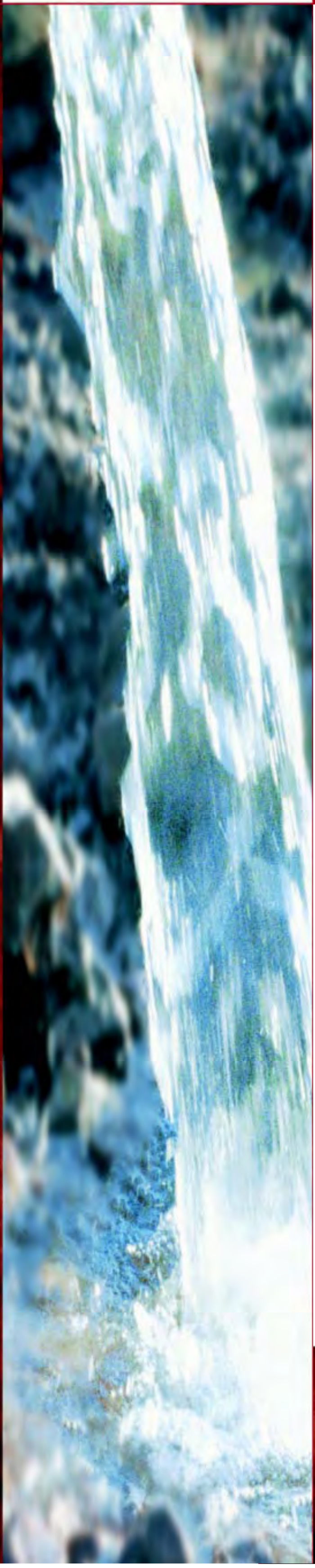

Rockwater
PROPRIETARY LIMITED

DAWESVILLE TO BINNINGUP TECHNICAL ENVIRONMENTAL STUDIES

HYDROGEOLOGY STUDY

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REPORT FOR
DEPARTMENT OF ENVIRONMENT AND CONSERVATION

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1 INTRODUCTION

1.1 BACKGROUND

The coastal region between Mandurah and Bunbury is coming under increasing pressure for rural and residential development, tourist facilities, and intensive horticulture. The area includes a major coastal reserve (Yalgorup National Park), and coastal wetlands; the latter are part of the Peel-Yalgorup wetland system which is recognised as a “wetland of international importance” under the Ramsar Convention. Important biological features include thrombolite communities (similar to stromatolites), regionally significant fauna populations, and coastal vegetation such as tuart forest which is largely degraded on much of the Swan Coastal Plain.

The EPA (Environmental Protection Authority) proposes to develop strategic advice under Section 16e of the *Environmental Protection Act 1986* to provide its position on acceptable development in the region. A series of reviews covering the flora, fauna, geology, coastal geomorphology and hydrogeology of the area will be consolidated into a report to provide an assessment of the environmental features of the area. This report by Rockwater describes the hydrogeological component of the series of investigations. Groundwater in the shallow, unconfined superficial aquifer influences the surface environmental features of the area and is the focus of this report.

1.2 STUDY AREA

The study area is bounded by Tims Thicket Road to the north, the Old Coast Road to the east, Buffalo Road to the south, and the coastline to the west (Fig. 1). It covers 286 km^2 and contains the coastal settlements of Preston Beach, Myalup and Binningup. The only major road is the Old Coast Road, although smaller roads lead from the highway to the coastal settlements.

1.3 PREVIOUS HYDROGEOLOGICAL WORK

Investigations involving the installation of monitoring bores into the superficial aquifer were undertaken by the Geological Survey of Western Australia for the Lake Clifton Project (Commander 1988). Bores were constructed at about one-kilometre intervals along seven east-west lines covering approximately the same north-south extent as the present study area. The report on the Lake Clifton Project described the hydrogeology and groundwater flow systems in the superficial aquifer and their relationship with the coastal lake systems. Field investigations for the Harvey Shallow Project (Deeney 1989a) included the installation of monitoring bores at several sites just east of the eastern boundary of the study area.

Hammond (1989) prepared a groundwater management review of the South West Coastal Groundwater Area, defining management subareas and recommending general groundwater allocation strategies for the subareas. Kern (1998) investigated groundwater salinities and water-table levels in the western part of the Myalup area as part of a re-evaluation of groundwater extraction policies in the area. An assessment of the hydrogeology of the Yalgorup Lakes (Shams 1999) included the installation of additional bores which extended the Lake Clifton Project monitoring-bore network. It provided a review of the hydrogeology of the lake systems and included water balances for the major lakes (Lakes Clifton and Preston).

Rosen *et. al* (1996) investigated the hydrochemistry and nutrient recycling in Lakes Clifton, Hayward and Preston based on data collected between November 1990 and September 1992. They concluded that the lake waters are all Na-Cl-SO_4 brines, similar to seawater in composition, but with concentrations that vary greatly between lakes as well as seasonally within individual lakes due to the high seasonality of rainfall and groundwater inflow, and evaporation. Lindsay (2002) investigated the effects of climate and land use on groundwater levels in the Lake Clifton and Lake Preston areas. He concluded that the largest influence on groundwater-level changes has been climatic variation, followed by man-induced influences such as clearing, groundwater extraction and the establishment of pine plantations. Similarly, Barr (2003) concluded that climatic variation (notably rainfall and evaporation) had the major effect on water levels and salinity in Lake Clifton, based on water-balance investigations.

The groundwater extraction policy for the superficial aquifer in the study area is set out in Water and Rivers Commission (2005) and Department of Water (2009a, b) which describe the aquifer systems and groundwater resources.

Investigations of the groundwater resources in the confined aquifers of the Perth Basin by the Geological Survey of Western Australia include deep bores, for the Harvey Line (Deeney 1989b) and the Binningup Line (Deeney 1989c), which penetrate the confined aquifers beneath the study area.

1.4 LANDFORMS

Landforms in the study area are described as part of other investigations for this project and, consequently, are only briefly described here.

The area comprises the western part of the Swan Coastal Plain and includes the main landforms, from east to west, of the Mandurah-Eaton ridge (Semeniuk 1997), the Yalgorup Plain (Semeniuk 1995) and the Quindalup Dunes (Playford *et. al* 1976) along the coast (Fig. 2). The Mandurah-Eaton ridge is a comparatively elevated, north-south elongate ridge about 3 to 4 km wide and underlain by Pleistocene-age eolian yellow quartz sand and limestone. It occupies the comparatively-elevated, northeastern part of the study area on the western side of the Harvey Estuary, where it reaches maximum elevations of about 65 m AHD; elsewhere, it lies to the east of the study area.

The Yalgorup Plain, the next unit to the west, is up to 6 km wide. It is underlain by Pleistocene-age carbonate- and quartz-sand sedimentary sequences which crop out as a series of elongate north-south deposits that have accreted against the western side of the Mandurah-Eaton ridge. These sedimentary sequences produce subsidiary landforms within the Yalgorup Plain. The subsidiary landform units of the Yalgorup Plain are, from east to west (Semeniuk 1995): Youdaland (older limestone and beachridge plain), Myalup Sand Shelf (quartz sand shelf), Myalup Sand Ridge (quartz sand barrier ridge) and Kooallupland (younger limestone beachridge plain). The Yalgorup Plain has generally low to undulating relief of about 4 to 10 m with some relict dune ridges up to 15 m high.

The Quindalup Dunes form an elevated coastal belt of Holocene-age eolian quartz and carbonate sand, reaching about 50 m AHD.

A series of shallow, north-south elongate, coastal lakes (Yalgorup lakes) are developed in three lines parallel to the coast within the Yalgorup Plain, generally along the borders of the different landforms: Lake Clifton along the border between Youdaland and Myalup Sand Ridge in the north, and the Myalup Sand Shelf and the Myalup Sand Ridge in the south; the Lake Yalgorup chain of lakes along the border between the Myalup Sand Ridge and Kooallupland; and Lake Preston along the western border of Kooallupland. The lakes are maintained by groundwater inflow and direct accession of rainfall to the lake surfaces, with very little surface water inflow (Section 1.5).

1.5 DRAINAGE

The area contains no major natural drainage lines, but artificial drainage lines – constructed to remove excess surface water and relieve water logging – traverse or occur inside the area. The Harvey River Diversion drain receives excess surface water from areas to the east and directs it across the study area to discharge into the ocean just south of Myalup (Fig. 1). Locally, surface water is removed by smaller drains (1) in the area east of Lake Preston and discharging into the lake, and (2) in the area south of Lake Preston and discharging into Leschenault Inlet.

1.6 CLIMATE

The area has a Mediterranean-type climate characterised by warm to hot dry summers and cool wet winters. The BoM (Bureau of Meteorology) has two active weather stations in the area (Fig. 2), Lake Preston Lodge (site no. 9679, operating since 1960) and Parkfield (site no. 9634, operating since 1913); however, records for both stations are not complete including only two (Lake Preston) and nine (Parkfield) years of complete data over the last 10 years. An automatic weather station was set up in 2007 at Myalup by the Department of Food and Agriculture but there are insufficient data from this site to provide meaningful long-term climate statistics.

The average annual rainfall in the area is about 850 mm (Table 1) and based on data from other BoM stations across the Swan Coastal Plain, rainfall probably increases slightly towards the east across the study area. The nearest evaporation data are available from Wokalup (about 15 km east of the study area) where the average annual evaporation is about 1,800 mm based on readings prior to 2000. Monthly data indicate that average potential evaporation exceeds average rainfall in all months but May to August, which is the period when there is most potential for groundwater recharge. However, intense or prolonged rainfall events outside these months are also likely to lead to groundwater recharge.

Table 1: Rainfall and Evaporation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
Lake Preston rainfall (1960–2008)													
Average	14.9	12.1	18.6	51.6	119.2	171.3	167.2	118.7	81.2	48.9	33.1	12.0	863.2
Median	2.5	5.1	11.4	44.3	117.0	167.0	153.1	118.2	75.6	43.2	31.0	6.8	852.5
Parkfield rainfall (1931–2008)													
Average	12.0	12.3	20.5	41.0	117.0	169.3	161.4	113.2	80.0	48.5	26.4	12.7	822.7
Median	2.6	4.8	11.6	36.2	112.1	165.9	155.7	108.8	72.8	47.3	22.5	8.6	789.4
Wokalup evaporation (1968–2000)													
Average	277.8	240.8	210.0	128.9	83.3	62.2	62.6	74.8	95.4	134.7	177.6	240.8	1801.0

1.7 DATA SOURCES

This report is a desktop investigation based mainly on previous work. New hydrogeological data are limited to water levels and groundwater licence data, provided by the DoW (Department of Water). Data that are available from other sources are generally limited to values obtained when the projects were undertaken.

Superficial aquifer water levels in DoW monitoring bores (Fig. 3) are recorded several times per year; sites include bores from the Lake Clifton Project (Commander 1988), Harvey Shallow Project (Deeney 1989a) and the Yalgorup Lakes investigation (Shams 1999). Water quality data are not monitored. Water quality data in most of these bores were collected at the time of bore installation with some subsequent monitoring of EC and pH at a few bores for short periods after installation. Water levels were regularly monitored for up to about 19 years in some private bores in the study area but the available data cease in 1996. Hydrographs for DoW monitoring bores and other bores for which there is a substantial period of data are provided in Appendix I.

Lake water data have been obtained from several published sources (including Commander 1988 and Rosen *et. al* 1996). The hydrochemistry and water levels have been monitored twice per year at a site in Lake Clifton (Fig. 1) since late-1985 (J. Lane, DEC, written communication)

2 GEOLOGY

The geology of the area is described as part of other investigations for this project and, consequently, is only briefly described here. The geology forms the framework for the hydrogeology in terms of aquifer lithologies and their associated hydraulic properties.

2.1 SETTING

The study area comprises the western part of the onshore Perth Basin which here contains about 5,000 m of Phanerozoic sedimentary rocks (Playford *et al.* 1976). The Quaternary to early Tertiary section of this sequence extends to between -20 and -25 m AHD and has a maximum thickness of about 90 m (Commander 1988) west of Harvey Inlet. It rests on an erosional unconformity at the top of the Cretaceous Leederville Formation or, north of Lake Clifton, the Osborne Formation.

2.2 STRATIGRAPHY

The Quaternary to early-Tertiary formations in the area have been informally termed the superficial formations (Commander 1988) and this terminology is used here. The entire section of the superficial formations has previously been referred to the Tamala Limestone and, at the surface along the coast, the Safety Bay Sand. However, Semeniuk (1995) has redefined the stratigraphy of the upper part of the Pleistocene and Holocene section in the Yalgorup Plain area. For convenience, these new units are herein included as part of the superficial formations. This work has provided detail which describes complex lithological sequences. The lower part of the superficial formations remains undifferentiated under Semeniuk's (1995) scheme and the previous terms, Tamala Limestone and Ascot Formation, have been retained here for this section. The available lithological data are not as detailed for the lower part of superficial formations as for the upper part in the study area.

The stratigraphy of the area is summarised in Table 2.

The Ascot Formation has been recognised only in the extreme south-east of the study area where it occurs at the base of the superficial formations; it occurs more extensively further to the east. The section here ascribed to the Tamala Limestone underlies the Mandurah-Eaton Ridge and extends beneath the overlying strata to offshore limestone ridges (reefs).

Table 2: Stratigraphy

	Age		Formation	Lithology
Quaternary	Holocene	superficial formations	Safety Bay Sand	medium to coarse grained quartz sand and shells
			unassigned	Calcilutite, marl, shelly in places
			Preston Beach Coquina	shell grit, shelly sand, medium to coarse grained quartz sand
			Becher Sand	quartz sand and shelly sand
			Bridport Calcilutite	calcilutite, shelly calcilutite
			Leschenault Formation	quartz sand and mud; locally shelly
	Pleistocene		Kooallup Limestone	calcarenite, calcilutite
			Myalup Sand	fine to medium quartz sand
			Tims Thicket Limestone	fine to medium calcarenite
			Tamala Limestone	sand and calcarenite
Late Tertiary			Ascot Formation	medium to coarse quartz sand, silt and clay; shelly
Early-Late Cretaceous		Osborne Formation		sandstone, siltstone and shale
Early Cretaceous		Leederville Formation		sandstone, siltstone and shale

Note: Holocene and Pleistocene information (except Tamala Limestone) from Semeniuk (1995)

The Pleistocene formations – extending to about -12 m AHD beneath the Yalgorup Plain – occur in discrete wedges which are separated by unconformities. They become younger across the plain to the west being, in turn, accreted against the western flanks of the adjacent (older) formations. They crop out as elongate north-south ribbons that correspond to the various landforms described in Section 1.4 (Youdaland is underlain by the Tims Thicket Limestone; the Myalup Sand Shelf and Ridge are underlain by Myalup Sand; and Kooallupland is underlain by the Kooallup Limestone, Fig. 2; Semeniuk 1997). The Tims Thicket Limestone rests unconformably on the Tamala Limestone at depth and where it pinches out against sand and limestone of the Mandurah-Eaton Ridge. It is overlain on its western flank by the Myalup Sand along a sharp, karstic unconformity surface. The Myalup Sand is, in turn, unconformably overlain along a sharp contact by the Kooallup Limestone; its contact with the Tamala Limestone is difficult to recognise. Unconformity surfaces on limestone lithologies are calcretised whereas those on sand have truncated the underlying formation. Diagenetic processes in the zone immediately above the positions of the present and former water table have caused the formation of thin calcrete sheets which may transect stratigraphic boundaries and unconformities (Semeniuk and Meagher 1981).

The Holocene formations have not been mapped in detail in the study area. The surficial part of the coastal barrier dunes is eolian sand of the Safety Bay Sand. Calcilutite, mud and shells of Holocene to Pleistocene age have been identified by Semeniuk (1995) infilling low areas within the Myalup Sand; similar lithologies were recognised by Commander (1988) on the lake bed of Lake Preston.

3 HYDROGEOLOGY

3.1 SUPERFICIAL AQUIFER

The superficial formations form an unconfined aquifer which contains fresh and saline groundwater and extends across the study area to the ocean. In the northern section the aquifer is bounded to the east by the Harvey Inlet but further south it is continuous to the east beyond the study area with groundwater flow systems of the Yanget and Mialla Mounds (Deeney 1998a). It is continuous to the north and south beyond the study area. The superficial aquifer is in hydraulic connection with the underlying Leederville aquifer at the base of the superficial formations.

Saline groundwater occurs in the lower part of the superficial aquifer beneath a large part of the study area. The fresher water in the aquifer rests on the saline water due to its lower density and because it is recharged from the surface. There is minimal connection between the fresh-water and saline-water flow systems except along a mixing zone which represents the interface between the two. Salinity-depth profiles from bores in the area suggest that the mixing zone ranges from comparatively sharp, over about one metre, to more diffuse, over 10 to 15 m (Commander 1988, Barr 2003). Groundwater flow in the deeper, more saline parts of the superficial formations would be relatively small and these parts are not considered further here.

Low-salinity water occurs as thin lenses in the northern part of the study area, whereas it extends to the base of the aquifer in the southern part: from Lake Preston to Leschenault Inlet (Commander 1988; Shams 1999). In this southern part, a saline-water (~35,000 mg/L TDS) wedge extends inland at the base of the aquifer from the coast for as far as about two kilometres (Fig. 4). The Harvey Inlet is underlain by saline groundwater (oceanic salinity of ~35,000 mg/L TDS) and the Yalgorup lakes are underlain by hypersaline groundwater (40,000 to 60,000 mg/L TDS).

Lenses of low-salinity groundwater occur between the coast and Harvey Inlet, Lake Clifton, Lake Preston, the Lake Yalgorup lakes, and Leschenault Inlet (immediately south of the study area). Similarly, lenses of low-salinity groundwater occur between the lakes. Diagrammatic sections to illustrate salinity and flow directions are presented in Figure 4.

Lithological variation and complexity within the superficial aquifer (Section 2.2) are significant in the upper part of the aquifer where groundwater recharge and discharge processes occur. Lithologies range from clay and marl to coarse sand and limestone (displaying some karstic features), and vary within and between the geological formations. Additionally, calcrete layers, formed by diagenetic processes associated with past and present water-table positions, may transect stratigraphic boundaries and unconformities. The different lithologies exhibit different hydraulic properties and impart an inhomogeneous and anisotropic character to the aquifer, particularly when considering local-scale hydrogeological processes such as those affecting GDEs (groundwater dependent ecosystems). Data are not available to allow local-scale descriptions of the hydrogeology with detail similar to that for the geology.

3.2 GROUNDWATER FLOW SYSTEMS

Groundwater flow in the superficial aquifer occurs within separate flow systems which are named after the major discharge locations (Fig. 5). These flow systems correspond to the separate lenses or wedges of fresher groundwater noted in Section 3.1. They are delineated by groundwater divides, bounding flow lines, and groundwater discharge sites along the Harvey Estuary and the ocean. There is no groundwater flow across flow-system boundaries although boundaries that are defined by groundwater divides or flow lines may shift slightly to-and-fro as a result of the high seasonality of groundwater recharge.

The lakes are groundwater sinks which receive groundwater inflow from their associated flow systems, and rainfall on the lakes' surfaces. They discharge water from the flow systems by evaporation.

Lake Preston contains water of between 8,000 and 90,000 mg/L TDS, the Lake Yalgorup group of lakes contains water of between 20,000 and 207,000 mg/L TDS and Lake Clifton contains water from 15,000 to 68,000 mg/L (Commander 1988; Rosen *et. al* 1996; J. Lane, DEC, written communication). Salinity in the lakes varies seasonally with lower values generally in spring to early-summer, associated with the seasonal inflow of comparatively low-salinity groundwater, and higher values generally in late-summer to autumn, when evaporation is highest. Salinity also varies between different parts of some lakes due to differences in water depths (and therefore evaporation rates) and groundwater inflow. The lakes are underlain by hypersaline groundwater (about 40,000 to 211,000 mg/L TDS). Lakes Hayward, North Newnham and Yalgorup, and in some years, South Newnham, are stratified into two stable layers which exhibit different hydrochemistry and temperatures during spring to early-summer (Rosen *et. al* 1996; B. Knott, unpublished report). This is a result of the presence of benthic microbial mats which seal the lakes from the underlying groundwater. A rise in the water table after winter rainfall results in seepage of lower-salinity groundwater over the edges of the mats into the lakes forming a layer of less saline lake water (which subsequently becomes more concentrated due to evaporation). At these times of the year in Lake Hayward, for example, water of 55,000 to 120,000 mg/L TDS has been recorded overlying water of 153,000 to 211,000 mg/L TDS (Burke and Knott 1989; Rosen *et. al* 1996).

