.019	12.16	-0.041	12.12	-0.001	12.07	0.049
Y2/4B	11.85	0.285	-	-	11.99	0.145	12.085	0.05	12.12	0.015	12.17	-0.035	12.14	-0.005	12.09	0.045
Y2/5A	37.51	0.287	-	-	37.65	0.147	-	-	37.74	0.057	37.87	-0.073	37.76	0.037	37.74	0.057
Y2/5B	37.65	0.281	-	-	37.6	0.331	-	-	37.82	0.111	37.9	0.031	37.89	0.041	37.87	0.061
Y2/6A	1.7	0.24	-	-	1.83	0.11	1.9	0.04	1.95	-0.01	1.94	0	1.93	0.01	1.84	0.1
Y2/6B	1.77	0.199	-	-	1.88	0.089	1.98	-0.011	2.02	-0.051	2.02	-0.051	1.99	-0.021	1.87	0.099
Y3/1A	1.6	0.223	-	-	1.75	0.073	1.87	-0.047	1.92	-0.097	1.92	-0.097	1.91	-0.087	1.84	-0.017
Y3/1B	1.6	0.233	-	-	1.77	0.063	1.885	-0.052	1.94	-0.107	1.93	-0.097	1.93	-0.097	1.85	-0.017
Y3/2A	3.81	0.32	-	-	3.97	0.16	4.09	0.04	4.15	-0.02	4.18	-0.05	4.17	-0.04	4.11	0.02

Appendix II. *(continued)*

Bore name	*WL(Nov)*		*WL(Dec)*		*WL(Jan)*		*WL(Feb)*		*WL(Mar)*		*WL(Apr)*		*WL(May)*		*WL(Jun)*	
	mbtoc	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*
Y3/2B	3.8	0.317	-	-	3.95	0.167	4.08	0.037	4.14	-0.023	4.17	-0.053	4.16	-0.043	4.1	0.017
B4	3.85	0.313	-	-	4	0.163	4.12	0.043	4.18	-0.017	4.2	-0.037	4.19	-0.027	4.14	0.023
Y3/3A	25.5	0.49	-	-	25.62	0.37	25.76	0.23	25.79	0.2	25.85	0.14	25.84	0.15	25.84	0.15
Y3/3B	25.55	0.548	-	-	25.62	0.478	25.75	0.348	25.68	0.418	25.83	0.268	25.83	0.268	25.86	0.238
Y3/3C	25.88	0.526	-	-	25.93	0.476	26.06	0.346	26.03	0.376	26.15	0.256	26.15	0.256	26.18	0.226
Y3/4A	3.09	2.214	-	-	3.3	2.004	3.42	1.884	3.49	1.814	3.54	1.764	3.59	1.714	3.59	1.714
Y3/4B	3.23	2.114	-	-	3.35	1.994	3.47	1.874	3.54	1.804	3.6	1.744	3.64	1.704	3.63	1.714
B6	1.95	3.508	-	-	2.1	3.358	2.365	3.093	2.15	3.308	2.19	3.268	2.72	2.738	2.7	2.758
Y4/1A	1.37	-0.263	-	-	1.56	-0.453	1.73	-0.623	1.85	-0.743	1.91	-0.803	1.9	-0.793	1.86	-0.753
E1B	1.4	-0.43	-	-	1.56	-0.59	1.715	-0.745	1.82	-0.85	1.9	-0.93	1.9	-0.93	1.89	-0.92
Y4/2A	4.31	1.837	-	-	4.69	1.457	4.99	1.157	5.16	0.987	5.37	0.777	5.44	0.707	5.53	0.617
E2A	4.38	1.76	-	-	4.74	1.4	5.03	1.11	5.22	0.92	5.4	0.74	5.48	0.66	5.57	0.57
E2B	4.31	1.77	-	-	4.67	1.41	4.96	1.12	5.15	0.93	5.35	0.73	5.41	0.67	5.5	0.58
Y4/3B	3.2	3.465	-	-	3.76	2.905	4.14	2.525	4.27	2.395	4.48	2.185	4.53	2.135	4.53	2.135
Y4/3C	3.18	3.479	-	-	3.74	2.919	4.13	2.529	4.25	2.409	4.46	2.199	4.52	2.139	4.53	2.129
E3C	3.185	3.437	-	-	3.72	2.902	4.08	2.542	4.22	2.402	4.24	2.382	4.24	2.382	4.24	2.382
E4A	8.17	8.93	-	-	8.34	8.76	8.47	8.63	8.54	8.56	8.63	8.47	8.6	8.5	8.62	8.48
Y4/4B	8.31	9.223	-	-	8.47	9.063	8.62	8.913	8.7	8.833	8.78	8.753	8.76	8.773	8.78	8.753
E4C	8.23	8.87	-	-	8.41	8.69	8.54	8.56	8.61	8.49	9.83	7.27	8.68	8.42	8.7	8.4
Y4/5A	2.12	10.631	-	-	2.22	10.531	2.34	10.411	2.41	10.341	2.5	10.251	2.53	10.221	2.59	10.161
E5B	2.3	11.603	-	-	-	-	2.5	11.403	2.58	11.323	2.6	11.303	2.69	11.213	2.75	11.153
Y4/6	12.39	11.641	-	-	12.42	11.611	12.51	11.521	12.53	11.501	12.61	11.421	12.63	11.401	12.69	11.341