The lakes are shallow, being generally less than three metres deep (Rosen *et. al* 1996) but up to four metres in small areas of Lake Preston (WAPC 1999) and between 3.8 to 4.7 m for Lake Clifton (J. Lane, DEC, written communication). Recorded lake levels ranged from

0.1 to -1.0 m AHD in Lake Preston (1976 to 1978; Commander 1988) and from -0.20 to 0.65 m AHD in Lake Clifton (1985 to 2008; J. Lane, DEC, written communication). The data from Lake Clifton suggest a trend of decreasing lake water levels since 1985 (Fig. 6). B. Knott (unpublished report) reports an autumnal low water level of -0.6 m for Lake Hayward but no other water level data are available for the Lake Yalgorup chain of lakes; however, similar levels to those recorded for Lake Preston could be expected. Water levels below sea level are recorded at times because the hypersaline groundwater which occurs below the lakes is denser than ocean water.

3.2.1 Recharge

Groundwater is recharged by direct infiltration of rainfall over the areas within each of the flow systems. Recharge rates are likely to vary considerably depending on surface lithology, vegetation cover and type, depth to the water table, and position in the flow system. Elevated locations where the surface is permeable and sparsely vegetated are the most favoured for recharge. Recharge rates of between 5% and 40% depending on the location have been estimated for the Myalup area (Kern 1998), and a similar range may apply to the study area. Commander (1989) concluded, based on three methods of calculation, that about 5% of rainfall contributed to the groundwater discharge to Lake Preston.

Water-level monitoring data from Harvey Line site 1 (HL1 Fig. 3; Appendix I) indicate decreasing-upwards hydraulic head differences of two to three metres between the Leederville and superficial aquifers, providing potential for recharge to the superficial aquifer from below, in the study area. Groundwater movement from the Leederville aquifer to the superficial aquifer would be impeded by the presence of low permeability layers in the Leederville aquifer and may not happen where there is hypersaline groundwater in the superficial formations, due to density differences.

3.2.2 Leschenault Inlet Flow System

The Leschenault Inlet Flow System extends from an eastern groundwater divide, which includes the Mialla Mound (Deeney 1989a) to a western groundwater divide within the coastal dunes. It is separated from the Lake Preston Flow System to the north by a flow line south of Lake Preston. It continues to the south beyond the study area (Fig. 5).

The water table slopes downwards to the west from about 2 m AHD along Old Coast Road (Figs 7 and 8) and to the east from about 2 m AHD at the top of the groundwater divide beneath the coastal dunes at Binningup (Kern 1998). Monitoring-bore water levels varied seasonally during 2008 by up to a metre (Fig. 9), although seasonal variations of up to about 1.5 m have been reported.

Groundwater flow is mainly to the west, with a small proportion of eastwards flow from the coastal groundwater divide, towards the topographically low area between Lake Preston and the Leschenault Inlet. A drain extends northwards from Leschenault Inlet into most of this area and carries groundwater discharge southwards to the inlet. Groundwater discharge also occurs by evapotranspiration from the shallow water table which is present over much of the area between Lake Preston and the inlet. Water-logging is relieved by drains directing flow into the inlet, and by extraction of groundwater for irrigation. Excess irrigation water is recycled to the water table as seepage.

Fresh to brackish groundwater extends to the base of the aquifer at about -25 m AHD where there is potential for recharge from the underlying Leederville aquifer under an upwards hydraulic gradient (Commander 1988). The groundwater salinity at the water table is mainly between 700 and 2,000 mg/L TDS based on DoW bore data; recycling of irrigation water may have increased the salinity in places. Natural plumes of brackish groundwater extend from the east into the study area from beneath Myalup Swamp and Myalup Lagoon (associated with evapotranspiration from the swamp); the salinity associated with these plumes is highest at the base of the aquifer in the study area (Kern 1998).

3.2.3 Lake Preston Flow System

The Lake Preston Flow System extends from a groundwater divide that includes the Yanget Mound (Deeney 1989a) in the east, outside the study area, and from a groundwater divide adjacent to the coast to Lake Preston. It is separated from the Lake Clifton Flow System to the north and the Leschenault Inlet Flow System to the south by groundwater flow lines (Fig. 5).

Groundwater flows from the east towards Lake Preston except for a small area on the western side of Lake Preston where groundwater flow is towards the lake from the west. Groundwater discharges to the lake above a hypersaline water interface, by evapotranspiration where the water table is sufficiently shallow and by groundwater extraction for irrigation. Excess irrigation water would be returned to the aquifer by seepage past the root zone.

The water table slopes from about 2 to 3 m AHD along the Old Coast Road to 0 m AHD or lower along the shore of Lake Preston (Figs 7 and 8). Commander (1988) calculated that the equilibrium level of the lake water was about -0.6 m AHD in the early-1980s, based on the density difference with ocean water. Water levels in the lake (as represented by Lake Clifton Project bore E1B), which in the early-1980s fluctuated seasonally around 0 m AHD, have declined and are now continuously below 0 m AHD (-0.26 to -0.89 m AHD since March 2001; Fig. 10). Groundwater levels varied seasonally during 2008 by up to 1.8 m (Fig. 9). The larger seasonal variations in water levels near the centre of the flow system may be influenced by groundwater extraction and the occurrence of sections of fine grained sediment in the aquifer (Commander 1988). The saturated thickness of the aquifer is about 20 to 25 m east of Lake Preston but decreases rapidly above the saline water interface adjacent to the lake.

The saline interface in Lake Clifton Project bore D1, located adjacent the eastern shore of the lake, occurs at about eight metres below the water table; the salinity in this bore rises from about 1,000 mg/L TDS to over 50,000 mg/L TDS over about one metre depth. A thin lens of low-salinity water occurs within the Safety Bay Sand on the western side of the lake. Groundwater salinity close to the water table is mainly less than 1,000 mg/L TDS but the salinity increases to between 1,000 and 2,500 mg/L in bores close to Lake Preston (Lake Clifton Project lines D and E bores, Fig. 3).

3.2.4 Martins Tank Flow System

The Martins Tank Flow System covers a comparatively small area surrounding the chain of lakes including Lake Yalgorup and Martins Tank Lake. It is bounded on all sides by groundwater divides (Fig. 5). The water table is at less than 1 m AHD and groundwater flows under a low gradient towards the lakes where discharge occurs. Water levels fluctuated seasonally in 2008 by about 0.5 m in Lake Clifton Project bore B2 (Fig. 9), the only active monitoring bore within the Martin's Tank Flow System.

Commander (1988) reports salinities of between 1,000 and 7,000 mg/L TDS in monitoring bores and a 14 m of thickness of groundwater with salinity between 5,000 and 7,000 mg/L TDS sitting with a sharp interface on hypersaline groundwater (42,000 to 44,000 mg/L TDS) in Lake Clifton Project bore B3, located between Lake Clifton and Martins Tank Lake (Fig. 3). The lens of low-salinity water is expected to be of similar thickness elsewhere. The water in Lakes Hayward, and North and South Newnham is hypersaline all year (Section 3.2) despite the groundwater inflow (Burke and Knott 1989; Rosen *et. al* 1996).

3.2.5 Lake Clifton Flow System

The Lake Clifton Flow System surrounds Lake Clifton and is bounded by groundwater divides between the lake and the Harvey River and Harvey Estuary to the east, and the Martins Tank and Ocean Flow Systems to the west, and by a groundwater flow line from the Lake Preston Flow System to the south (Fig. 5).

Water levels are highest along the eastern groundwater divide, where they are about 12 m AHD in the south and slope downwards to less than 1 m AHD at the northern end of the divide (Figs 7 and 8). Water levels on the western side of the lake are less than 1 m AHD.

The fresher water section extends to the base of the aquifer in the east to the south of Harvey Inlet where it is up to about 20 to 25 m thick. The thickness of fresher water reduces adjacent to Lake Clifton where groundwater discharges to the lake above a hypersaline water interface. The discharge zone in Lake Clifton occurs over extensive areas stretching into the lake from the lake shore (DCLM 2003). This results in horizontal salinity gradient away from the shore. Fresher groundwater occurs as lenses resting above the deeper hypersaline water elsewhere in the flow system.

Commander (1988) found the salinity of the hypersaline water beneath Lake Clifton was much higher (about 42,000 mg/L TDS) than in the lake itself (about 15,000 to 26,000 mg/L TDS), and suggested there was poor hydraulic connection between the lake and the underlying groundwater. Monitoring of the lake by DEC since 1985 (J. Lane, DEC, written communication) shows a trend of rising salinity such that it is now similar to the value reported by Commander (1988) for the underlying water (Fig. 6). The DEC salinity data suggest a relationship between rainfall and the recorded salinity, with higher lake salinities following low winter rainfall (e.g. 2001) and lower salinities following high winter rainfall (e.g. 2005). Numerical groundwater-flow modelling has shown that Lake Clifton is unlikely to have been affected by the opening of the Dawesville Cut, to the north of the study area, and the resultant changes in the Harvey Estuary (Barr 2003).

3.2.6 Harvey Estuary Flow System

Only part of the Harvey Estuary Flow System is included in the study area. The flow system is separated from the Lake Clifton and the Ocean Flow Systems to the west by groundwater divides and by the Harvey Estuary to the east: however, at times the water levels along the divide with the Ocean Flow System degrade to such an extent that the divide is absent, and the water table has very low hydraulic gradients towards either the estuary or the ocean (Commander 1988). Very little difference in water levels is evident across the peninsula in the hydrographs for Lake Clifton Project Line A bores (Fig. 3, Appendix I). The flow system is continuous to the north towards the Dawesville Cut. Groundwater is assumed to flow eastwards from the divides and to discharge to the estuary above a saline water wedge. It is unlikely that groundwater which originates in the study area discharges to the Dawesville Cut; any effects due to the construction of the cut are likely to have had little, if any, impact on groundwater in the study area.

The Harvey Estuary Flow System occurs mainly under elevated topography of the Mandurah-Eaton Ridge and consequently the water table in the study area, being at an elevation of less than 1 m AHD, is at considerable depth except adjacent to the estuary where the topography is lower.

Salinity data from the widest section of the peninsula between the estuary and the ocean (Lake Clifton Project bores along line A, Fig. 3) indicate that low-salinity water extends to a maximum depth of about 10 m beneath the centre of the peninsula (Commander 1988); it is underlain by saline water with concentrations increasing from 20,000 mg/L TDS beneath the centre of the peninsula towards both the estuary (32,000 mg/L TDS) and the ocean (35,000 mg/L TDS).

3.2.7 Ocean Flow System

The Ocean Flow System occurs beneath a narrow strip of land adjacent to the coast. It extends westwards to the ocean from a groundwater divide, which defines the western boundaries of other flow systems (Fig. 5). There is little information on water table elevations within the Ocean Flow System but it is likely to be up to about 1 m AHD along most of the groundwater divide. However, beneath Binningup townsite in Lake Clifton Project bore F1, the average annual water level is higher at about 2 m AHD (Figs 7 and 8, Fig. AI-4 in Appendix I); this could indicate groundwater recharge is enhanced in the township area. Groundwater flow is towards the ocean where discharge occurs above a saline water interface.

Data presented by Kern (1998) indicate that the lowest groundwater salinity in the Ocean Flow System in the Binningup townsite area ranges between about 800 and 5,000 mg/L TDS. No other salinity data are available for the flow system.

3.3 WATER-LEVEL TRENDS

Regular water-level monitoring data are available only from DoW monitoring bores. These data include a reasonably continuous record of water levels since 1979 for several sites. Hydrographs for bores which have considerable periods of monitoring data are included in Appendix I. Hydrographs from selected bores in the study area are shown in Figure 10 to illustrate broad trends. The data indicate seasonal water-level variations of up to about 1.8 m (D4, Fig. 3); seasonal fluctuations are generally smallest near the ultimate groundwater discharge areas of each of the flow systems.

Water levels in the northern part of the study area indicate little long-term variation (e.g. Bore A1, Fig. 10); a reflection of their low levels (less than one metre AHD). Water levels in most other bores appear to respond to a period of below-average rainfall in 1985 to 1987 but show a recovery after increased rainfall from 1988 to 1992 (e.g. Bore F3, Fig. 10). Water levels at these sites again show downward trends in the early 1990s, possibly associated with consecutive years of well below-average rainfall and the effects of groundwater extraction. However, the hydrographs for E4B and E5A (Appendix I), located just east of the study area (Fig. 3), show rises in water levels during the early-1990s of as much as two metres. These bores are within and in the vicinity of a pine plantation and variations in water levels may be associated with clearing and the establishment of the plantation.

Water levels since 2003 in the Lake Clifton Project lines C and E bores appear to fluctuate seasonally about new lower equilibrium levels whereas some of the line F bores show a recovery of water levels since the early 2000s (e.g. Bore F3). The lower equilibrium levels in the line E bores can be attributed to the effects of an overall reduction in rainfall and groundwater extraction east of Lake Preston (Fig. 11). There is no licensed groundwater extraction in the vicinity of the line C bores and so the reduced “equilibrium” water levels in these bores are likely to be in response to an overall reduction in rainfall: the average rainfall at Wokalup from 1979 to 1992 was 974 mm compared to the average from 1993 to 2008 of approximately 850 mm.

3.4 NUTRIENTS IN GROUNDWATER

Nutrient (nitrogen and phosphorus) concentrations in the groundwater were examined as part of investigations by Shams (1999). Also, nitrogen and phosphorous concentrations in the lake water at a site on Lake Clifton (Fig. 1) were regularly monitored by DEC for 16 years (PO_4) and 9 years (N) until 2007 (J. Lane, DEC Science Division, Busselton, written communication). Data from these sources are discussed here.

Nutrients have been found to be critical for the survival of thrombolite communities along the shore of Lake Clifton – along with a constant source of carbonate and bicarbonate ions, and sufficient light (Moore 1993). However, high concentration of nutrients in lake water can favour the growth of algae, reducing light penetration, and potentially affecting microbialite formation and increasing the potential for eutrophication. Several sources of nitrogen in the groundwater were identified: natural sources (nitrogen-fixing vegetation, decaying vegetation), fertilisers, excreta from grazing animals and sewage. Phosphorus was believed to be derived from fertilisers and from natural sources within the sediment. Additionally, nutrients may be carried into the study area within groundwater flow from the east.

Elevated concentrations of total nitrogen (nitrate-nitrogen, nitrite-nitrogen, ammonia nitrogen and organic nitrogen) – compared to the guideline of 0.1 to 0.5 mg/L (Terry and George 1995) – were found to occur over most of the study area with organic nitrogen, derived from natural sources, comprising the major component. The highest concentrations were found near the water table, implying surface sources, with elevated concentrations found in deeper levels at only a few sites. Local total nitrogen concentrations of up to about 16 mg/L were identified; in these, nitrate- plus nitrite-nitrogen derived from fertilisers or grazing activities were the major contributors. The nitrate-nitrogen guideline level for eutrophication in lakes is 0.25 mg/L (Terry and George 1995). Other elevated nitrate- plus nitrite-nitrogen concentrations were mainly associated with fertilisers or grazing. Ammonia-nitrogen concentrations in most of the bores were between 0.005 and 0.5 mg/L compared to the guideline limit of 0.9 mg/L for 90% protection in marine waters

(ANZECC and ARMCANZ 2000). Animal excreta were attributed to the source of a few local values of up to 2 mg/L ammonia-nitrogen. High winter concentrations of ammonia-nitrogen in the lakes were believed to be derived from surface runoff with higher concentrations in Lake Preston due to the greater amount of grazing on the land to the east. Organic nitrogen forms the major part of total nitrogen in the lakes (Table 3) except in Lake Preston in September where ammonia-nitrogen is dominant due to contributions from winter runoff into the lake. DEC monitoring data from 1999 to 2007 indicate that total nitrogen and total soluble nitrogen concentrations in Lake Clifton have varied between 1.0 and 3.8 mg/L (Fig. 6).

Table 3: Nitrogen Concentrations in Lakes Preston and Clifton in 1992

Date	Lake Clifton (mg/L)	Lake Preston (mg/L)
Total nitrogen		
June-July 1992	2.87	3.80
November 1992	1.72	0.89
Nitrate- plus Nitrite-nitrogen		
June-July 1992	0.043	0.042
November 1992	<0.001	<0.001
Organic-nitrogen		
June-July 1992	2.82	3.10
November 1992	1.61	0.19
Ammonia-nitrogen		
June-July 1992	0.13	0.80
November 1992	<0.01	0.01

Note: Data from Rosen *et. al* (1996)

Total phosphorus concentrations, comprising ortho-phosphate and organic phosphorus, in groundwater were measured by Shams (1999). Concentrations of organic phosphorous were found to be generally much greater than those of ortho-phosphate. Concentrations at the water table were found to be below the limit set for eutrophication (0.005 to 0.05 mg/L; Terry and George 1995) in the area between Harvey Inlet and Lake Clifton but increased towards the south so that concentrations in the groundwater from most bores on the eastern side of Lake Preston exceeded the guideline. Elevated concentrations of ortho-phosphate (up to 0.21 mg/L) in groundwater from the base of the superficial aquifer are believed to be derived from phosphatic minerals in the aquifer. DEC data from Lake Clifton indicate total phosphorous concentrations varied between 0.005 and 0.05 mg/L and total soluble phosphorous concentrations between 0.005 to 0.01 mg/L (except for one high value of 0.84 mg/L in November 1995) between 1991 and 1997 (Fig. 6; J. Lane, DEC, written communication). No consistent trends of change are evident in the DEC lake-water data, although, Moore (1993) reports increases in total phosphorous concentrations in Lake Clifton from 0.048 mg/L to 0.186 mg/L between July 1979 and August 1988. However, Rosen *at. al* (1996) report that any potential increase in the phosphate load to Lake Clifton is taken up by invigorated growth of macroalgae and may not be reflected in lake-water phosphate concentrations. They also report that phosphate concentrations in the lake water vary depending on the time of year and the biological activity in the lake.

3.5 LIMITATIONS OF THE HYDROGEOLOGICAL DATA

The groundwater data that are available in the study area provide a broad-scale description of the flow systems but, because the aquifer is stratigraphically and lithologically complex, the hydrogeology at smaller scales is complex. Variations in the hydraulic properties of the aquifer at the local-scale (for example the occurrence of sub-horizontal sheets of calcrete) can control the location of discharge zones which may extend laterally for a considerable distance on top of a low-permeability layer. In such cases, a small fall in the water table, to below a low-permeability layer, may cause a large change in the location of the zone where groundwater discharge is occurring. This could displace a discharge zone from the location where it supports an ecosystem.

4 GROUNDWATER RESOURCES MANAGEMENT

4.1 SUPERFICIAL AQUIFER

The study area falls within the South West Coastal Groundwater Area for DoW groundwater resources management purposes under the Rights in Water and Irrigation Act (1914), (DoW 2009a, b; Water and Rivers Commission 2005, Hammond 1989). Groundwater extraction in the South West Coastal Groundwater Area is licensed by the DoW except for water drawn from the superficial aquifer for stock watering and domestic supplies; these sources were exempted from licensing in 2001. The South West Coastal Groundwater Area is divided into subareas for managing groundwater extraction allocations; subareas for the superficial aquifer which overlap the study area are shown in Fig. 12. The available allocations in each subarea are based on groundwater resources assessment investigations. The resources in the southern part of the South West Coastal Groundwater Area have recently been reassessed (DoW 2009a, b) but a reassessment of the resources in the northern subareas would be prudent, as the current data are based on investigations from about 20 years ago (Hammond 1989).

Groundwater licences include an allocation which indicates the maximum volume of water that may be drawn annually from the designated aquifer. The actual volume that is drawn annually for each licence may be less than the allocation but this is not recorded as the DoW has no suitable database to hold the information. Additionally, only licences with allocations of more than 500,000 kL/a have been required to meter extraction volumes meaning that the extraction associated with about half of the total licensed allocations is presently not metered. New policies will require metering for most extraction licences with allocations of more than 50,000 kL/a in the South West Groundwater Area (DoW 2009a); this will apply elsewhere in the project area from July 2010 (DoW 2009c).

Allocation limits and the current allocation (1 September 2009) for the subareas which include the study area are shown in Table 4 and the extraction sites, indicating their relative allocations, are shown in Figure 11. Historical data to allow assessment of changes over time are not available. Domestic and stock watering bores have been exempted from licensing since 2001 but the allocations for these bores which were previously licensed are included in Table 4 and their locations are shown in Figure 11. A considerable proportion of the drawpoints shown in Figure 11 are located in parts of the subareas that are east of the study area.

Table 4: DoW Superficial Aquifer Groundwater Allocations in Subareas which Overlap the Study Area

Subarea	Aquifer	Allocation Limit	Licensed Allocation	Stock and Domestic	Additional Allocations Requested	Total Allocated Committed and Requested	% Allocated Committed and Requested	Balance Available for Future Licensing
		kL	kL	kL	kL	kL		kL
Coastal	Perth - Superficial	4,100,000	82,250	13,700	0	82,250	2.0%	4,017,750
IslandPoint	Perth - Superficial	1,600,000	314,800	152,150	0	314,800	19.7%	1,285,200
LakeClifton	Perth - Superficial	3,000,000	515,360	167,000	0	515,360	17.2%	2,484,640
LakePrestonNorth	Perth - Superficial Swan	9,300,000	1,195,200	0	0	1,195,200	12.9%	8,104,800
LakePrestonSouth	Perth - Superficial Swan	10,500,000	11,149,240	0	-248,000	10,901,240	103.8%	-401,240
Myalup	Perth - Superficial Swan	7,350,000	7,240,000	3,650	270,000	7,510,000	102.2%	-160,000
Whitehills	Perth - Superficial	200,000	184,909	98,500	7,600	192,509	96.3%	7,491

Note: a data current at 1 September 2009 provided by DoW

The licensed groundwater extraction sites are located on land outside the areas that are held under DEC tenure (including Yalgorup National Park). The allocations for individual licences are mainly comparatively large (>100,000 kL/a) in the Lake Preston North and South, and Myalup Subareas, suggesting that a major component of water use in these areas is for irrigation. There are numerous extraction sites in the White Hills, Island Point and the northern part of the Lake Clifton Subareas (the southern part of the Lake Clifton Subarea is mainly DEC tenure). Extraction from these bores is mainly for stock watering and domestic purposes and involves volumes of less than 1,500 kL/a (Table 4).

The data indicate that the superficial aquifer in the Lake Preston South Subarea is over-allocated and, if the requested allocations are allowed, a similar situation will arise in the Myalup Subarea. The DoW is likely to attempt to resolve the over-allocation in the Lake Preston South Subarea, possibly by recouping any unused portions of existing allocations. New requests for allocations in the Lake Preston South and Myalup Subareas are likely to be refused and applicants would then have to undertake an appeals process to proceed any further with their requests.

Irrigation for horticulture is the major user of groundwater in the area. The crops require fertiliser applications to maximise yields and quality. Excess irrigation water percolates past the root zone carrying with it any excess fertiliser (mainly nutrients) and recharges the water table. This results in a rise in nutrient concentrations in the groundwater beneath and down-gradient from the irrigated land. Fertiliser programmes are designed to minimise this leaching while maintaining the benefits of fertilisers for the crops. Suitable monitoring should be in place to ensure that nutrient concentrations in the groundwater do not increase above levels agreed by the DoW for the licensee.

4.2 LEEDERVILLE AQUIFER

Groundwater management subareas for the confined aquifers in the study area (including the Leederville aquifer) are similar to those for the superficial aquifer except that the Kemerton North Subarea includes the area of the Myalup Subarea, and the Lake Preston Subarea includes the combined areas of the Lake Preston North and South Subareas of the superficial aquifer. Groundwater allocations for the Leederville aquifer are presented in Table 5.

Most of the allocated and committed Leederville aquifer resource in the Kemerton North Subarea is reserved for public water supply (3,000,000 kL). The present DoW policy reserves the groundwater resources in the Leederville aquifer for public purposes. The water supply for Preston Beach (Coastal Subarea) is obtained from the Leederville aquifer. Existing licences in the Lake Preston and Kemerton North Subareas (Fig. 11) are held privately and are for irrigation water supplies.

Table 5: DoW Leederville Aquifer Groundwater Allocations in Subareas which Overlap the Study Area

Subarea	Aquifer	Allocation Limit	Licensed Allocation	Stock and Domestic	Additional Allocations Requested	Total Allocated Committed and Requested	% Allocated Committed and Requested	Balance Available for Future Licensing
		kL	kL	kL	kL	kL		kL
Coastal	Perth - Leederville	100,000	20,000	0	0	20,000	20.0%	80,000
Island Point	Perth - Leederville	10,000	1,500	0	0	1,500	15.0%	8,500
Lake Clifton	Perth - Leederville	10,000	1,500	0	0	1,500	15.0%	8,500
Lake Preston	Perth - Leederville	500,000	420,000	0	80,000	500,000	100.0%	0
Whitehills	Perth - Leederville	150,000	0	0	0	40,000	26.7%	110,000
KemertonNorth	Perth - Leederville	3,500,000	150,000	0	255,700	3,405,700	97.31%	94,300

Note: a data current at 1 September 2009 provided by DoW

5 GROUNDWATER AND THE ENVIRONMENT

5.1 GENERAL

Groundwater-dependent ecosystems (GDEs) are characterised by a dependency to some extent on groundwater to maintain their composition, integrity and function (Boulton and Hancock 2006). These may include, aquatic or riparian ecosystems supported by river baseflow systems or springs, wetlands, terrestrial vegetation (phreatophytes), aquifer ecosystems (stygofauna communities) and near-shore marine ecosystems.

Groundwater provides a source of freshwater for the maintenance (either directly or indirectly) of numerous ecosystems in the study area including:

- coastal lake ecosystems including the Yalgorup Lakes system

- microbialite communities (thrombolites), which occur mainly on the eastern shore of Lake Clifton;
- numerous wetlands and riparian vegetation at the lakes, and at uncleared sumplands and damplands; and
- vegetation throughout the area with roots that access a shallow water table.

Changes in groundwater conditions that may affect these ecosystems are broadly changes in:

- groundwater level (depth to the water table);
- salinity; and
- groundwater quality.

5.2 ENVIRONMENTAL PROTECTION

The ecological status and potential impacts of development on wetlands, lakes and associated communities of the Swan Coastal Plain and more specifically the Peel-Harvey system and Lake Clifton catchment have been the focus of several studies, reports and policies (e.g. EPA 1997, 1998, 1999, 2003 and 2007).

All wetlands are protected by provisions under the *Environmental Protection Act 1986*. A series of Environmental Protection Policies (EPPs) provide statutory protection of wetlands on the Swan Coastal Plain and these have undergone several reviews since their inception. The coastal lakes of the survey area were protected by the *Environmental Protection (Swan Coastal Plain Lakes) Policy 1992* (The Lakes EPP). The Lakes EPP was reviewed in 1999 and a *Draft Environmental Protection (Swan Coastal Plain Wetlands) Policy 1999* was also released. In 2004, the *Draft Environmental Protection (Swan Coastal Plain Wetlands) Policy* and *Regulations 2004* were released together with a draft Wetlands Register. The following year, the Minister for the Environment appointed the Regulatory Impact Assessment Panel (RIAP) to undertake a Regulatory Impact Assessment of the *Revised Draft Swan Coastal Plain Wetlands Environmental Protection Policy 2004* (RIAP 2005).

5.3 GROUNDWATER DEPENDENT ECOSYSTEMS

5.3.1 Wetlands

Wetlands in the study area have been mapped as part of the Wetlands of the Swan Coastal Plain project (Hill *et al.* 1996) and their dataset is presented to show wetland locations in Figure 13.

Wetlands types which are represented in the survey area are mainly basin wetlands – the lakes, sumplands (seasonally inundated) and damplands (seasonally water logged) on the Yalgorup Plain – and estuarine wetlands (Harvey and Leschenault Inlets). The Yalgorup system is listed under the Ramsar Convention as having international importance, the system includes Lake Clifton where a thrombolite community exists along its eastern shore.

The basin wetlands are maintained by groundwater which supports associated ecosystems. They are sites of groundwater discharge by evapotranspiration to varying degrees. The water level in inundated sumplands is an expression of the water table which otherwise occurs at shallow depth below the sumplands. The water table also occurs at shallow depth below damplands.

5.3.2 Lake Clifton Thrombolites

The thrombolite community of Lake Clifton (stromatolite-like freshwater microbialite community of coastal brackish lakes) has been listed by the DEC as a "threatened ecological community" (TEC) within the "critically endangered" category. This community has also been nominated for listing as "critically endangered" under the Federal *Environmental Protection and Biodiversity Conservation Act 1999*. Management of the Lake Clifton thrombolite community, in particular the controls/actions for threatening processes, are detailed in an Interim Recovery Plan (DCLM 2004).

The thrombolites occur almost exclusively along the eastern side of Lake Clifton in a 10 km-long zone up to 30 m wide (B. Knott, unpublished report), occupying a total area of over 4 km^2 (Moore 1991). They are associated with hyposaline water (salinity less than sea water), although higher salinity occurs beneath the lake itself. Low-salinity groundwater discharges to the lake along the shoreline of the northeastern section where it:

- maintains salinity levels suitable for thrombolite growth;
- provides a source of carbonate and bicarbonate ions that precipitate and make up the structures; and
- provides low-concentrations of nutrients to support the growth of the cyanophyta on the bottom of the lake. Too high concentrations of nutrients, however, could support algal growth that would reduce the light available for bacterial growth.

Groundwater discharge to the lake is likely to be unevenly distributed along the shoreline due to local-scale variations in the lithology and, hence, the hydraulic properties of the aquifer. Any reduction in the quantity and quality of the discharge will affect these factors.

Monitoring data, collected by the DEC from Lake Clifton since 1985, indicate trends of increasing salinity and possibly slightly decreasing pH in the lake water at a site near the thrombolites (Fig. 1) and of decreasing depth of water in the lake (Fig. 6). An increase in salinity may lead to a change in the environmental conditions that support the thrombolite-forming microbial community along the lake shore (Luu *et. al* 2004). Groundwater extraction and land development within the Lake Clifton Flow System on the eastern side of the lake should be managed to minimise any human-induced changes to the quantity and quality of groundwater that discharges to the lake. Reducing extraction from the aquifer would make more low-salinity groundwater available for discharge to the lake. An increase in groundwater discharge to the lake is likely to reduce the trend of increasing salinity and increase lake water levels.

5.3.3 Coastal Lakes

Groundwater discharge to coastal lakes such as the Yalgorup lakes maintains the lakes and water quality. Changes in the quantity and quality of discharge to the lakes could affect the ecosystems that rely on low-salinity water. A reduction in discharge would lead to increases in salinity, not only due to the reduced inflow of low-salinity water, but also the resulting lower lake levels would result in a rising of the underlying saline water which could make its way into the lakes. This could affect the viability of ecosystems which are intolerant to such changes.

5.3.4 Groundwater Dependent Vegetation

It has been suggested previously that long-term distribution trends and reductions in the vigour of tree species such as *Banksia* and *Melaleuca* fringing wetland areas and lakes on the Swan Coastal Plain may be a function of the species' dependency on groundwater to fulfil their water requirements (e.g. Groom *et. al* 2001). A reduction in water table levels could increase stress on vegetation whose roots access the water table. This cause has been suggested as a possible contributor to a reduction in the vigour of tuart forests in the study area (DCLM 2003). Water table levels have been found to have reduced in most bores by comparatively small amounts (up to about one metre) over the last 30 years based on the available monitoring data. Much of this change can be attributed to a reduction in rainfall. There has been recovery of water levels from the lowest levels in the early-1990s to close to the pre-1990 levels in many bores. It seems unlikely that water level changes of this magnitude would have had a large impact on the tuart trees and other (terrestrial) native vegetation.

The area south of the Yalgorup National Park on the east of Lake Preston is largely cleared for horticulture and grazing which has modified the previous wetland environments. Drains have been constructed to reduce seasonal water logging caused by shallow water tables in parts of this area. Lowering of the water table would reduce water losses by evapotranspiration and thereby possibly reduce groundwater salinity. However, irrigation would produce a countering effect as a result of evaporation from excess irrigation water that percolates to the water table. Fertiliser use would potentially add nutrients to the groundwater in the irrigation return water. Consequently, the groundwater conditions associated with ecosystems that are within such cleared land are likely to be changed.

5.4 STYGOFAUNA

Stygofauna are groundwater-dwelling aquatic fauna made up predominantly of crustaceans but also include worms, snails, insects, several other invertebrate groups and two species of blind fish.

The occurrence of stygofauna communities is determined by local geological and groundwater conditions. There are few records of stygofauna from the South-West of Western Australia and none of these are from the Dawesville to Binningup area (Bill Humphreys[1], personal communication). Karstic strata, such as the limestone beneath the Swan Coastal Plain and are considered to have a high probability of containing a rich subterranean fauna (EPA 2007).

Eberhard (2003) recorded stygofauna in superficial sediments on the Scott Coastal Plain, and the Swan Coastal Plain between Bunbury and Capel. Both of these general areas contain extensive groundwater environments considered suitable for stygofauna. It is likely that the superficial aquifer beneath the narrow section of coastal plain between Dawesville and Binningup contains suitable habitat for stygofauna. The absence of any records of stygofauna within the study area is likely a result of a lack of targeted sampling.

6 DATA GAPS AND FURTHER WORK

6.1 MONITORING BORE NETWORK

The existing monitoring network (Fig. 3) comprises project bores that were installed as for hydrogeological investigations by the Geological Survey of Western Australia and the DoW. Bore sites were selected where access could be gained to the land, mainly within east-west trending road reserves (Commander, 2009, written communication). The network provides a reasonable coverage of sites for regional groundwater level monitoring but it is not particularly suitable for assessing the effects of extraction and land-use changes. For example, only a few bores are positioned close to areas of irrigated horticulture (the major user of groundwater in the project area) which are likely to have the greatest impacts on groundwater levels and quality in the area. Monitoring bores should be designed and positioned with regard to specific monitoring objectives, such as investigating the effects of horticultural activities and monitoring of groundwater quality upstream of Lake Clifton.

[1] Dr W.F. Humphreys, Senior Curator, Western Australian Museum

6.2 MONITORING DATA

Groundwater Levels

Water levels are monitored several times per year in the active monitoring bores. Some sites are not presently monitored; these are located mainly to the west of the Yalgorup lakes (e.g. Y2-1 and Y2-2). Water levels in these sites lie only just above 0 m AHD and have previously shown very small fluctuations, so recommencement of monitoring at these sites may not be justified.

Groundwater Quality

There is a significant lack of groundwater quality monitoring data. Existing information is mainly from once-off sampling at the time when the bores were installed. There are no subsequent regular monitoring results which can be analysed for trends of change.

Nutrients in the groundwater are derived from both natural sources and sources associated with land-use practices (particularly fertiliser use). Nutrients that enter the lakes via groundwater would contribute to the potential for eutrophication. Monitoring for nutrients in areas where there are human-induced nutrient additions to the groundwater should be undertaken regularly. This is usually required of irrigators as part of their groundwater licence obligations. Additional monitoring of nutrients in the groundwater on the eastern side (upstream) of the Lake Clifton thrombolite communities should be undertaken to compare with previously-collected data.

The suitability of each site (bore condition and relevant location) and the proposed monitoring interval should be assessed before implementing any sampling programmes.

Groundwater Extraction

The DoW maintains data on groundwater allocations and the locations of drawpoints for licences to take water in the South West Coastal Groundwater Area. The allocations indicate the maximum volume that may be drawn from the aquifer; they are not the actual extracted quantities. Extraction quantities are annually reported to the DoW under the licence conditions but are not stored in the licence database. Compilation of the actual extraction volumes would contribute significantly to the assessment of monitoring trends. The DoW should be requested to store groundwater extraction volumes against licences so that the data can be extracted to assess the actual draw on the aquifer.

Historical groundwater allocation data could not be provided for this investigation. If these data can be collated, they should be reviewed to provide an indication of any significant changes in the demand on the groundwater resources in the area. Historical extraction data would be even more useful although most bores are not metered.

6.3 HYDROGEOLOGICAL DATA

Local groundwater flow systems support the three major lake systems in the study area, and there are strong variations in lithology within the aquifers. Local-scale variations in the hydrogeology may influence the location and extent of groundwater discharge zones at the lakes. For these reasons, the collection of additional hydrogeological data in sensitive areas would be beneficial to the assessment of changes (if any) to the hydrogeological regimes, and the effects incurred by the changes.

Comprehensive analysis of the hydrogeological aspects of specific features (e.g. the Lake Clifton thrombolite communities) would require detailed, focussed investigations. The investigations would include drilling and sampling locally. Such investigations would need to be carried out in areas and with procedures to avoid damage to the existing hydrogeological systems and ecosystems. For example, care would have to be taken that any drilling does not provide a vertical flow path for groundwater by perforating hydraulic confining layers.

7 SUMMARY AND CONCLUSIONS

The study area is underlain by the superficial formations which overlie Cretaceous-age sedimentary strata of the Leederville and Osborne Formations at elevations of about -25 m AHD. Groundwater resources which support the surface environmental features in the study are contained in the superficial aquifer, which is the shallow (mainly unconfined) aquifer of the area. The aquifer contains local groundwater flow systems which discharge to the main lake systems (Lake Clifton, Lake Preston and Lake Yalgorup chain of lakes), Harvey Estuary, Leschenault Inlet or the ocean. The lakes are groundwater sinks.

The superficial formations comprise several juxtaposed lithological units and, consequently, the superficial aquifer is hydrogeologically complex as a result of variations in the hydraulic properties of the various lithologies: predominantly sand, limestone and clay. Additionally, thin calcrete sheets, formed by diagenesis, may extend subhorizontally across stratigraphic boundaries. The existing hydrogeological data provide a regional-scale picture of the hydrogeology which is useful for regional management of groundwater resources but is not suitable for investigations of the hydrogeology on a more local scale.

Ecosystems associated with the lakes may be dependent on local-scale influences such as low-permeability layers which may control the locations of groundwater discharge zones. Groundwater discharge to the lakes will vary according to local variations in the hydraulic properties of the superficial aquifer. In some cases, a small fall in the level of the water table, for example from above to below a low-permeability layer, may cause a substantial change in the location of the zone where groundwater discharge is occurring. This could displace such a discharge zone from where it supports a local ecosystem.

Groundwater levels range in elevation from 3 to 5 m AHD in the southeastern part of the study area but lie below sea level near some lakes, due to the higher density of the underlying hypersaline water. Seasonal variations are up to 2 m but mainly less than 1 m and reflect the seasonality of rainfall recharge. Groundwater levels in most monitoring bores in the area have shown overall reductions over the last about 30 years, but by less than one metre. This is mainly attributed to reductions in rainfall but groundwater extraction has probably influenced water levels locally. A few drains, designed to reduce water logging, are located west of Lake Preston and north of Leschenault Inlet. These may slightly reduce groundwater levels but would decrease evapotranspiration and, consequently, may reduce salinity in the local groundwater. It is unlikely that the Dawesville Cut is having an influence on groundwater levels in the study area.

The flow systems contain low-salinity groundwater occurring as lenses which lie above hypersaline water associated with the lakes, or as fresh-water bodies overlying saline water wedges adjacent to the Harvey Estuary and the coast. Low-salinity or fresh groundwater extends to the base of the aquifer only in the southern and eastern sectors, where there is groundwater throughflow from further to the east. The aquifer is recharged by rainfall and provides discharge to the lakes, (from where is water is lost by evapotranspiration), estuaries, and the ocean. Groundwater salinity at the water table varies from less than 500 mg/L TDS to about 2,000 mg/L TDS. The groundwater contains nutrients at suitably low levels for maintaining the thrombolite communities along the eastern shore of Lake Clifton. Higher levels of nutrients in lake water can favour the growth of algae, reducing light penetration, potentially affecting microbialite formation, and increasing the potential for eutrophication. Most of the nutrients in the groundwater are derived from natural sources; however, fertilisers and grazing activities are sources of locally higher nutrient concentrations.

Groundwater in the study area provides a source of domestic and stock water supplies for small landholders, and irrigation water supplies for horticulture The study area is in the South West Groundwater Area where there is a total available allocation in subareas that overlap the study area of 72,500,000 kL/a of which about 35,000,000 kL are currently allocated. The larger groundwater users, accounting for about half of the total allocations, are in the south, where there is considerable irrigation usage; there are many small supplies for domestic and stock purposes in the north. Current allocations are either above or approaching the DoW allocation limits in the south.

Groundwater resources in the superficial aquifer support important environmental features, such as the Yalgorup lakes and the Lake Clifton thrombolite communities. Investigations have shown that these features can be particularly sensitive to changes in groundwater level which are reflected by changes in the quality and quantity of discharge to the lakes. Groundwater discharge to Lake Clifton provides a source of carbonate and bicarbonate ions, low-level nutrient concentrations, and appropriate salinities for the thrombolite communities. Monitoring of Lake Clifton by DEC since 1985 indicates trends of falling lake water depth, rising salinity and, possibly, slightly falling pH. These trends suggest that groundwater inflow to the lake could be reducing and signify potential threats to the viability of the thrombolite communities. Nutrient concentrations in the lake water appear stable. Groundwater also provides a source of low-salinity water for vegetation around the lake system. It is unlikely that the slightly lowered water table levels have affected the vigour of tuart forests in the area.