Appendix II. *(continued)*

Bore name	*WL(Nov)*		*WL(Dec)*		*WL(Jan)*		*WL(Feb)*		*WL(Mar)*		*WL(Apr)*		*WL(May)*		*WL(Jun)*	
	mbtoc	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*
Lakeside shallow bores																
YSH1	0.43	0.468	-	-	0.62	0.278	0.675	0.223	0.7	0.198	0.7	0.198	0.67	0.228	0.61	0.288
YSH2	0.75	0.077	-	-	0.75	0.077	0.82	0.007	0.86	-0.033	0.87	-0.043	0.82	0.007	0.76	0.067
YSH3	0.9	0.174	-	-	1	0.074	1.08	-0.006	1.14	-0.066	1.15	-0.076	1.1	-0.026	1.04	0.034
YSH4	0.75	0.23	-	-	1.18	-0.2	1.28	-0.3	1.32	-0.34	1.34	-0.36	1.3	-0.32	1.32	-0.34
YSH5	0.65	0.242	-	-	-	-	-	-	0.92	-0.028	0.96	-0.068	0.93	-0.038	0.86	0.032
YSH6	0.93	0.363	-	-	1.28	0.013	-	-	-	-	-	-	-	-	-	-
YSH7	1.05	-0.314	-	-	1.16	-0.424	1.285	-0.549	1.34	-0.604	-	-	1.42	-0.684	1.38	-0.644
YSH8	0.71	-0.236	-	-	1	-0.526	1.07	-0.596	1.2	-0.726	1.21	-0.736	1.2	-0.726	1.2	-0.726
Inspected private bores																
YPR2	8.95	0.328	-	-	9.12	0.158	9.24	0.038	9.27	0.008	9.31	-0.032	9.28	-0.002	9.24	0.038
YPR3	6.2	0.322	-	-	6.37	0.152	6.37	0.152	6.37	0.152					6.46	0.062
YPR6	40.12	0.495	-	-	40.26	0.355	40.41	0.205	40	0.615	40.55	0.065	40.47	0.145	40.52	0.095
YPR7	0.59	3.393	-	-	1.12	2.863	1.35	2.633	1.86	2.123	1.76	2.223	1.69	2.293	1.72	2.263
YPR8	27	0.455	-	-	27.15	0.305	27.29	0.165	27.3	0.155	27.3	0.155	27.36	0.095	27.37	0.085
YPR9	55.28	0.514	-	-	55.42	0.374	-	-	-	-						
YPR10	8.26	0.331	-	-	8.4	0.191	8.53	0.061	8.57	0.021	-	-	8.58	0.011	8.52	0.071
YPR11	2	0.34	-	-	2.18	0.16	2.28	0.06	2.33	0.01	-	-	2.34	0	2.28	0.06
YPR12	4.8	0.432	-	-	5.03	0.202	5.15	0.082	5.2	0.032	-	-	5.22	0.012	5.18	0.052
YPR13	13.04	0.32	-	-	13.2	0.16	13.31	0.05	13.39	-0.03	-	-	13.36	0	13.32	0.04
YPR14	38.25	-2.355	-	-	38.37	-2.475	-	-	-	-	-	-	38.6	-2.705	38.65	-2.755
YPR15	44.51	-2.629	-	-	44.66	-2.779	44.69	-2.809	44.81	-2.929	-	-	44.85	-2.969	44.84	-2.959
South-west region bores																
Rose bore A	2.8	-0.13	2.99	-0.32	3.33	-0.66	3.89	-1.22	3.89	-1.22	3.87	-1.2	3.78	-1.11	3.69	-1.02
JE Giblett bore C	1.7	1.33	2.14	0.89	2.43	0.6	2.69	0.34	3	0.03	2.67	0.36	2.62	0.41	2.59	0.44
LR Armstrong bore B	-	-	1.65	2.61	1.825	2.435	2	2.26	2.26	2	2.45	1.81	2.5	1.76	-	-
RV Armstrong bore I	2.77	-	2.84	-	2.935	-	3.02	-	3.23	-	3.14	-	-	-	3.04	-