There is an extensive network of DoW groundwater monitoring bores which are monitored frequently for water levels; however, groundwater quality data are available only from samples taken when the bores were installed. Additional groundwater quality monitoring should be instigated to allow assessments of any changes that may be occurring. This monitoring may involve the installation of new bores to target specific monitoring objectives. A database of groundwater extraction volumes would reflect actual extraction rather than licensed allocations and allow historical data to be assessed.

8 RECOMMENDATIONS

- In the eastern parts of the Island Point and Lake Clifton Subareas of the South West Coastal Groundwater Area, limit or curtail activities that may cause reductions in the quantity or deterioration of the quality of the groundwater discharge that supports the Lake Clifton thrombolite communities.
- Request that the Department of Water include the actual extraction volumes associated with groundwater licences in the South West Coastal Groundwater Area in their database so that the actual draw on the aquifer can be assessed. Metering of all bores should be considered.
- Request DoW to compile historical groundwater licence allocations for the area to assist in the analysis of trends in groundwater monitoring data.
- Ensure that groundwater resource allocations are within the allocation limits calculated through groundwater resource assessment studies. Update the resources assessments for the northern subareas of the South West Coastal Groundwater Area.
- Establish groundwater quality monitoring at selected sites in the area. If existing bores are unsuitable, establish bores at new sites to target specific monitoring objectives, such as the quality of groundwater upstream of discharge zones to the lakes and the effects of irrigated horticulture on the groundwater.

- Ensure fertiliser applications for irrigated horticulture are managed so that nutrient concentrations in the underlying groundwater remain below acceptable levels agreed with the DoW for the holder of the groundwater extraction licence and no adverse trends of change are apparent.
- Undertake detailed geological and hydrogeological investigations to describe the processes and quality of groundwater discharge in the complex hydrogeological system at selected sites of the Yalgorup lakes, such as in the vicinity of the Lake Clifton thrombolite communities. Any investigations should be carefully targeted to meet specific objectives.

Dated: **4 December 2009** **Rockwater Pty Ltd**

John Moncrieff
Principal Hydrogeologist

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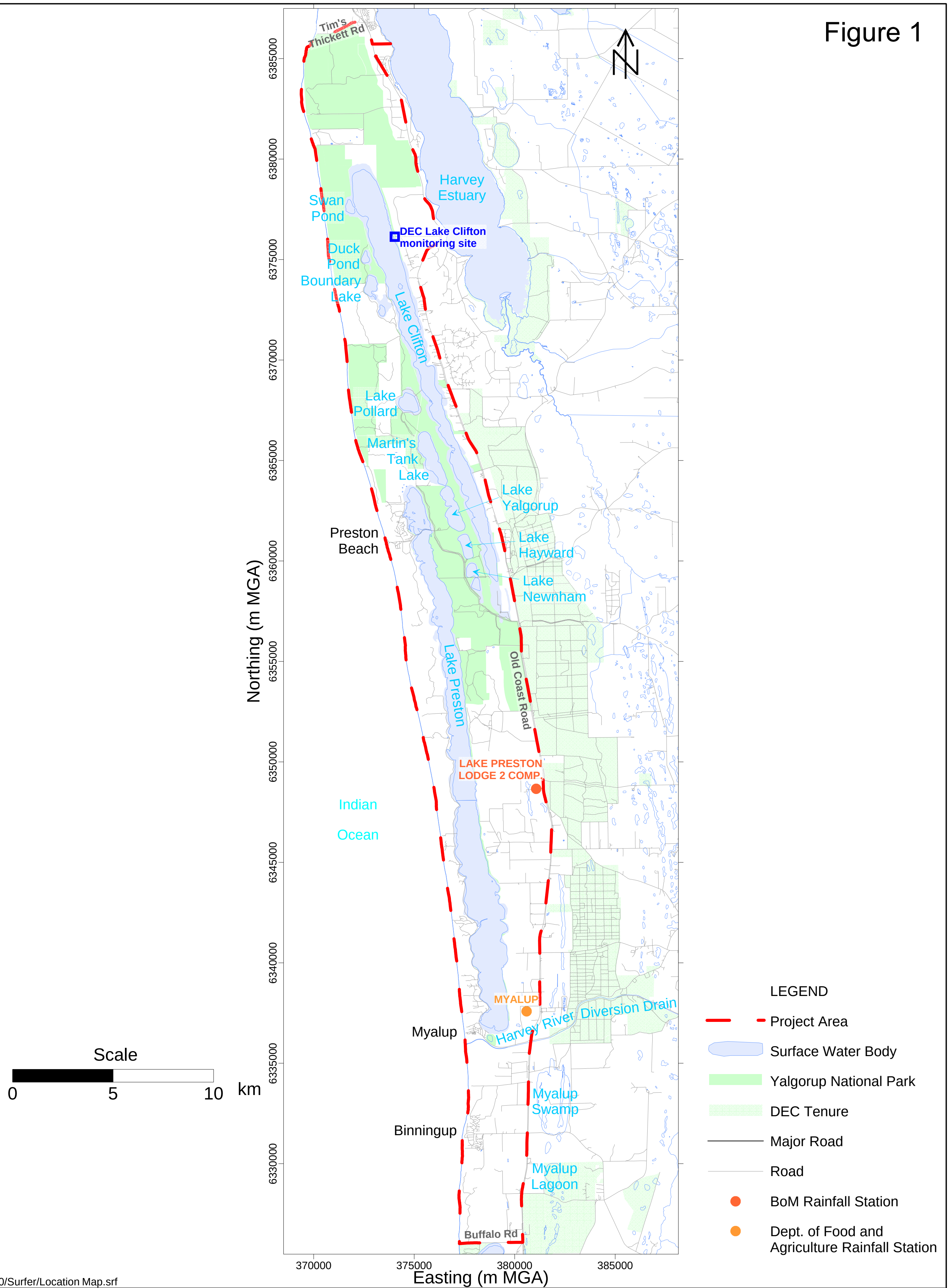
FIGURES

Figure 1



CLIENT: Department of Environment and Conservation

PROJECT: Dawesville to Binningup Hydrogeology Study

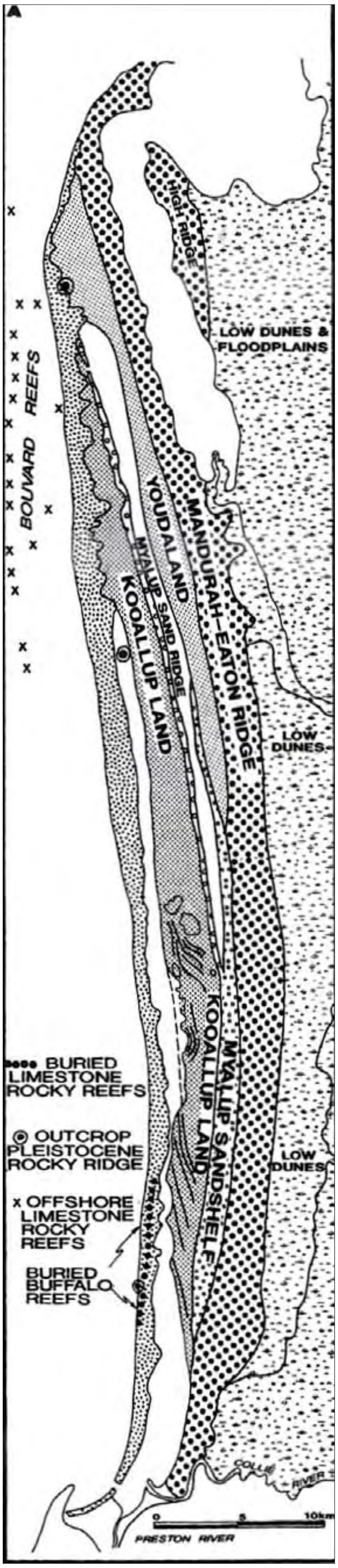
DATE: September 2009

Dwg. No: 360.0/09/01-1

LOCATION PLAN

Rockwater

Figure 2



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CLIENT:	Department of Conservation and Environment
PROJECT:	Dawesville to Binningup Hydrogeology Study
DATE:	September 2009
Dwg. No:	360.0/09/01-2

LANDFORMS
(after Semeniuk 1997)

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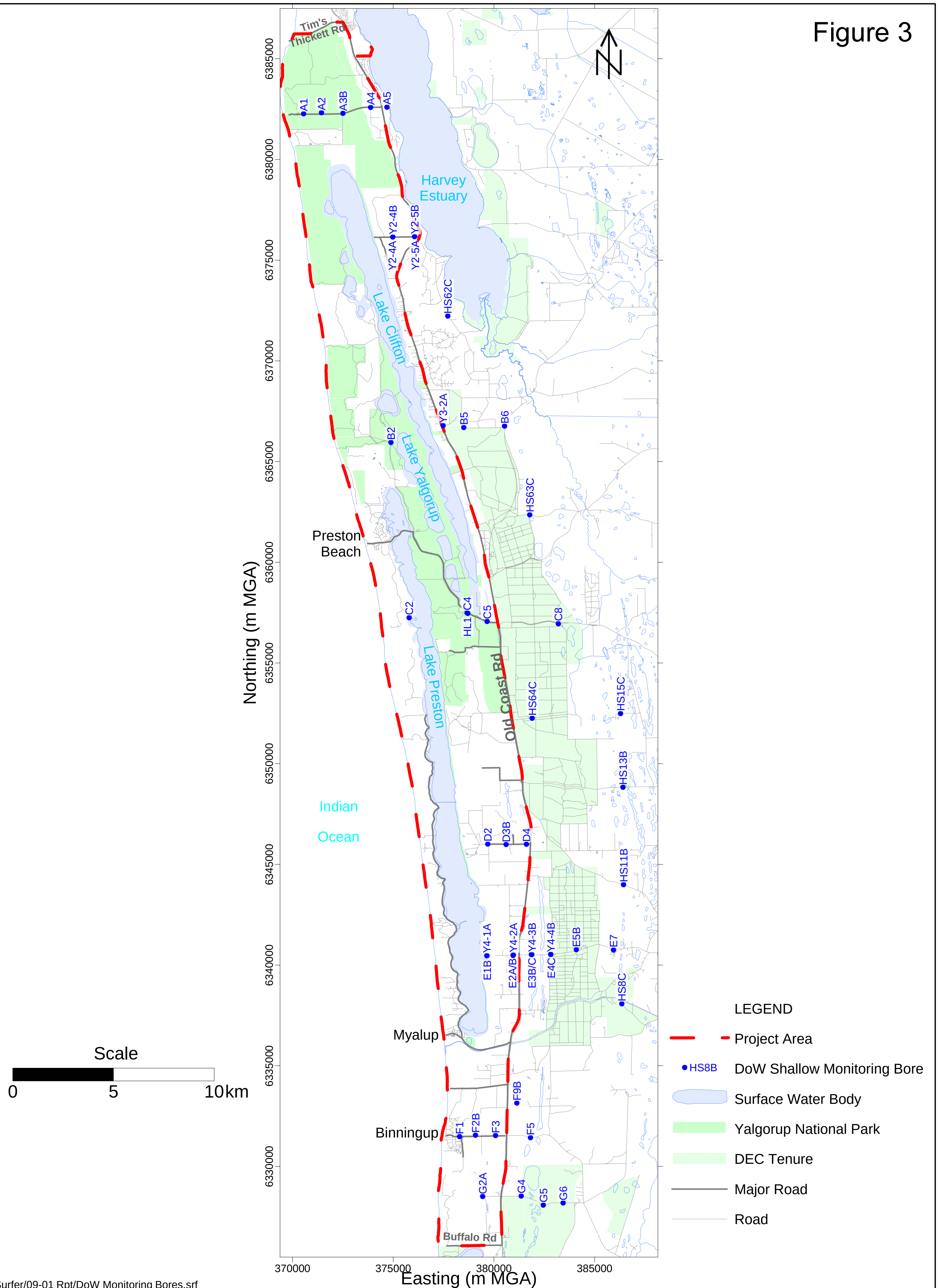
Figure 3



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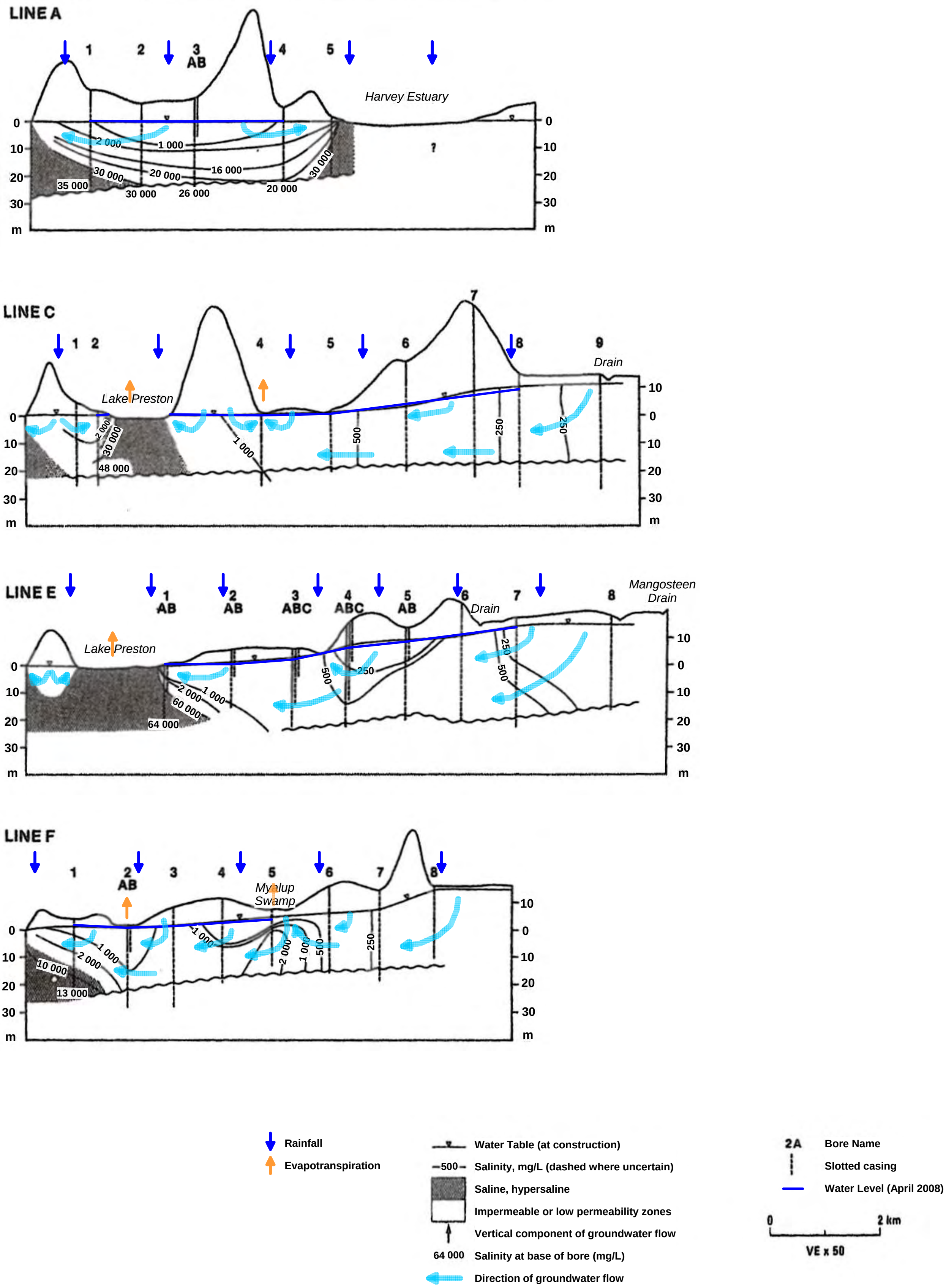
CLIENT:	Department of Environment and Conservation
PROJECT:	Dawesville to Binningup Hydrogeology Study
DATE:	September 2009
Dwg. No:	360.0/09/01-3

DoW MONITORING BORE LOCATIONS

Rockwater

Figure 4



360.0/Surfer/09-01 Rpt/Cross-Sections.srf

CLIENT: Department of Conservation and Environment

PROJECT: Dawesville to Binningup Hydrogeology Study

DATE: September 2009

Dwg. No: 360.0/09/01-4

HYDROGEOLOGICAL CROSS-SECTIONS
(modified after Commander 1989)

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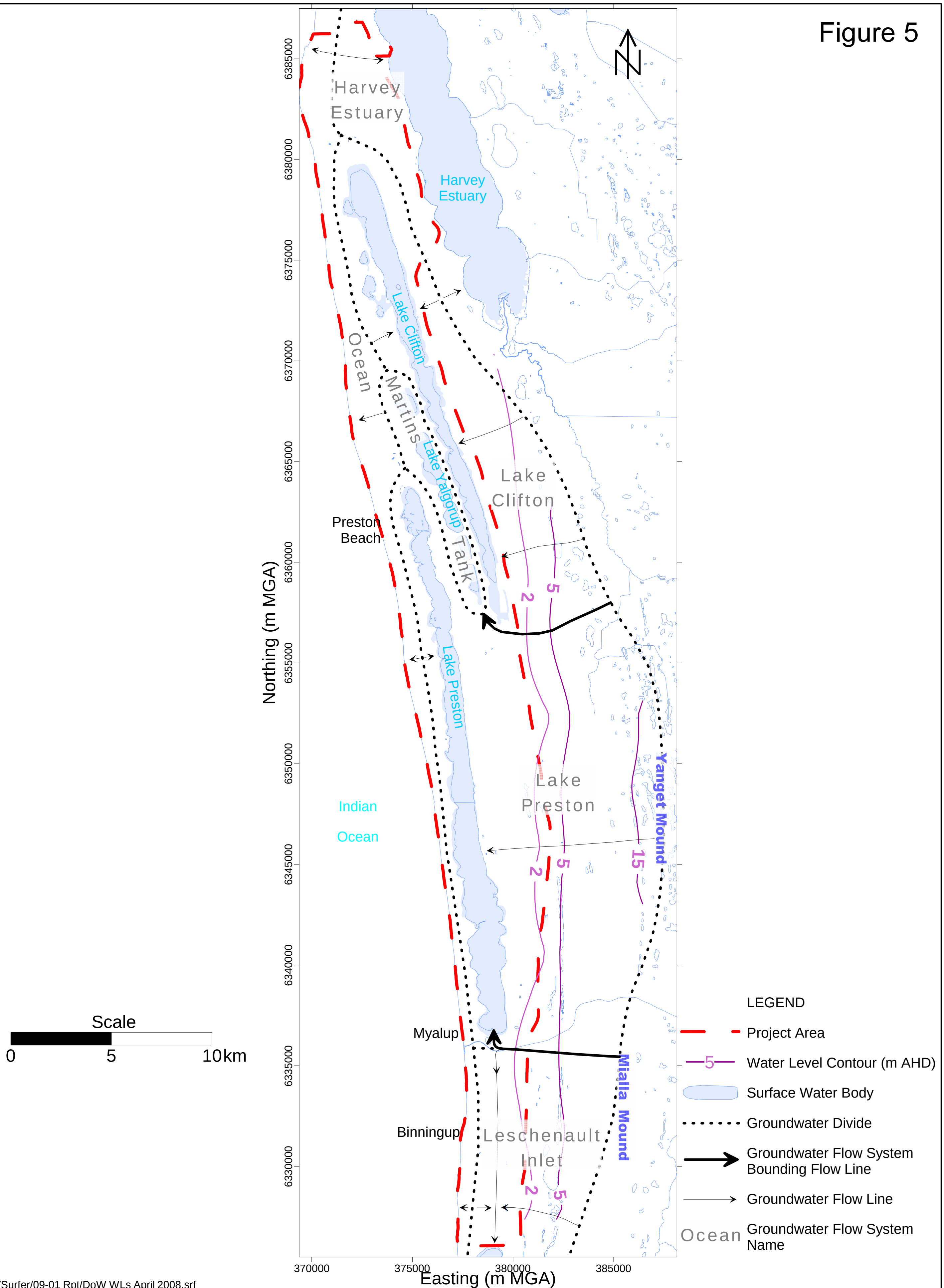
Figure 5



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CLIENT: Department of Environment and Conservation

PROJECT: Dawesville to Binningup Hydrogeology Study

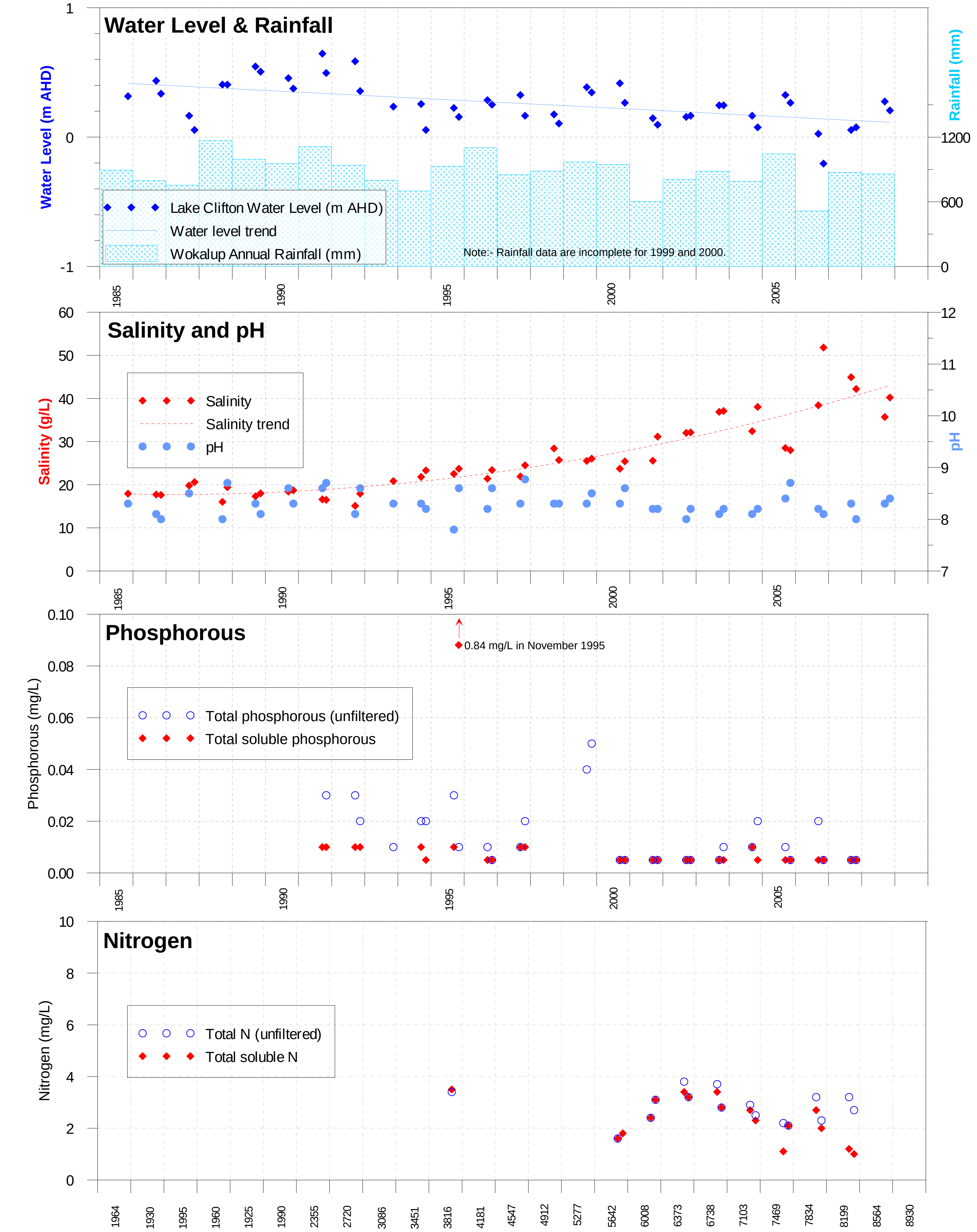
DATE: Spetember2009

Dwg. No: 360.0/09/01-5

GROUNDWATER FLOW SYSTEMS
(after Commander 1998)

Rockwater

Figure 6



I:/360.0/Grapher/09-01 Rpt/Lake Clifton DEC Monitoring.grf

Client: Department of Environment and Conservation

Project : Dawesville to Binningup Hydrogeology Study

Date : September 2009

Dwg. No:360.0/09/1-6

LAKE CLIFTON
DEC WATER MONITORING DATA

Data (other than BoM rainfall) provided by
J. Lane, DEC Science Division, Busselton

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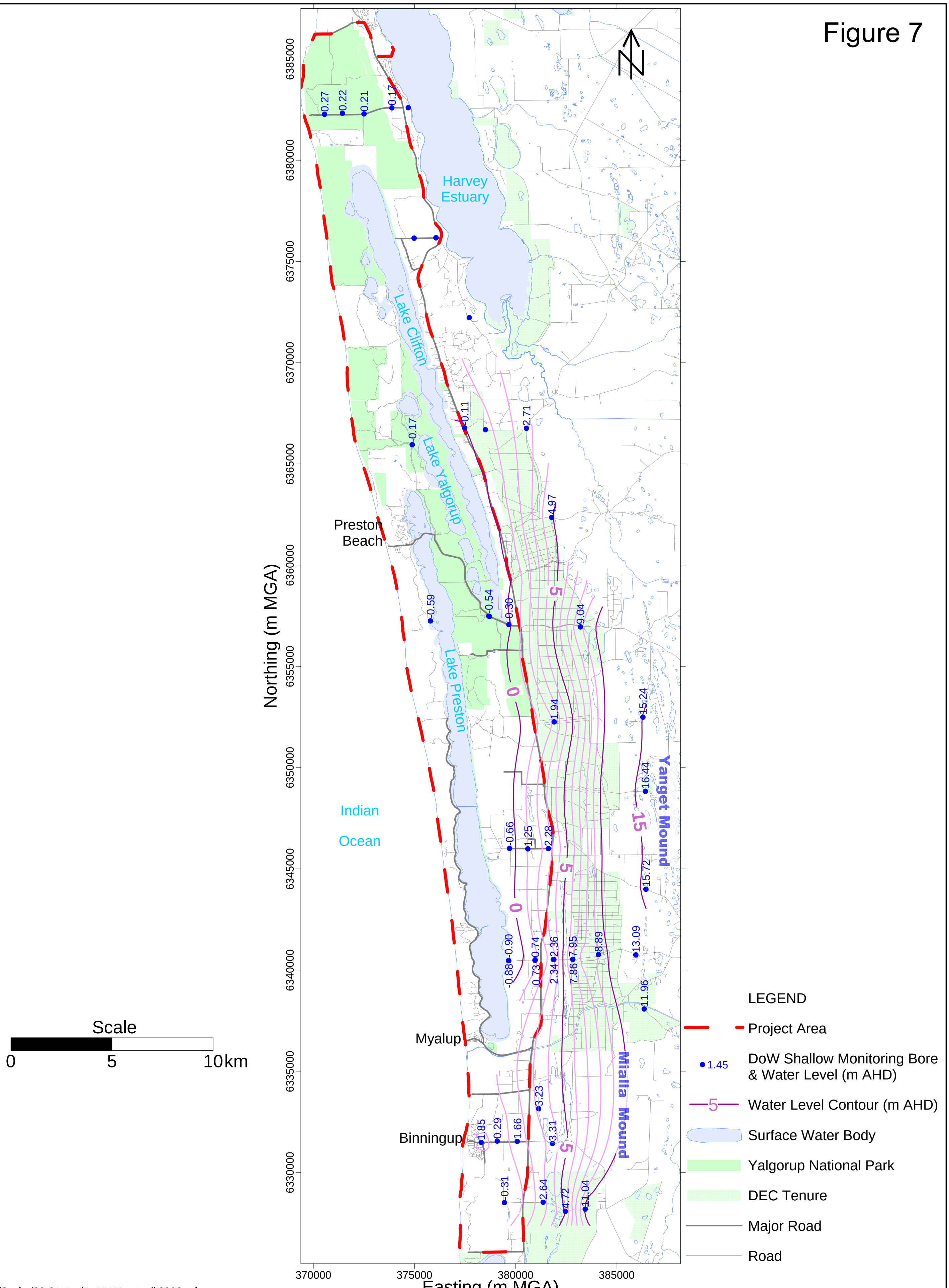
Figure 7



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CLIENT: Department of Environment and Conservation

PROJECT: Dawesville to Binningup Hydrogeology Study

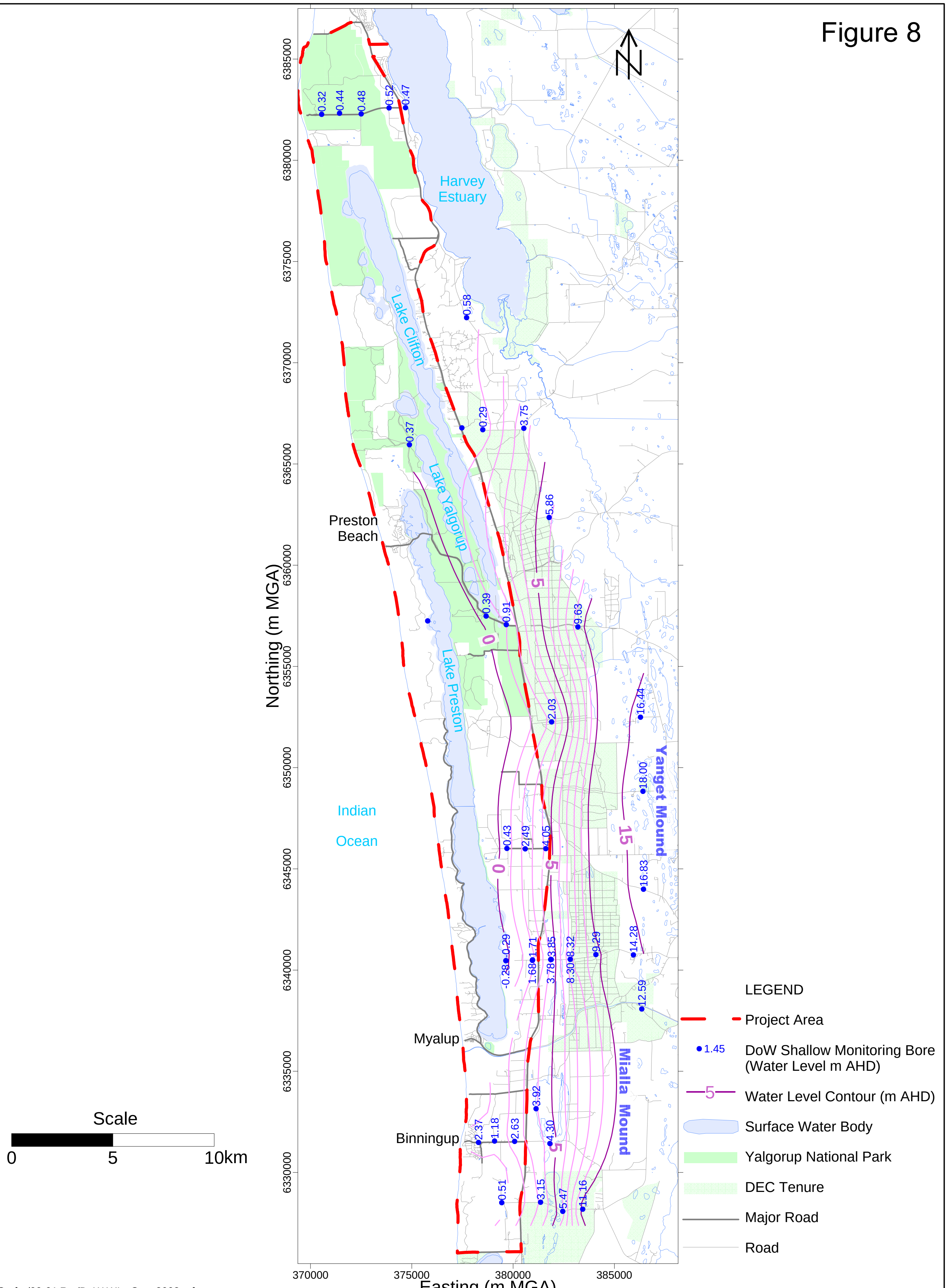
DATE: September 2009

Dwg. No: 360.0/09/01-7

WATER LEVEL CONTOURS
MARCH/APRIL 2008

Rockwater

Figure 8



360.0/Surfer/09-01 Rpt/DoW WLs Sept 2008.srf

CLIENT: Department of Environment and Conservation

PROJECT: Dawesville to Binningup Hydrogeology Study

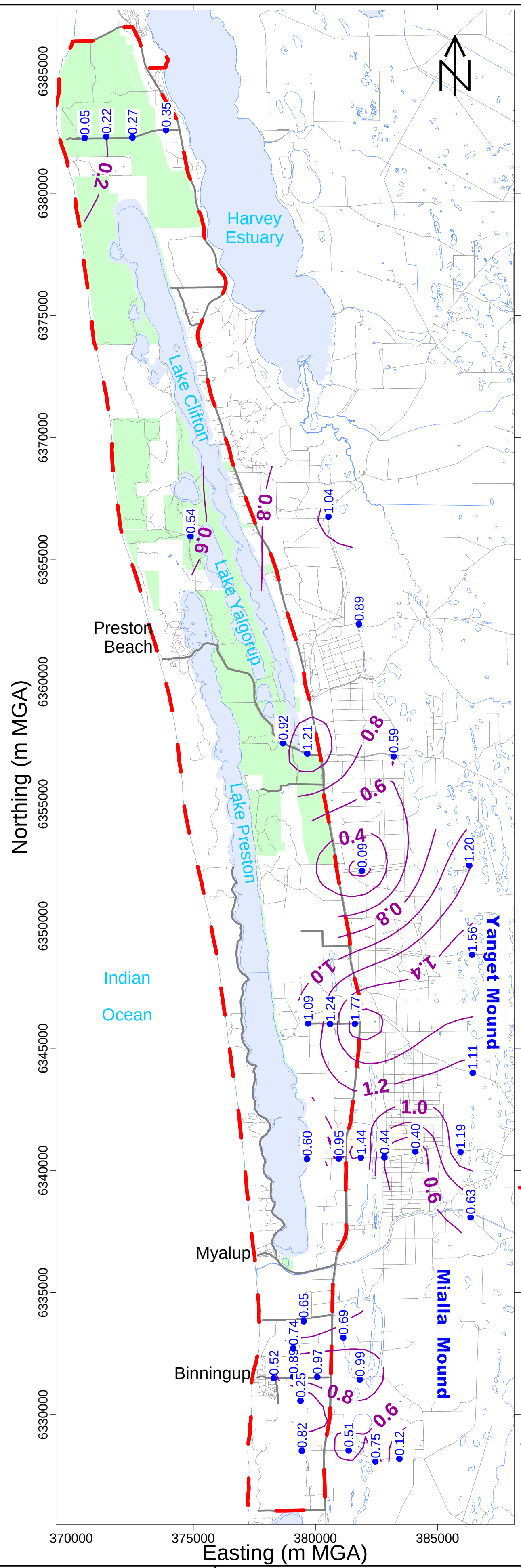
DATE: September 2009

Dwg. No: 360.0/09/01-8

WATER LEVEL CONTOURS SEPTEMBER 2008

Rockwater

Figure 9



Scale

0 5 10km

LEGEND

- Project Area
- 0.27 DoW Shallow Monitoring Bore, Difference in Water Levels (m)
- —0.2— Water Level Change Contour (m)
- Surface Water Body
- Yalgorup National Park
- DEC Tenure
- Major Road
- Road

360.0/Surfer/09-01 Rpt/DoW WLs Diff 2008.srf

CLIENT: Department of Environment and Conservation

PROJECT: Dawesville to Binningup Hydrogeology Study

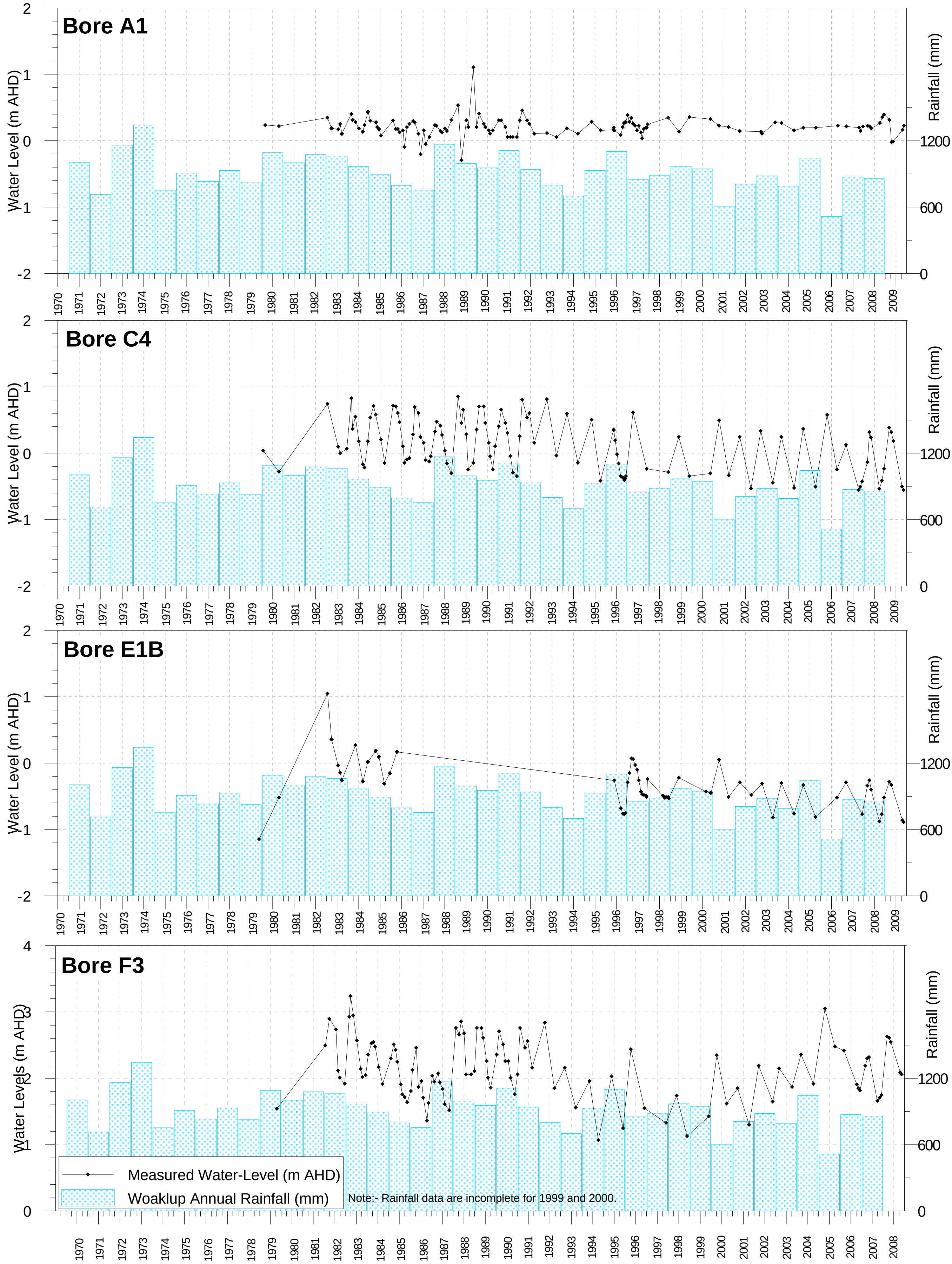
DATE: September 2009

Dwg. No: 360.0/09/01-9

WATER LEVEL DIFFERENCE
SEPTEMBER 2008 MINUS APRIL 2008

Rockwater

Figure 10



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Client: Department of Environment and Conservation