Appendix II. *(continued)*

Bore name	*WL(Nov)*		*WL(Dec)*		*WL(Jan)*		*WL(Feb)*		*WL(Mar)*		*WL(Apr)*		*WL(May)*		*WL(Jun)*	
	mbtoc	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*	*mbtoc*	*mAHD*
Rose bore M	2.26	0.96	2.45	0.77	2.76	0.46	3.29	-0.07	4.16	-0.94	4	-0.78	3.84	-0.62	-	-
Rose bore O	2.7	1.13	2.42	1.41	2.66	1.17	-	-	-	-	2.96	0.87	2.9	0.93	-	-
Rose bore G	1.26	1.7	1.65	1.31	2	0.96	2.28	0.68	3.18	-0.22	4.85	-1.89	-	-	2.58	0.38
D1	-	-	2.2	-0.289	2.3	-0.389	2.41	-0.499	2.54	-0.629	2.65	-0.739	2.68	-0.769	2.68	-0.769
D2	10.29	0.606	10.5	0.396	10.69	0.206	10.85	0.046	11.01	-0.114	11.19	-0.294	11.2	-0.304	11.21	-0.314
D3A	-	-	17.6	2.436	17.77	2.266	17.97	2.066	18.21	1.826	18.45	1.586	18.58	1.456	18.64	1.396
D3B	-	-	17.57	2.43	17.72	2.28	17.93	2.07	18.18	1.82	18.42	1.58	18.56	1.44	18.63	1.37
D4	1.3	3.782	1.58	3.502	1.82	3.262	2.04	3.042	2.26	2.822	2.3	2.782	2.29	2.792	2.19	2.892
C4	1.1	0.355	1.26	0.195	1.47	-0.015	1.61	-0.155	1.8	-0.345	1.82	-0.365	1.86	-0.405	1.8	-0.345
C5	1.77	0.73	2.03	0.47	2.27	0.23	2.45	0.05	-	-	-	-	-	-	-	-
C7	30.77	8.561	30.76	8.571	30.76	8.571	30.77	8.561	30.82	8.511	30.87	8.461	30.87	8.461	30.89	8.441
C8	5.7	9.746	5.76	9.686	5.88	9.566	5.97	9.476	6.08	9.366	6.22	9.226	6.28	9.166	6.32	9.126
HS64A	15.13	2.403	15.11	2.423	15.09	2.443	-	-	15.24	2.293	15.29	2.243	15.33	2.203	-	-
HS64C	15.13	2.443	15.12	2.453	15.14	2.433	-	-	15.24	2.333	15.28	2.293	15.32	2.253	-	-
HS64B	14.65	2.923	-	-	-	-	-	-	14.6	2.973	14.51	3.063	14.52	3.053	-	-
HS63A	4.05	4.266	4.2	4.116	4.28	4.036	4.37	3.946	4.44	3.876	4.5	3.816	4.57	3.746	4.53	3.786
HS63B	3.39	5.003	3.52	4.873	3.65	4.743	3.77	4.623	3.9	4.493	3.9	4.493	4	4.393	3.95	4.443
HS63C	2.67	5.646	2.86	5.456	3.04	5.276	3.2	5.116	3.38	4.936	3.48	4.836	3.52	4.796	3.4	4.916
HS62B	3.32	0.44	3.42	0.34	3.5	0.26	3.6	0.16	3.7	0.06	3.7	0.06	3.77	-0.01	3.73	0.03
HS62C	3.38	0.43	3.45	0.36	3.43	0.38	3.46	0.35	3.45	0.36	3.37	0.44	3.37	0.44	3.38	0.43
Multiport 8/84	3.03	0.388	3.02	0.398	3.055	0.363	3.13	0.288	3.28	0.138	3.43	-0.012	3.54	-0.122	3.6	-0.182
Multiport 10/84	2.1	0.974	2.49	0.584	2.79	0.284	3.23	-0.156	3.6	-0.526	3.77	-0.696	3.78	-0.706		
Multiport 9/84	2.17	0.272	2.41	0.032	2.62	-0.178	2.84	-0.398	3.09	-0.648	3.28	-0.838	3.3	-0.858		
Multiport 11/84	2.53	0.236	2.67	0.096	2.81	-0.044	2.96	-0.194	3.14	-0.374	3.31	-0.544	3.38	-0.614	3.37	-0.604
Multiport 5/84	5.5	0.093	5.64	-0.047	5.76	-0.167	5.88	-0.287	6.08	-0.487	6.28	-0.687	6.32	-0.727	6.27	-0.677
Multiport 4/84	6.26	-0.086	6.31	-0.136	-	-	6.48	-0.306	6.59	-0.416	6.68	-0.506	6.73	-0.556	6.74	-0.566
Multiport 3/84	2.85	0.138	2.93	0.058	3.01	-0.022	3.11	-0.122	3.21	-0.222	3.27	-0.282	3.27	-0.282	3.24	-0.252
Multiport 1/84	2.75	0.011	2.75	0.011	2.77	-0.009	2.8	-0.039	2.86	-0.099	2.9	-0.139	2.96	-0.199	2.98	-0.219
Multiport 2/84	2.72	0.162	2.81	0.072	2.87	0.012	2.95	-0.068	3.03	-0.148	3.07	-0.188	4.2	-1.318	4.22	-1.338