Project : Dawesville to Binningup Hydrogeology Study

Date : September 2009

Dwg. No:360.0/09/1-10

HYDROGRAPHS FOR SELECTED BORES

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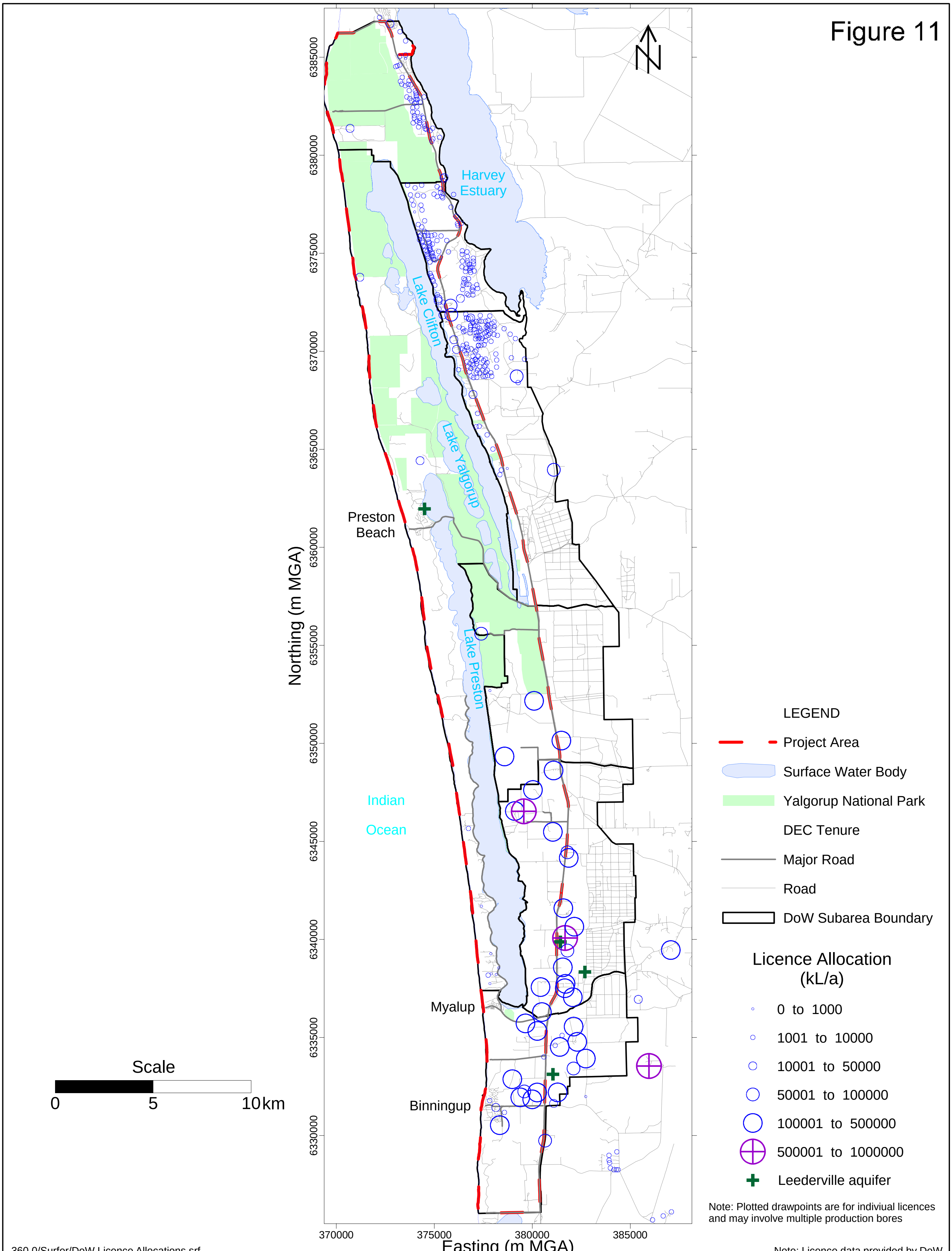

360.0/Surfer/DoW Licence Allocations.srf

Note: Licence data provided by DoW

CLIENT:	Department of Environment and Conservation
PROJECT:	Dawesville to Binningup Hydrogeology Study
DATE:	September 2009
Dwg. No:	360.0/09/01-11

SOUTH WEST COASTAL GROUNDWATER AREA GROUNDWATER DRAWPOINTS AND LICENCE ALLOCATIONS

(including domestic and stock bores licensed before 2001)

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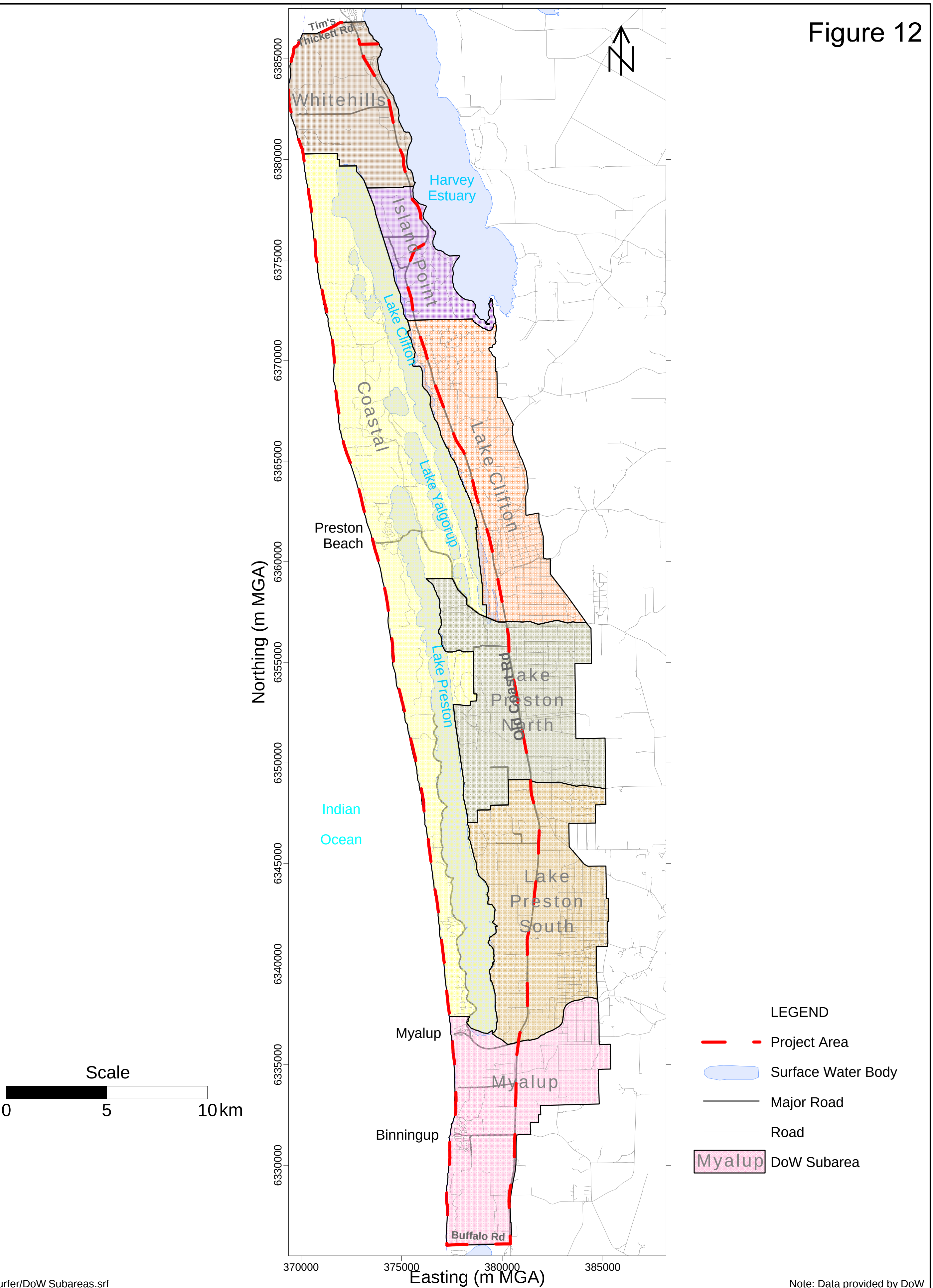
Figure 12



360.0/Surfer/DoW Subareas.srf

Note: Data provided by DoW

CLIENT: Department of Environment and Conservation

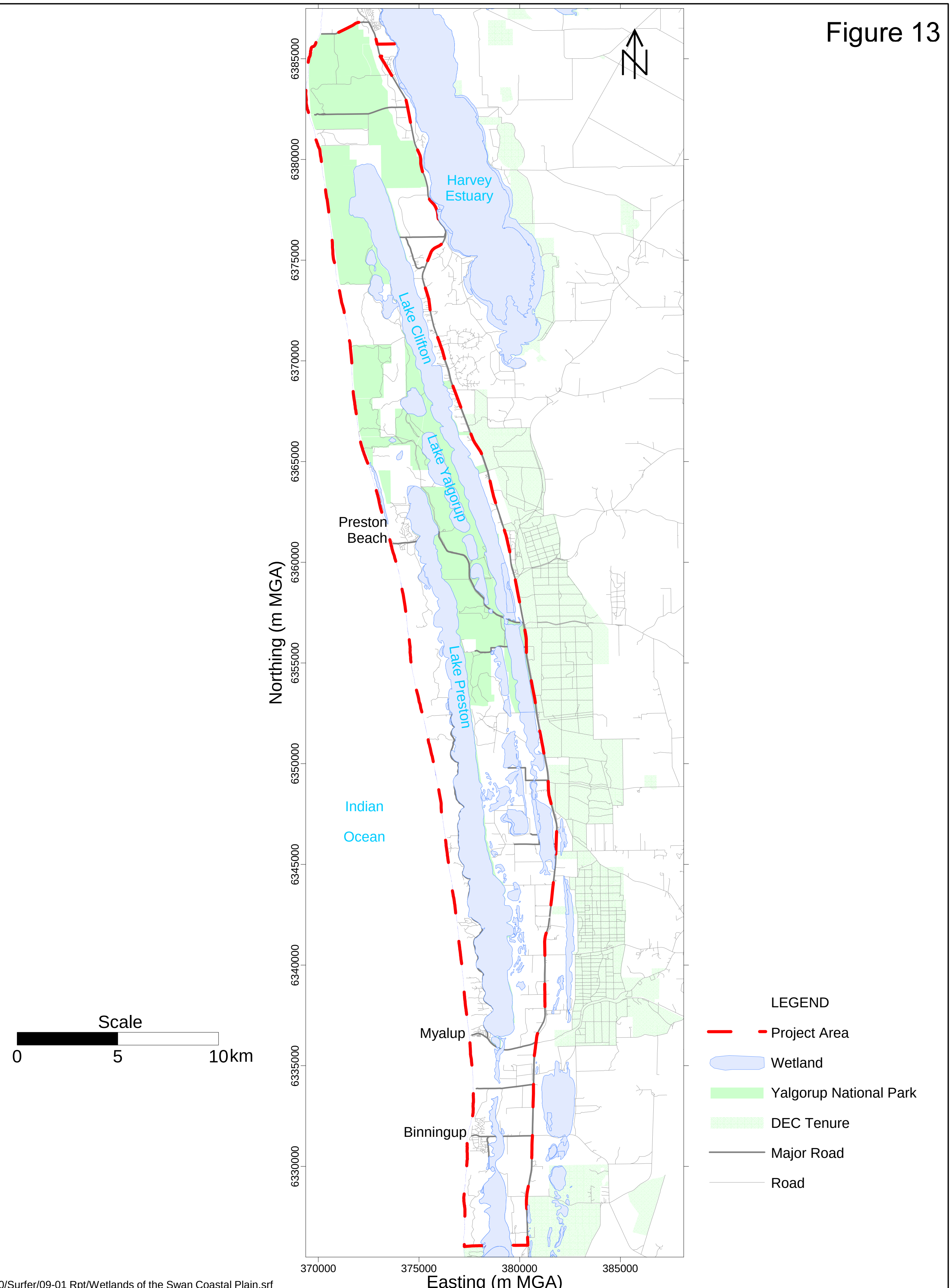
PROJECT: Dawesville to Binningup Hydrogeology Study

DATE: September 2009

Dwg. No: 360.0/09/01-12

SOUTH WEST COASTAL GROUNDWATER AREA GROUNDWATER SUBAREAS

Figure 13



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CLIENT: Department of Environment and Conservation

PROJECT: Dawesville to Binningup Hydrogeology Study

DATE: September 2009

Dwg. No: 360.0/09/01-13

WETLANDS

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APPENDIX I

DoW Monitoring Bore Data and Hydrographs

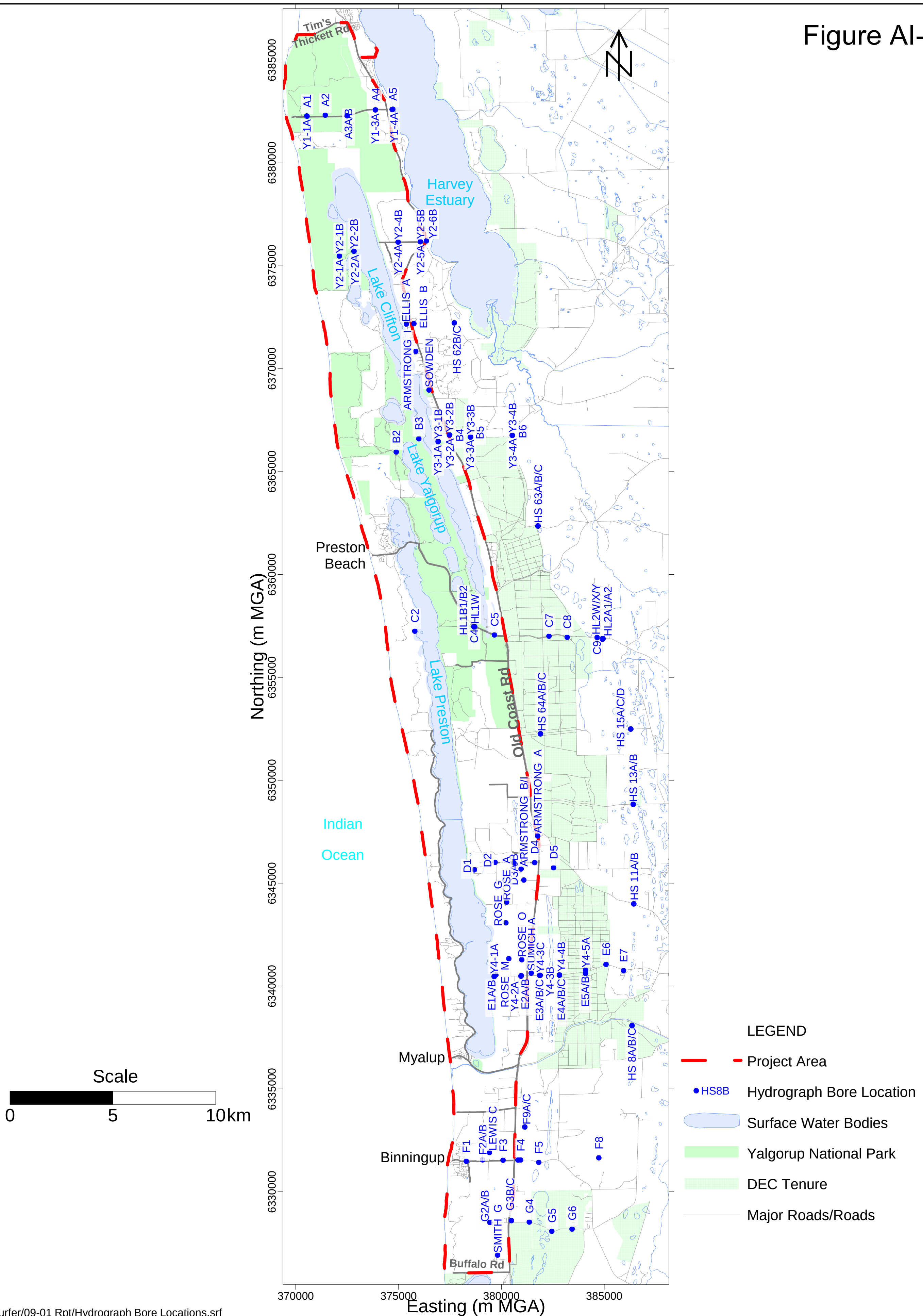
DoW Monitoring Bore Data

AQWABase Bore Name	AWRC Context Name	Date Drilled	Easting (m MGA)	Northing (m MGA)	TOC Elevation (m AHD)	Distance To Top of Slots (m bgl)	Aquifer
A1	Lake Clifton Project	Aug-79	370553	6382267	11.71	6	Superficial Swan
A2	Lake Clifton Project	Aug-79	371439	6382324	7.01	6	Superficial Swan
A3A	Lake Clifton Project	Oct-78	372507	6382292	8.63	15	Superficial Swan
A3B	Lake Clifton Project	Oct-78	372507	6382292	8.65	8	Superficial Swan
A4	Lake Clifton Project	Aug-79	373883	6382587	4.64	6	Superficial Swan
A5	Lake Clifton Project	Aug-79	374689	6382599	1.72	NA	Superficial Swan
B2	Lake Clifton Project	Aug-79	374889	6365948	4.63	2	Superficial Swan
B3	Lake Clifton Project	Aug-79	375989	6366598	4.11	2	Superficial Swan
B4	Lake Clifton Project	Oct-79	377477	6366779	4.16	NA	Superficial Swan
B5	Lake Clifton Project	Oct-79	378506	6366690	26.23	27	Superficial Swan
B6	Lake Clifton Project	Oct-79	380533	6366760	5.46	NA	Superficial Swan
C2	Lake Clifton Project	Jul-79	375789	6357248	2.81	2	Superficial Swan
C4	Lake Clifton Project	Jul-79	378671	6357482	1.46	2	Superficial Swan
C5	Lake Clifton Project	Jul-79	379664	6357063	2.50	1	Superficial Swan
C7	Lake Clifton Project	Oct-79	382314	6357002	39.33	31	Superficial Swan
C8	Lake Clifton Project	Jul-79	383198	6356951	15.45	2	Superficial Swan
C9	Lake Clifton Project	Jul-79	384653	6356938	14.39	2	Superficial Swan
D1	Lake Clifton Project	Jun-79	378689	6345648	1.91	1	Superficial Swan
D2	Lake Clifton Project	Jun-79	379695	6346005	10.90	16	Superficial Swan
D3A	Lake Clifton Project	Jul-79	380604	6345986	20.04	25	Superficial Swan
D3B	Lake Clifton Project	Jul-79	380604	6345986	20.00	10	Superficial Swan
D4	Lake Clifton Project	Jul-79	381616	6345998	5.08	1	Superficial Swan
D5	Lake Clifton Project	Jul-79	382539	6345748	14.36	6	Superficial Swan
E1A	Lake Clifton Project	Mar-79	379739	6340548	1.09	10	Superficial Swan
E1B	Lake Clifton Project	Mar-79	379659	6340460	1.14	NA	Superficial Swan
E2A	Lake Clifton Project	Jun-79	380956	6340476	6.14	10	Superficial Swan
E2B	Lake Clifton Project	Jun-79	380956	6340476	6.08	NA	Superficial Swan
E3A	Lake Clifton Project	Feb-79	381863	6340518	6.59	20	Superficial Swan
E3B	Lake Clifton Project	Feb-79	381863	6340518	6.61	9	Superficial Swan
E3C	Lake Clifton Project	Feb-79	381863	6340518	6.62	NA	Superficial Swan
E4A	Lake Clifton Project	Apr-79	382823	6340530	17.34	29	Superficial Swan
E4B	Lake Clifton Project	May-79	382823	6340530	17.38	15	Superficial Swan
E4C	Lake Clifton Project	May-79	382823	6340530	17.40	5	Superficial Swan
E5A	Lake Clifton Project	May-79	384091	6340760	14.03	6	Superficial Swan
E5B	Lake Clifton Project	May-79	384091	6340760	13.90	6	Superficial Swan
E6	Lake Clifton Project	May-79	385089	6341048	23.79	8	Superficial Swan
E7	Lake Clifton Project	May-79	385939	6340748	17.91	4	Superficial Swan
F1	Lake Clifton Project	Feb-79	378293	6331480	4.45	NA	Superficial Swan
F2A	Lake Clifton Project	Feb-79	379089	6331548	2.52	10	Superficial Swan
F2B	Lake Clifton Project	Feb-79	380806	6331542	2.63	NA	Superficial Swan
F3	Lake Clifton Project	Oct-79	380080	6331533	8.26	NA	Superficial Swan
F4	Lake Clifton Project	Feb-79	380935	6331543	11.85	NA	Superficial Swan
F5	Lake Clifton Project	Feb-79	381817	6331431	7.24	NA	Superficial Swan
F8	Lake Clifton Project	Jan-79	384739	6331648	14.33	1	Superficial Swan
G2A	Lake Clifton Project	Nov-78	379444	6328506	4.66	7	Superficial Swan
G2B	Lake Clifton Project	Nov-78	379444	6328506	4.66	4	Superficial Swan
G3B	Lake Clifton Project	Nov-78	380489	6328598	5.08	25	Superficial Swan
G3C	Lake Clifton Project	Nov-78	380489	6328598	4.03	15	Superficial Swan
G4	Lake Clifton Project	Nov-78	381360	6328530	12.99	17	Superficial Swan
G5	Lake Clifton Project	Nov-78	382454	6328081	8.54	7	Superficial Swan
G6	Lake Clifton Project	Nov-78	383437	6328185	39.10	11	Superficial Swan
F9A	Lake Clifton Project	Jun-97	381139	6333148	8.68	14	Superficial Swan
F9C	Lake Clifton Project	Jun-97	381139	6333148	8.69	14	Superficial Swan
FL+L ARMSTRONG BORE A	Private Bore	Jan-00	381764	6347293	3.47	13	NA
FL+L.ARMSTRONG BORE I	Private Bore	Jan-77	380959	6345688	3.76	13	NA
G.C.SMITH + SON BORE G	Private Bore	Jan-77	379819	6326918	4.95	NA	NA
G.J.ELLIS BORE A	Private Bore	Jan-77	375384	6372168	2.97	13	NA
G.J.ELLIS BORE B	Private Bore	Jan-77	375749	6372188	3.36	13	NA
HL1B1	Harvey Line	Apr-83	378672	6357451	2.33	25	Leederville
HL1B2	Harvey Line	Apr-83	378672	6357451	2.22	265	Cockleshell Gully
HL2A1	Harvey Line	Jun-83	384924	6356859	13.71	13	Leederville
HL2A2	Harvey Line	Jun-83	384940	6356879	13.84	13	Cockleshell Gully
HL2W	Harvey Line	Nov-82	384940	6356879	13.18	25	Superficial Swan
HL2X	Harvey Line	Oct-08	384915	6356860	13.62	2	NA
HL2Y	Harvey Line	Oct-08	384910	6356860	13.66	2	NA
HLIW	Harvey Line	Nov-82	378708	6357462	1.77	13	Superficial Swan
HS 11A	Harvey Shallow Project	Jun-82	386439	6343991	19.11	26	Superficial Swan
HS 11B	Harvey Shallow Project	Jun-82	386439	6343991	19.09	3	Superficial Swan
HS 13A	Harvey Shallow Project	Jun-82	386410	6348827	20.91	27	Superficial Swan
HS 13B	Harvey Shallow Project	Jun-82	386410	6348827	20.88	6	Superficial Swan
HS 15A	Harvey Shallow Project	May-82	386289	6352491	20.23	25	Superficial Swan
HS 15C	Harvey Shallow Project	May-82	386289	6352491	20.12	2	Superficial Swan
HS 15D	Harvey Shallow Project	Dec-82	386289	6352491	19.76	23	Superficial Swan
HS 62B	Harvey Shallow Project	Oct-82	377710	6372224	3.76	16	Superficial Swan