Appendix III. Water quality monitoring data (1995 - 1996)

Bore name	*Total- N*		*Nitrate+ Nitrite*		*Organic- N*		*Ammonia- N*	
	Nov '95	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*
	mg/L	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Transect bores								
Y1/1A	0.442	0.298	0.333	0.275	0.102	0.01	0.007	0.013
A1	2.254	1.603	0.48	0.46	1.632	1.119	0.142	0.024
A3A	-	-	-	-	-	-	-	-
A3B	1.87	-	1.625	-	0.229	-	0.016	-
Y1/3A	0.365	0.497	0.008	0.004	0.066	0.299	0.291	0.194
A4	0.807	0.665	0.006	0.003	0.366	0.556	0.435	0.106
Y1/4A	0.265	0.164	0.02	0.001	0.147	0.063	0.098	0.1
A5	0.692	0.201	0.008	0.015	0.554	0.094	0.13	0.092
Y2/1A	0.859	0.97	0.8	0.875	0.048	0.079	0.011	0.016
Y2/1B	1.249	1.3	1.05	1.125	0.129	0.123	0.07	0.052
Y2/2A	1.048	1.169	0.013	0.002	0.44	0.53	0.595	0.637
Y2/2B	1.272	1.474	0.004	0.004	0.598	0.838	0.67	0.632
CS19	-	-	0.138	-	-	-	-	-
Y2/4A	1.064	1.945	0.95	1.813	0.041	0.124	0.073	0.008
Y2/4B	0.819	0.565	0.015	0.003	0.55	0.198	0.254	0.364
Y2/5A	1.073	1.46	0.508	1.013	0.363	0.06	0.202	0.387
Y2/5B	2.131	2.264	1.75	2.063	0.208	0.105	0.173	0.096
Y2/6A	0.265	0.436	0.009	0.005	0.113	0.26	0.143	0.171
Y2/6B	1.221	1.16	1.1	1.025	0.11	0.128	0.011	0.007
Y3/1A	0.125	0.146	0.004	0.003	0.024	0.085	0.097	0.058
Y3/1B	0.15	0.258	0.005	0.003	0.133	0.222	0.012	0.033
Y3/2A	0.185	0.195	0.025	0.028	0.083	0.001	0.077	0.166
Y3/2B	0.07	0.14	0.05	0.045	0.013	0.085	0.007	0.01
B4	0.501	0.78	0.128	0.125	0.338	0.638	0.035	0.017
Y3/3A	0.281	0.284	0.004	0.005	0.051	0.084	0.226	0.195
Y3/3B	0.147	0.21	0.075	0.075	0.052	0.107	0.02	0.028
Y3/3C	0.334	0.385	0.295	0.33	0.043	0.042	0.006	0.013
Y3/4A	0.947	1.338	0.004	0.003	0.452	0.823	0.491	0.512
Y3/4B	1.244	1.06	0.005	0.005	0.781	0.56	0.458	0.495
B6	1.847	1.617	0.268	0.019	1.488	0.818	0.091	0.78
Y4/1A	1.618	1.083	0.006	0.004	0.366	0.379	1.246	0.7
E1B	1.613	-	0.248	-	0.99	-	0.375	

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Total- P*		*Ortho- P*		*Organic- P*		*Chloride*	
	Nov '95	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*
	mg/L	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Transect bores								
Y1/1A	0.011	0.031	0.01	0.005	0.001	0.026	2450	3000
A1	0.813	0.411	0.02	0.007	0.793	0.404	685	665
A3A	-	-	-	-	-	-	-	-
A3B	0.015	-	0.011	-	0.004	-	155	-
Y1/3A	0.08	0.069	0.069	0.056	0.011	0.013	5100	4900
A4	0.093	0.048	0.009	0.006	0.084	0.042	35	20
Y1/4A	0.097	0.056	0.025	0.041	0.072	0.015	4450	4550
A5	0.111	0.077	0.024	0.027	0.087	0.05	825	825
Y2/1A	0.024	0.036	0.023	0.028	0.001	0.008	4415	4550
Y2/1B	0.029	0.037	0.009	0.009	0.02	0.028	170	230
Y2/2A	0.047	0.041	0.034	0.029	0.013	0.012	3350	5040
Y2/2B	0.028	0.05	0.025	0.014	0.003	0.036	4650	4440
CS19	0.089	-	0.009	-	0.08	-	217.5	-
Y2/4A	0.028	0.03	0.02	0.016	0.008	0.014	1050	1100
Y2/4B	0.048	0.049	0.031	0.032	0.017	0.017	250	114
Y2/5A	0.051	0.053	0.03	0.032	0.021	0.021	1050	620
Y2/5B	0.017	0.037	0.012	0.012	0.005	0.025	430	375
Y2/6A	0.12	0.075	0.014	0.01	0.106	0.065	775	805
Y2/6B	0.034	0.038	0.024	0.02	-0.01	0.018	335	345
Y3/1A	0.042	0.045	0.032	0.026	0.01	0.019	1975	1665
Y3/1B	0.03	0.037	0.02	0.015	0.01	0.022	900	870
Y3/2A	0.031	0.04	0.024	0.017	0.007	0.023	1625	1980
Y3/2B	0.03	0.034	0.023	0.008	0.007	0.026	400	425
B4	0.058	0.05	0.016	0.005	0.042	0.045	375	360
Y3/3A	0.072	0.047	0.036	0.032	0.036	0.015	450	395
Y3/3B	0.031	0.045	0.028	0.024	0.003	0.021	260	250
Y3/3C	0.04	0.053	0.015	0.015	0.025	0.038	145	135
Y3/4A	0.152	0.239	0.117	0.197	0.035	0.042	300	305
Y3/4B	0.241	0.241	0.193	0.18	0.048	0.061	140	140
B6	0.158	0.236	0.034	0.16	0.124	0.076	26	37
Y4/1A	0.094	0.254	0.09	0.063	0.004	0.191	12000	10400
E1B	0.103	-	0.009	-	0.094	-	500	-

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Salinity*		*pH*		*Dissolved oxygen*		*Redox potential*	
	Nov '95	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*
	mg/L	*mg/L*			*mg/L*	*mg/L*	*mV*	*mV*
Transect bores								
Y1/1A	4174.5	4933	7.3	7.1	5	0.8	-19	7
A1	1177	1391.5	8.7	7.2	4.2	4.9	45	-2
A3A	544.5	-	-	-	-	-	-	-
A3B	-	-	7.2	-	5.1	-	-41	-
Y1/3A	7331.5	8640.5	7	6.9	6.2	0.1	-68	16
A4	220	287.1	7.6	7.4	4.7	3	-121	-11
Y1/4A	6655	7876	7.7	7.3	4.2	0.1	-13	-9
A5	1457.5	1936	9.2	7.4	4.7	4.7	11	-14
Y2/1A	-	10336	-	7.2	-	0.1	-	2
Y2/1B	-	516.45	-	7.3	-	2.8	-	-5
Y2/2A	-	8360	-	7	-	0.1	-	12
Y2/2B	-	8305	-	7	-	0.1	-	12
CS19	-	-	-	-	-	-	-	-
Y2/4A	-	2112	-	6.7	-	1.1	-	27
Y2/4B	594	494.45	6.6	7	0.7	0.1	-104	11
Y2/5A	1666.5	1353	7	6.8	0.3	0.1	-85	25
Y2/5B	852.5	1009.3	6.8	6.8	0.4	0.6	-40	25
Y2/6A	-	1787	-	6.8	-	0.12	-	26
Y2/6B	-	977	-	6.7	-	3.52	-	28
Y3/1A	-	3305	-	7	-	0.1	-	11
Y3/1B	-	1958	-	6.9	-	0.2	-	16
Y3/2A	-	4015	-	7	-	-	-	12
Y3/2B	-	1043	-	7	-	-	-	10
B4	731.5	911.9	7.5	7	4.3	3.5	14	10
Y3/3A	-	1007	-	6.9	-	0.1	-	17
Y3/3B	-	710	-	6.9	-	1.1	-	17
Y3/3C	-	506	-	6.9	-	4.8	-	16
Y3/4A	-	785	-	6.7	-	0.1	-	28
Y3/4B	-	350	-	5.8	-	0.1	-	83
B6	154	187	6.8	5.9	2.8	2.22	112	76
Y4/1A	-	14740	8.9	7.5	-	3.7	-	-17
E1B	968	-	-	-	2.8	-	-4	