DoW Monitoring Bore Data

AQWABase Bore Name	AWRC Context Name	Date Drilled	Easting (m MGA)	Northing (m MGA)	TOC Elevation (m AHD)	Distance To Top of Slots (m bgl)	Aquifer
HS 62C	Harvey Shallow Project	Oct-82	377710	6372224	3.81	2	Superficial Swan
HS 63A	Harvey Shallow Project	Oct-82	381783	6362356	8.32	22	Superficial Swan
HS 63B	Harvey Shallow Project	Oct-82	381783	6362356	8.39	13	Superficial Swan
HS 63C	Harvey Shallow Project	Oct-82	381783	6362356	8.32	2	Superficial Swan
HS 64A	Harvey Shallow Project	Nov-82	381904	6352254	17.55	29	Superficial Swan
HS 64B	Harvey Shallow Project	Nov-82	381904	6352254	17.57	13	Superficial Swan
HS 64C	Harvey Shallow Project	Nov-82	381904	6352254	17.57	25	Superficial Swan
HS 8A	Harvey Shallow Project	Nov-82	386352	6338076	19.35	27	Superficial Swan
HS 8B	Harvey Shallow Project	Nov-82	386352	6338076	19.34	18	Superficial Swan
HS 8C	Harvey Shallow Project	Nov-82	386352	6338076	19.35	5	Superficial Swan
J.C.LEWIS BORE C	Private Bore	Jan-77	379419	6331903	2.76	NA	NA
L.SUMICH + SONS BORE A	Private Bore	Jan-77	381454	6340623	6.72	NA	NA
L+R.ARMSTRONG BORE B	Private Bore	Jan-77	381094	6345148	4.26	13	NA
R.V.ARMSTRONG BORE I	Private Bore	Jan-77	375839	6370838	2.87	13	NA
ROSE BORE A	Private Bore	Jan-77	380259	6344073	2.67	13	NA
ROSE BORE G	Private Bore	Jun-66	380219	6343068	2.96	13	NA
ROSE BORE M	Private Bore	Jan-77	380364	6341328	3.22	13	NA
ROSE BORE O	Private Bore	Jan-77	380994	6341278	3.83	13	NA
T.SOWDEN	Private Bore	Jan-77	376484	6368968	0.21	13	NA
Y1-1A	Yalgorup Lakes NLP	Oct-95	370541	6382278	11.90	17	Superficial Swan
Y1-3A	Yalgorup Lakes NLP	Oct-95	373875	6382578	4.81	15	Superficial Swan
Y1-4A	Yalgorup Lakes NLP	Oct-95	374722	6382608	1.68	8	Superficial Swan
Y2-1A	Yalgorup Lakes NLP	Oct-95	372125	6375479	5.10	13	Superficial Swan
Y2-1B	Yalgorup Lakes NLP	Oct-95	372125	6375477	5.20	4	Superficial Swan
Y2-2A	Yalgorup Lakes NLP	Oct-95	372833	6375707	1.62	7	Superficial Swan
Y2-2B	Yalgorup Lakes NLP	Oct-95	372832	6375707	1.71	NA	Superficial Swan
Y2-4A	Yalgorup Lakes NLP	Oct-95	374981	6376153	12.12	20	Superficial Swan
Y2-4B	Yalgorup Lakes NLP	Oct-95	374983	6376152	12.14	14	Superficial Swan
Y2-5A	Yalgorup Lakes NLP	Oct-95	376065	6376171	37.80	46	Superficial Swan
Y2-5B	Yalgorup Lakes NLP	Oct-95	376063	6376170	37.93	38	Superficial Swan
Y2-6B	Yalgorup Lakes NLP	Nov-95	376359	6376212	1.97	NA	Superficial Swan
Y3-1A	Yalgorup Lakes NLP	Oct-95	376929	6366460	1.82	10	Superficial Swan
Y3-1B	Yalgorup Lakes NLP	Oct-95	376928	6366461	1.83	0	Superficial Swan
Y3-2A	Yalgorup Lakes NLP	Oct-95	377477	6366783	4.13	17	Superficial Swan
Y3-2B	Yalgorup Lakes NLP	Oct-95	377477	6366781	4.12	11	Superficial Swan
Y3-3A	Yalgorup Lakes NLP	Oct-95	378497	6366676	25.99	41	Superficial Swan
Y3-3B	Yalgorup Lakes NLP	Oct-95	378501	6366677	26.10	35	Superficial Swan
Y3-4A	Yalgorup Lakes NLP	Oct-95	380532	6366757	5.30	17	Superficial Swan
Y3-4B	Yalgorup Lakes NLP	Oct-95	380532	6366759	5.34	10	Superficial Swan
Y4-1A	Yalgorup Lakes NLP	Oct-95	379647	6340462	1.11	7	Superficial Swan
Y4-2A	Yalgorup Lakes NLP	Oct-95	380964	6340502	6.15	16	Superficial Swan
Y4-3B	Yalgorup Lakes NLP	Oct-95	381889	6340518	6.67	14	Superficial Swan
Y4-3C	Yalgorup Lakes NLP	Oct-95	381889	6340518	6.66	9	Superficial Swan
Y4-4B	Yalgorup Lakes NLP	Oct-95	382823	6340530	17.53	25	Superficial Swan
Y4-5A	Yalgorup Lakes NLP	Oct-95	384090	6340607	12.75	22	Superficial Swan

Figure AI-1



360.0/Surfer/09-01 Rpt/Hydrograph Bore Locations.srf

CLIENT: Department of Environment and Conservation

PROJECT: Dawesville to Binningup Hydrogeology Study

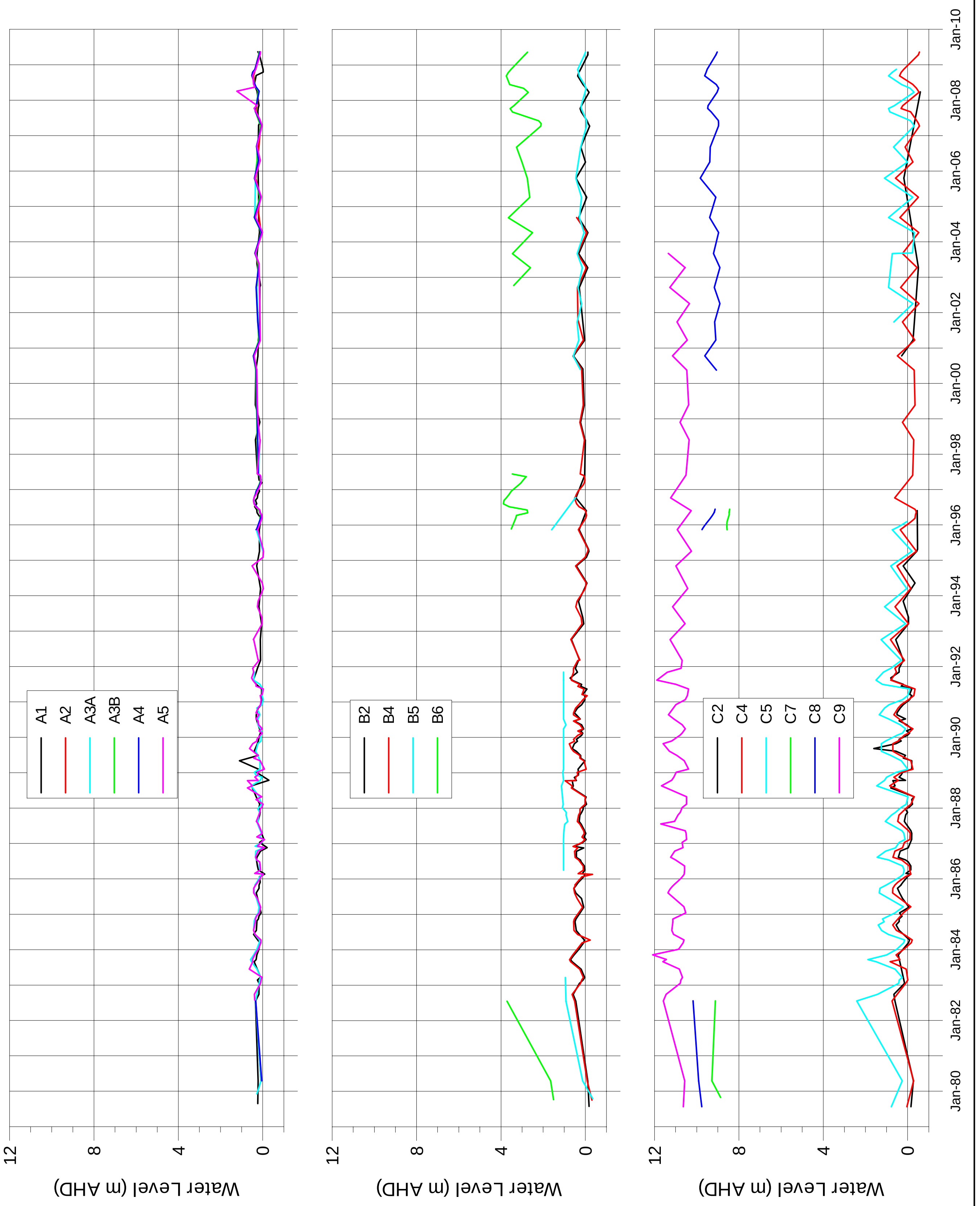
DATE: September 2009

Dwg. No: 360.0/09/01-AI-1

HYDROGRAPH BORE LOCATIONS

Rockwater PROPRIETARY LIMITED

Figure AI-2



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Client: Department of Environment and Conservation

Project : Dawsville to Binningup Hydrogeology Study

Date : September 2009

Dwg. No: 360.0/09/1-AI-2

LAKE CLIFTON PROJECT
LINES A–C BORES
HYDROGRAPHS

Rockwater PROPRIETARY LIMITED

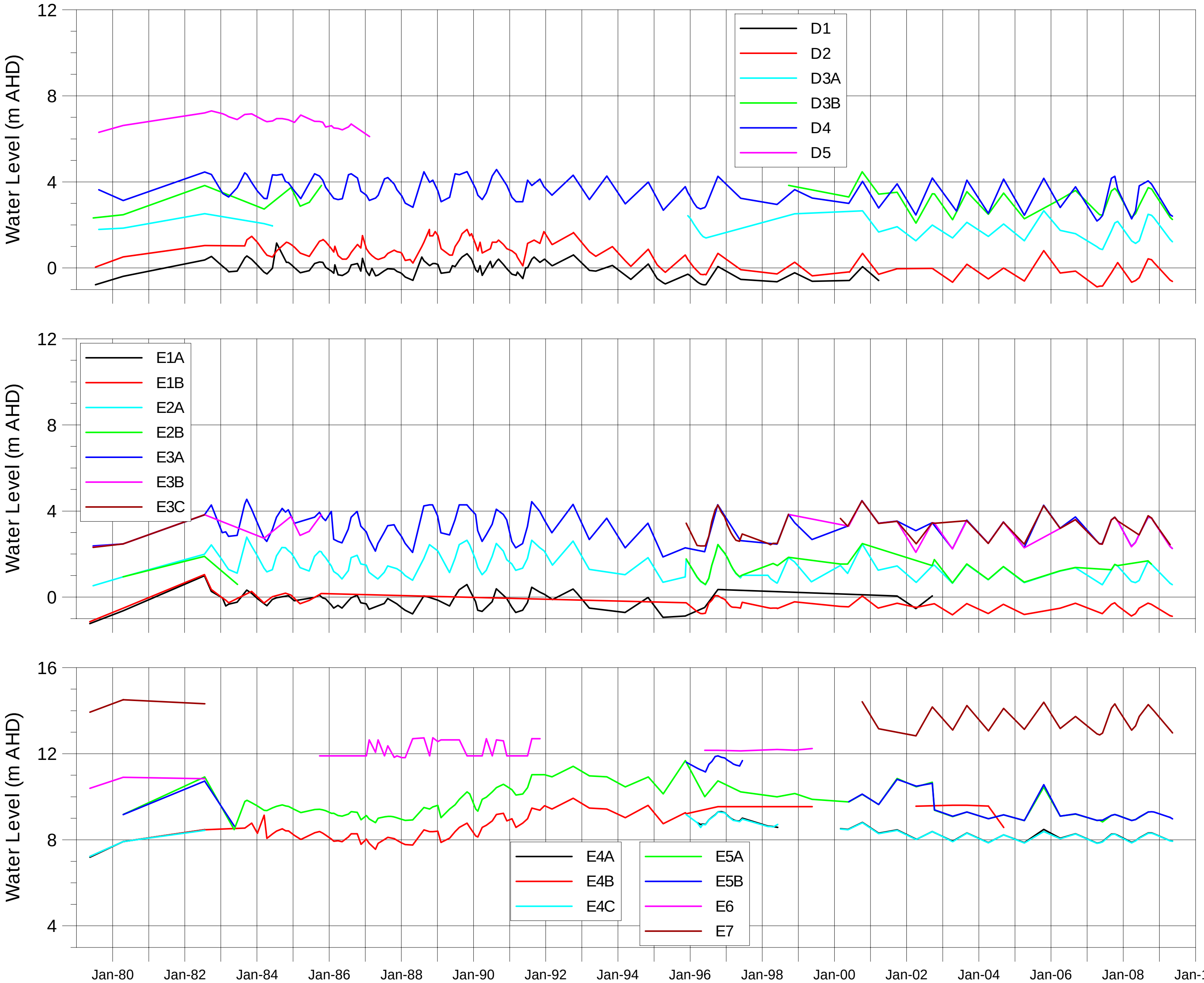

Figure AI-3

LAKE CLIFTON PROJECT
LINES D–E BORES
HYDROGRAPHS

I:/360.0/Grapher/09-01 Rpt/App I/Lake Clifton Lines D-E.grf

Client: Department of Environment and Conservation

Project : Dawsville to Binningup Hydrogeology Study

Date : September 2009

Dwg. No: 360.0/09/1-AI-3

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Client: Department of Environment and Conservation

Project : Dawsville to Binningup Hydrogeology Study

Date : September 2009

Dwg. No: 360.0/09/1-AI-4

I:/360.0/Grapher/Rpt 09-01/APP I/Lake Clifton Lines F-G.grf

LAKE CLIFTON PROJECT LINES F-G BORES HYDROGRAPHS

Rockwater

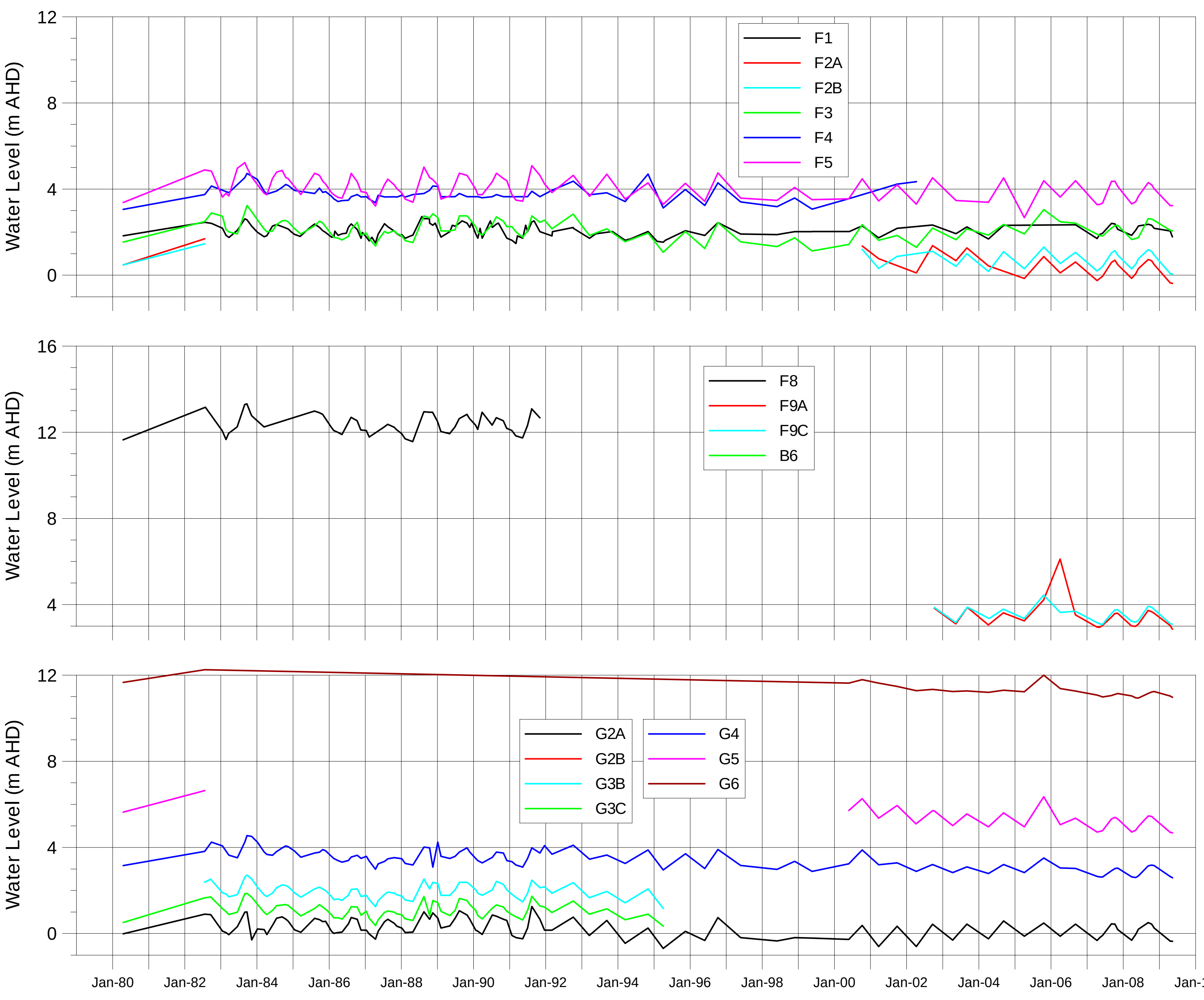
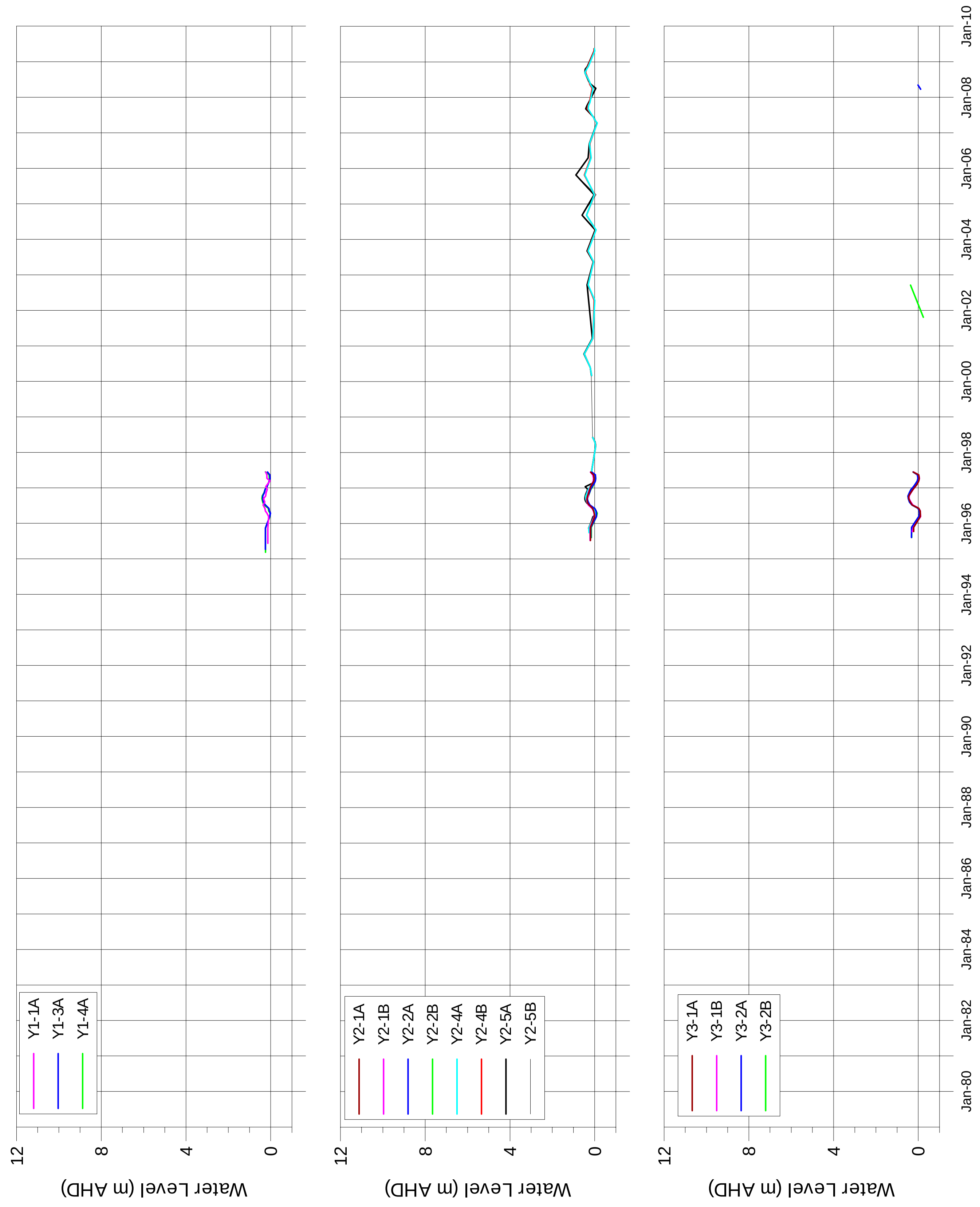