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Total- N*		*Nitrate+ Nitrite*		*Organic- N*		*Ammonia- N*	
	Nov '95	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*
	mg/L	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Y4/2A	0.605	1.037	0.004	0.006	0.18	0.563	0.421	0.468
E2A	0.82	0.431	0.015	0.007	0.632	0.265	0.173	0.159
E2B	16.805	7.978	16	7.6	0.77	0.363	0.035	0.015
Y4/3B	1.136	-	0.003	-	0.445	-	0.688	-
Y4/3C	0.753	-	0.004	-	0.444	-	0.305	-
E3C	1.219	-	0.03	-	1.081	-	0.108	-
E4A	1.629	1.181	0.011	0.004	1.105	1.046	0.513	0.131
Y4/4B	0.441	-	0.004	-	0.383	-	0.054	-
E4C	4.204	3.749	3.325	3.125	0.833	0.6	0.046	0.024
Y4/5A	1.613	-	0.004	-	0.714	-	0.895	-
E5B	-	0.573	-	0.011	-	0.485	-	0.077
Y4/6	1.792	-	0.007	-	0.882	-	0.903	-
Lakeside shallow bores								
YSH1	6.039	2.663	0.005	0.011	5.928	2.537	0.106	0.115
YSH2	2.053	1.383	0.008	0.009	2.026	1.336	0.019	0.038
YSH3	1.767	-	0.006	-	1.762	-	-	-
YSH4	0.952	1.674	0.005	0.012	0.897	1.602	0.05	0.06
YSH5	0.968	1.348	0.004	0.006	0.933	1.271	0.031	0.071
YSH6	5.475	-	0.005	-	5.44	-	0.03	-
YSH7	3.421	-	1.375	-	-	-	-	-
YSH8	2.965	-	0.335	-	2.577	-	0.053	-

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Total- P*		*Ortho- P*		*Organic- P*		*Chloride*	
	Nov '95	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*
	mg/L	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Y4/2A	0.045	0.087	0.039	0.021	0.006	0.066	650	650
E2A	0.343	0.078	0.03	0.019	0.313	0.059	525	755
E2B	0.275	0.065	0.006	0.009	0.269	0.056	85	42
Y4/3B	0.047	-	0.045	-	0.002	-	275	-
Y4/3C	0.042	-	0.042	-	0	-	205	-
E3C	0.146	-	0.011	-	0.135	-	90	-
E4A	0.191	0.08	0.039	0.038	0.152	0.042	250	250
Y4/4B	0.061	-	0.009	-	0.052	-	135	-
E4C	0.121	0.048	0.019	0.007	0.102	0.041	40	30
Y4/5A	0.07	-	0.067	-	0.003	-	245	-
E5B	-	0.017	-	0.008	-	0.009	-	20
Y4/6	0.023	-	0.012	-	0.011	-	360	-
Lakeside shallow								
YSH1	0.112	0.32	0.099	0.006	0.013	0.314	7300	10600
YSH2	0.138	0.142	0.022	0.006	0.116	0.136	925	650
YSH3	0.124	-	0.058	-	0.066	-	9600	-
YSH4	0.041	0.069	0.024	0.016	0.017	0.053	2600	820
YSH5	0.096	0.194	0.011	0.012	0.085	0.182	260	290
YSH6	0.799	-	0.02	-	0.779	-	1000	-
YSH7	0.269	-	0.011	-	0.258	-	710	-
YSH8	0.446	-	0.021	-	0.425	-	2700	-

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Salinity*		*pH*		*Dissolved oxygen*		*Redox potential*	
	Nov '95 mg/L	*Apr'96* mg/L	*Nov '95*	*Apr'96*	*Nov '95* mg/L	*Apr'96* mg/L	*Nov '95* mV	*Apr'96* mV
Y4/2A	-	1457.5	-	6.9	-	3.4	-	14
E2A	1276	1584	7.2	6.9	2.8	7.4	-97	15
E2B	291.5	301.95	8.4	7.7	3.4	5.1	51	-32
Y4/3B	-	916.3	-	6.7	-	0.1	-	27
Y4/3C	-	1003.2	-	6.5	-	0.1	-	42
E3C	1210	-	11.8(?)	-	3.7	-	-148	
E4A	522.5	589.05	6.6	6.4	3	3.3	-74	49
Y4/4B	-	326.7	-	5.9	-	0.1	-	80
E4C	198	127.6	7.6	6.6	3.8	5.2	23	38
Y4/5A	-	722.15	-	6.7	-	0.1	-	29
E5B	-	124.3	-	6	-	0.1	-	72
Y4/6	-	753.5	-	6.5	-	0.1	-	41
Lakeside shallow								
YSH1	-	20000	-	9.1	-	5.2	-	-116
YSH2	-	1375	-	7.1	-	6.02	-	4
YSH3	-	-	-	-	-	-	-	-
YSH4	-	1606	-	7.1	-	4.22	-	4
YSH5	-	779.9	-	7.2	-	4.22	-	1
YSH6	-	-	-	-	-	-	-	-
YSH7	-	-	-	-	-	-	-	-
YSH8	-	-	-	-	-	-	-	-