Figure AI-4

Figure AI-5



I:/360.0/Grapher/09-01 Rpt/App I/Yalgorup Lakes.grf

Client: Department of Environment and Conservation Project : Dawsville to Binningup Hydrogeology Study Date : September 2009 Dwg. No: 360.0/09/1-AI-5	YALGORUP LAKES BORES Y1 to Y3-2B HYDROGRAPHS Rockwater PROPRIETARY LIMITED

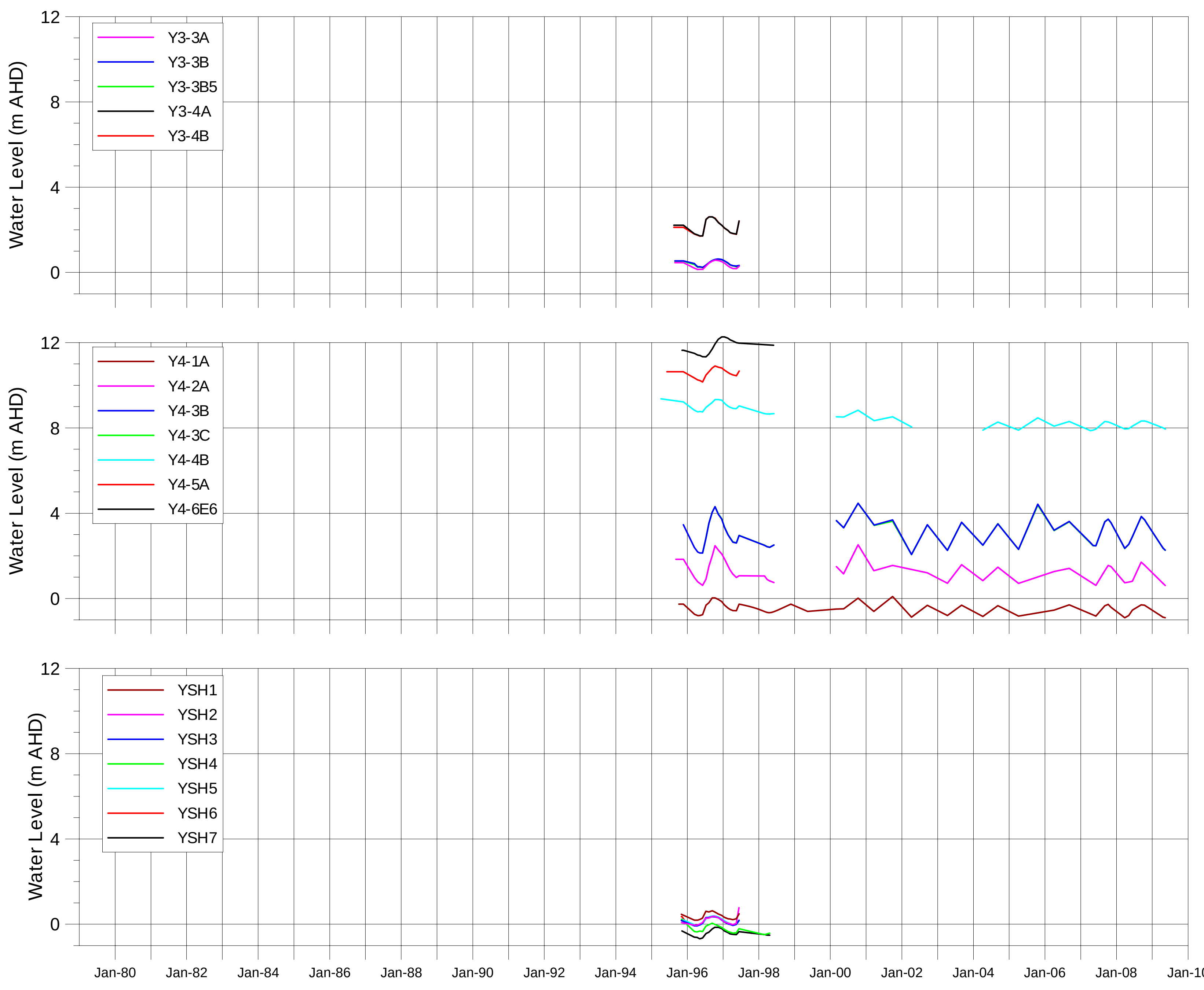


Figure AI-6

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Client: Department of Environment and Conservation

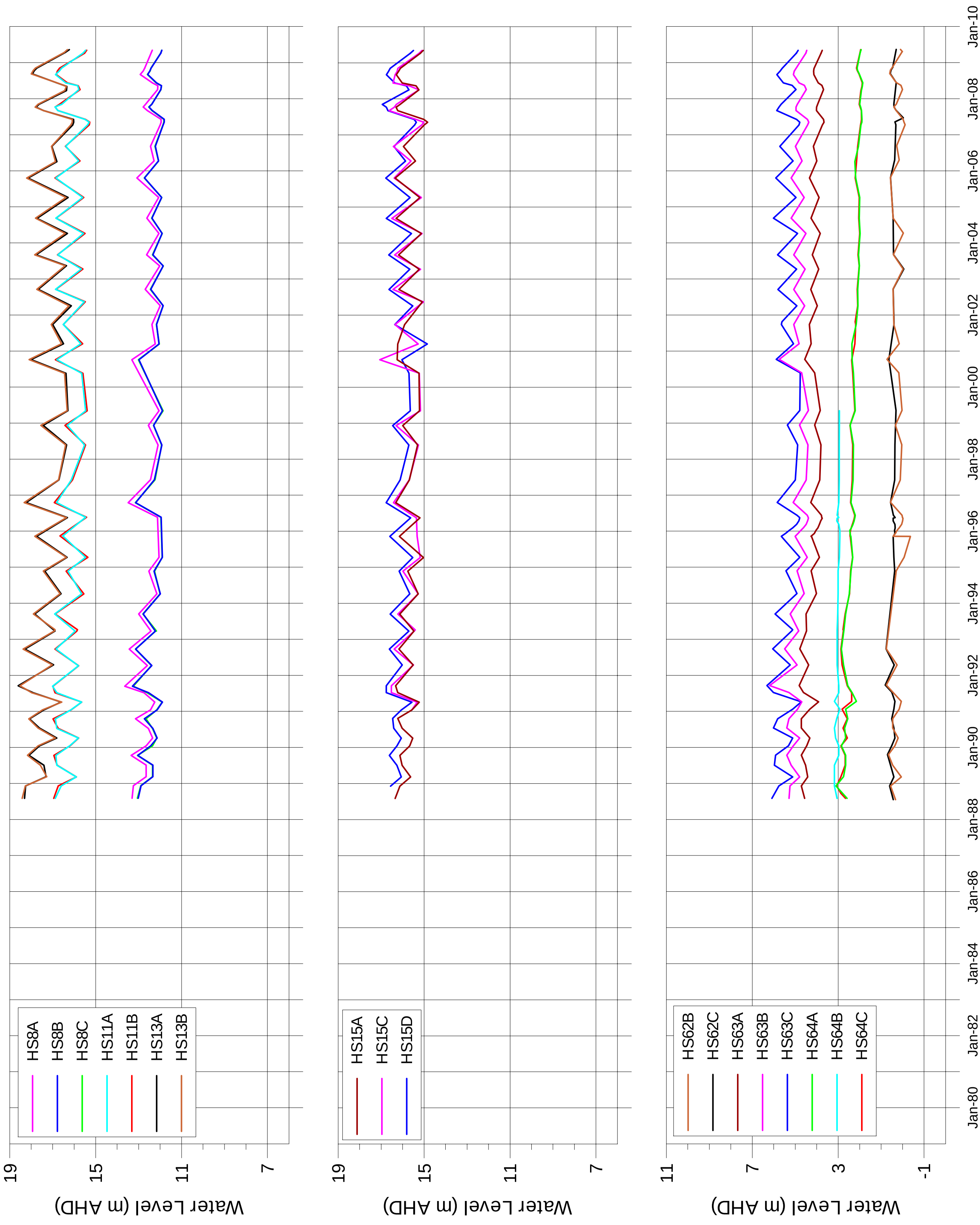
Project : Dawsville to Binningup Hydrogeology Study

Date : September 2009

Dwg. No: 360.0/09/1-AI-6

YALGORUP LAKES BORES
Y3-3A to Y3-4B, Y4-1A to Y4-6E6 & YSH1-7
HYDROGRAPHS

Figure AI-7



I:/360.0/Grapher/09-01 Rpt/App I/Harvey Shallow..grf

Client: Department of Environment and Conservation

Project : Dawsville to Binningup Hydrogeology Study

Date : September 2009

Dwg. No: 360.0/09/1-AI-7

HARVEY SHALLOW PROJECT: SOME BORES ON LINES 8, 11, 13, 15, 62 - 64 HYDROGRAPHS

Rockwater PROPRIETARY LIMITED

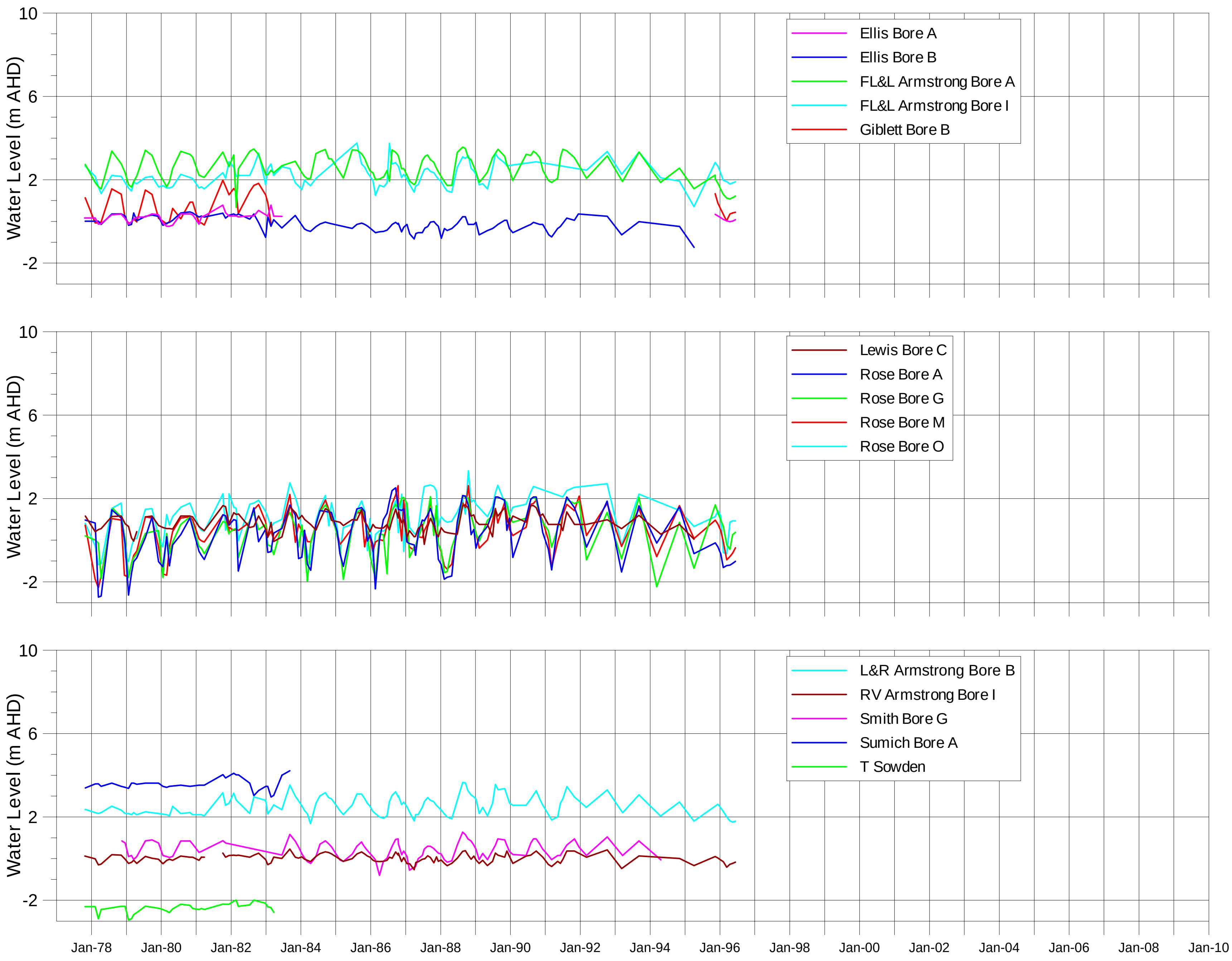


Figure AI-8

I:/360.0/Grapher/09-01 Rpt/App I/SW Coastal GW Area.grf

Client: Department of Environment and Conservation

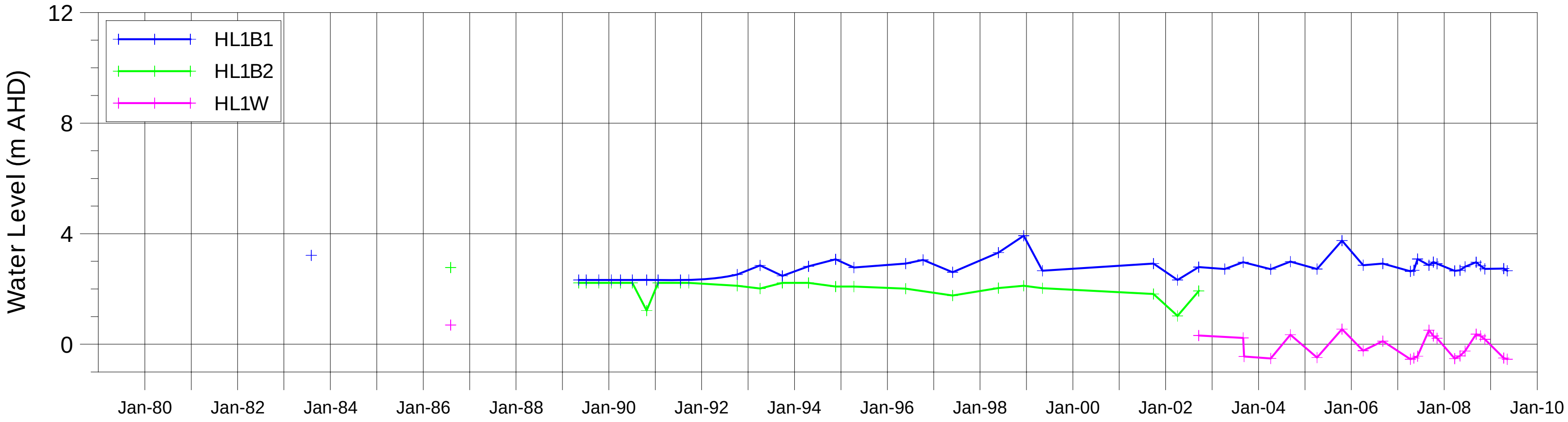
Project : Dawsville to Binningup Hydrogeology Study

Date : September 2009

Dwg. No: 360.0/09/1-AI-8

SW COASTAL GW AREA
SELECTED BORE
HYDROGRAPHS

Rockwater



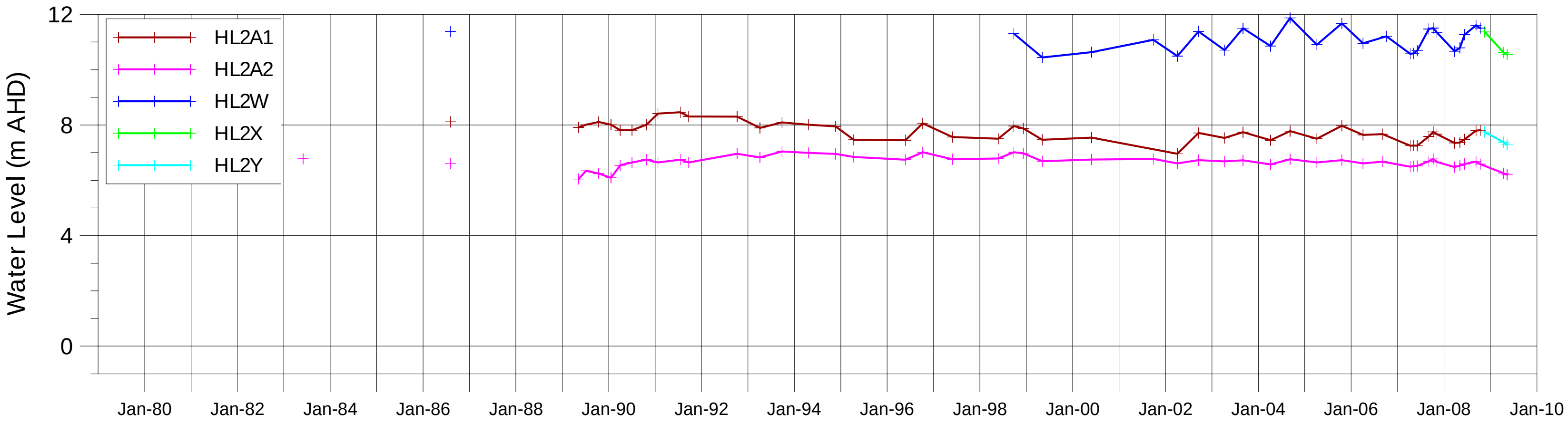


Figure AI-9

I:/360.0/Grapher/09-01 Rpt/App I/Harvey Line 1&2.grf

Client: Department of Environment and Conservation

Project : Dawsville to Binningup Hydrogeology Study

Date : September 2009

Dwg. No: 360.0/09/1-AI-9

HARVEY LINE SITES 1 & 2 HYDROGRAPHS

Rockwater