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Total- N*		*Nitrate+ Nitrite*		*Organic- N*		*Ammonia- N*	
	Nov '95 *mg/L*	*Apr'96* *mg/L*	*Nov '95* *mg/L*	*Apr'96* *mg/L*	*Nov '95* *mg/L*	*Apr'96* *mg/L*	*Nov '95* *mg/L*	*Apr'96* *mg/L*
Inspected private bores								
YPR1	-	1.102	-	0.975	-	0.113	-	0.014
YPR2	-	9.017	9.5	8.8	-	0.212	-	0.005
YPR3	9.296	9.686	9.125	9.375	0.157	0.303	0.014	0.008
YPR4	1.048	0.674	1	0.475	-	0.191	-	0.008
YPR5	0.539	0.862	0.475	0.495	0.039	0.345	0.025	0.022
YPR6	1.958	1.211	1.875	1.125	0.067	0.078	0.016	0.008
YPR7	1.225	1.76	0.012	0.004	0.743	1.236	0.47	0.52
YPR8	1.891	2.167	1.82	2	-	0.157	-	0.01
South-west region bores								
FL+L Armstrong bore I	14.325	12.599	14	12.25	0.222	0.295	0.103	0.054
RD Mckay	3.362	1.81	2.725	0.203	0.221	0.822	0.416	0.785
F Roberts native bore	1.863	1.225	1.25	0.631	0.473	0.543	0.14	0.051
S Palmer	0.378	0.996	0.053	0.011	0.178	0.815	0.147	0.17
TW Pearson	-	0.893	-	0.028	-	0.603	-	0.262
L Sumich & Sons 2C	-	1.488	-	0.008	-	0.916	-	0.564
L Sumich Carrot Wash	-	2.041	-	0.019	-	1.277	-	0.745
D1	-	9.002	-	6	-	1.833	-	1.169
D3A	-	14.333	-	8.75	-	5.488	-	0.095
D3B	-	12.787	-	11.75	-	0.94	-	0.097
C4	-	1.973	-	0.298	-	1.317	-	0.358
C8	-	1.997	-	0.08	-	1.725	-	0.192

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Total- P*		*Ortho- P*		*Organic- P*		*Chloride*	
	Nov '95	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*
	mg/L	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Inspected private								
YPR1	-	0.039	-	0.037	-	0.002	-	485
YPR2	0.018	0.015	0.006	0.006	0.012	0.009	28	31
YPR3	0.007	0.021	0.007	0.007	-	0.014	45	63
YPR4	0.033	0.04	-	0.012	-	0.028	298	280
YPR5	0.043	0.068	0.04	0.023	0.003	0.045	122	137
YPR6	0.057	0.048	0.045	0.042	0.012	0.006	106	104
YPR7	0.031	0.044	0.023	0.031	0.008	0.031	66	60
YPR8	0.032	0.045	-	0.023	-	0.022	102	106
South-west region								
FL+L Armstrong bore I	0.023	0.026	0.013	0.009	0.01	0.017	210	215
RD Mckay	0.094	0.123	0.037	0.117	0.057	0.006	7520	9900
F Roberts native bore	0.063	0.062	0.024	0.036	0.039	0.026	440	430
S Palmer	0.067	0.078	0.045	0.062	0.022	0.016	125	132
TW Pearson	-	0.093	-	0.019	-	0.074	-	815
L Sumich & Sons 2C	-	0.124	-	0.014	-	0.11	-	520
L Sumich Carrot Wash	-	0.149	-	0.007	-	0.142	-	645
D1	-	0.27	-	0.027	-	0.243	-	10300
D3A	-	3.4	-	0.127	-	3.273	-	94
D3B	-	0.47	-	0.038	-	0.432	-	143
C4	-	0.212	-	0.005	-	0.207	-	475
C8	-	0.208	-	0.018	-	0.19	-	127

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Salinity* Nov '95 mg/L	*Salinity* Apr'96 mg/L	*pH* Nov '95	*pH* Apr'96	*Dissolved oxygen* Nov '95 mg/L	*Dissolved oxygen* Apr'96 mg/L	*Redox potential* Nov '95 mV	*Redox potential* Apr'96 mV
Inspected private								
YPR1	-	1144	-	6.9	-	4.82	-	17
YPR2	-	275.55	-	7.2	-	6.4	-	3
YPR3	-	507	-	-	-	-	-	-
YPR4	-	793.1	-	7.1	-	6.82	-	4
YPR5	-	458.81	-	7.2	-	3.62	-	1
YPR6	-	399.85	-	7.2	-	3.3	-	-2
YPR7	-	147.4	-	5.3	-	0.52	-	115
YPR8	-	427.35	-	7	-	6.3	-	-
South-west region								
FL+L Armstrong bore I	1078	646	-	-	4	-	-	-
RD Mckay	-	15235	-	-	-	2.4	-	-
F Roberts native bore	1452	1149	7.4	-	1.1	2.1	-	-
S Palmer	473	-	-	-	-	-	-	-
TW Pearson	-	1639	-	7.3	-	3.7	-	-
L Sumich & Sons 2C	-	1694	-	6.8	-	6.6	-	-
L Sumich Carrot Wash	-	1815	-	6.7	-	3.9	-	-
D1	-	14355	-	7	-	4.8	-	-
D3A	-	469	-	7.2	-	4.5	-	-
D3B	-	476	-	7.3	-	5.6	-	-
C4	-	1463	-	6.7	-	3.2	-	-
C8	-	285	-	6.7	-	4.1	-	-

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Total- N*		*Nitrate+ Nitrite*		*Organic- N*		*Ammonia- N*	
	Nov '95	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*
	mg/L	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
HS64A	0.405	0.64	0.008	0.024	0.17	0.375	0.227	0.241
HS64C	0.265	0.337	0.012	0.004	0.109	0.183	0.144	0.15
HS63A	2.024	3.233	0.015	0.106	1.38	2.299	0.629	0.828
HS63B	0.761	1.124	0.02	0.014	0.4	0.846	0.341	0.264
HS63C	0.62	0.96	0.015	0.01	0.37	0.735	0.235	0.215
HS62B	0.234	0.315	0.013	0.01	0.079	0.151	0.142	0.154
Multiport 8/84(port1)	0.499	0.847	0.078	0.013	0.142	0.423	0.279	0.411
port9	1.231	3.839	0.018	0.064	0.088	1.818	1.125	1.957
Multiport 9/84(port1)	0.684	0.986	0.015	0.016	0.183	0.543	0.486	0.427
port8	2.099	3.006	0.01	0.008	-	1.597	-	1.401
Multiport 4/84(port1)	1.285	-	1	-	0.045	-	0.24	-
port4	0.669	-	0.088	-	0.297	-	0.284	-
Multiport 1/84(port5)	1.682	1.184	1.525	0.95	0.038	0.079	0.119	0.155
port9	-	-	-	-	-	-	-	-
Multiport 2/84(port2)	6.181	3.686	6	3.4	0.13	0.215	0.051	0.071
port6	0.89	1.37	0.085	0.04	0.121	0.686	0.684	0.644

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Total- P*		*Ortho- P*		*Organic- P*		*Chloride*	
	Nov '95	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*
	mg/L	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
HS64A	0.072	0.082	0.058	0.056	0.014	0.026	180	180
HS64C	0.064	0.075	0.055	0.048	0.009	0.027	175	165
HS63A	0.157	0.186	0.122	0.062	0.035	0.124	500	450
HS63B	0.073	0.064	0.041	0.046	0.032	0.018	33	35
HS63C	0.062	0.049	0.043	0.02	0.019	0.029	29	21
HS62B	0.066	0.075	0.065	0.05	0.001	0.025	1160	1300
Multiport 8/84(port1)	0.031	0.029	0.009	0.017	0.022	0.012	360	430
port9	0.076	0.11	0.047	0.097	0.029	0.013	8200	17650
Multiport 9/84(port1)	0.068	0.075	0.026	0.025	0.042	0.05	650	830
port8	0.227	0.25	0.087	0.211	0.14	0.039	10800	16000
Multiport 4/84(port1)	0.077	-	0.069	-	0.008	-	650	-
port4	0.051	-	0.04	-	0.011	-	2210	-
Multiport 1/84(port5)	0.05	0.06	0.043	0.054	0.007	0.006	3760	4600
port9	-	-	-	-	-		-	-
Multiport 2/84(port2)	0.051	0.021	0.022	0.004	0.029	0.017	550	580
port6	0.06	0.115	0.035	0.066	0.025	0.049	8860	11150

Appendix III. Water quality monitoring data (1995 - 1996)....*contd.*

Bore name	*Salinity*		*pH*		*Dissolved oxygen*		*Redox potential*	
	Nov '95	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*	*Nov '95*	*Apr'96*
	mg/L	*mg/L*			*mg/L*	*mg/L*	*mV*	*mV*
HS64A	731.5	541	7.1	-	1.4	1.4	-	-
HS64C	704	525	7	-	0.8	1.3	-	-
HS63A	1111	814	6.4	-	3.1	3.7	-	-
HS63B	132	105	5.9	-	0.9	2.2	-	-
HS63C	92.4	73	5.7	-	1.8	2.2	-	-
HS62B	2711.5	2216	7.1	-	0.7	1.3	-	-
Multiport 8/84(port1)	1171.5	1034	7.2	-	1.7	2	-	-
port9	-	14355	6.8	-	1.3	1.3	-	-
Multiport 9/84(port1)	1749	1562	-	-	2.1	1.7	-	-
port8	-	22550	-	-	1.2	-	-	-
Multiport 4/84(port1)	1842.5	-	7.9	-	2.7	-	-	-
port4	4697	-	7.5	-	2	-	-	-
Multiport 1/84(port5)	-	7628	7.1	-	1.4	2.8	-	-
port9	-	25245	7	-	1.1	1.2	-	-
Multiport 2/84(port2)	1430	1270	-	-	1.8	2.4	-	-
port6	-	17215	-	-	2.3	1.3	-	-