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Development of EWRs in a Complex Hydrogeological Setting and High Biodiversity Environment

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EXECUTIVE SUMMARY

The Blackwood Groundwater Area is underlain by a complex and extensive aquifer system that potentially supports numerous groundwater dependent ecosystems (GDEs).

The preliminary identification of GDEs was based initially on geology, landforms, soils, hydrogeology and ecological components and then refined by field inspections. The GDEs were then dependency ranked and grouped into the following categories: wetlands; riparian systems; flora; fauna; vegetation; ecological processes (e.g. acid sulphate soils); estuarine and near-shore marine areas; and significant areas (proposed national parks).

Interim (R2) EWRs (ecological water requirements) were then determined and subsequently baseline surveys and monitoring programs have been designed to allow the refinement of interim EWRs (adaptive management) in the short term.

INTRODUCTION

The Blackwood Groundwater Area (Figure 1), located in the southwest of Western Australia, is underlain by a complex and extensive aquifer system that potentially supports numerous groundwater dependent ecosystems (GDEs). It has been estimated that the Yarragadee Formation aquifer system contains about 400 km³ (or 40 Lake Argyles) of potable (salinity less than 500 mg/L) groundwater, which represents a potential future water supply for the Perth Metropolitan Area. This latter fact has increased the urgency for EWR definition in the Blackwood Groundwater Area.

In a drying climate, competition for groundwater by ecosystems, agriculture and domestic consumption is becoming intense and the determination of EWRs is vital in recognising the long-term sustainability of these ecosystems. Future groundwater abstraction from aquifers and reduced rainfall and recharge can directly or indirectly cause groundwater level decline in aquifer systems that may support these ecosystems.

The Yarragadee Formation outcrop and subcrop areas support numerous GDEs (Terrestrial and Riparian Vegetation) where the water table or upper potentiometric surface (when confined) is near enough to ground surface to support these systems. Riverine systems (in-stream GDEs) also rely on groundwater discharge from the formation.

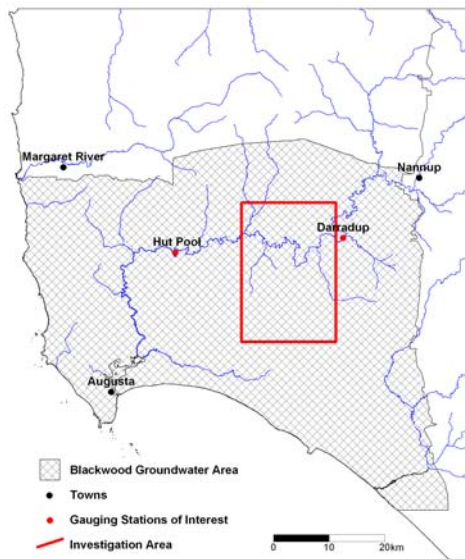


Figure 1 Location of the Blackwood Groundwater Area

SURFACE HYDROLOGY, PHYSIOGRAPHY AND RAINFALL

The Blackwood River system is a significant component of the drainage system for the south west of Western Australia (catchment area $2.3 \times 10^4 \text{ km}^2$) and extends 300 km inland from the river mouth at Augusta inland past Nannup, Bridgetown and Boyup Brook (Figure 1). The lower catchment extends from Nannup to Augusta and includes the Blackwood Plateau, Donnybrook Sunklands and Leeuwin Block Zone. The upper catchment is the catchment east of Nannup, including the Darling Range, Zone of Rejuvenated Drainage, and Zone of Ancient Drainage (Grien 1995). The Lower Blackwood River is tidal and receives estuarine water up to 42 km from the mouth.

Topography varies from 0-50 mAHD along the flat low-lying Scott Coastal Plain to the south, rising to 100-200 mAHD in the north and east through the undulating landscape of the Blackwood Plateau. Average rainfall in the area varies from 1,200 mm/year at Augusta to 1,000 mm/year at Nannup (Figure 1). This area is considered to be part of the “Intermediate Rainfall Zone”, characterised by moderate concentrations of salt stored in the landscape and potentially saline groundwater. Land use in the Donnybrook Sunklands covers a range of broadacre cropping and grazing activities, intensive horticulture, viticulture, dairying, forestry and tourism.

Blackwood River Stream Flow

Stream flow in the Blackwood River is strongly seasonal. Winter stream flows, mainly as a result of rainfall-runoff, occur between June and November. During summer, flow (i.e.

baseflow) is strongly influenced by groundwater discharge from shallow aquifers and the Leederville and Yarragadee Formations.

Gauging station 609019 (Hut Pool) is located 43 km upstream from the river mouth and downstream of the Yarragadee aquifer outcrop areas in the Blackwood River valley (Figure 1). Gauging station 609025 (Darradup) is 107 km upstream of the river mouth, 64 km upstream of the Hut Pool gauging station, and upstream of the Yarragadee aquifer outcrop areas.

The magnitude of baseflow is poorly defined for the Lower Blackwood River. The estimation of average baseflow (Table 1), gives some indication of the total baseflow along a 64 km river reach between the two stations, however, these data are not detailed enough to derive the contribution of groundwater flows from the Yarragadee Formation into the Blackwood River.

Table 1 Stream Flow In The Lower Reaches of The Blackwood River

Month	Station 609019 (Hut Pool)				Station 009613 (Warner Glen BOM)	Station 609025 (Darradup)		Station 009585 (Nannup BOM)
	Observed Stream Flow (GL/mth)	Estimated Baseflow (GL/mth)	Observed Total Stream Flow Salinity (mg/L)	Estimated Baseflow Salinity (mg/L)	Average Rainfall (mm)	Observed Stream Flow (GL/mth)	Estimated Baseflow (GL/mth)	Average Rainfall (mm)
Jan	3.4	3.4	1,860	1,860	10.5	1.6	1.6	10.4
Feb	2.4	2.4	1,041	1,041	19.8	1.1	1.1	16.7
Mar	4.3	3.4	2,853	1,000	29.1	3.1	2.4	27.5
Apr	4.9	3.2	1,065	900	44.1	3.0	2.0	41.3
May	7.8	2.9	874	800	132.8	6.2	2.3	115.7
Jun	38.1	3.2	2,000	700	175.0	36.3	3.0	143.7
Jul	130.6	4.6	2,760	700	191.5	129.4	4.6	158.9
Aug	175.1	5.4	1,926	700	143.1	156.7	4.9	136.2
Sep	133.2	5.2	1,906	700	113.1	117.0	4.6	92.9
Oct	51.5	4.4	1,532	750	61.2	36.9	3.1	59.7
Nov	18.7	4.1	1,415	800	42.9	11.0	2.5	38.0
Dec	7.0	3.6	1,590	900	18.7	4.0	2.0	27.1
Sum (GL/yr)	576.9	45.9			981.6	506.1	34.0	868.0
Average (GL/mth)			1,735	904				
Baseflow contribution between Hut Pool & Darradup (GL/yr)							11.8	

Note: Record length is 15 years (1984-1998).

A sampling transect was undertaken by the Water & Rivers Commission in March 2003 to help characterise the variation in baseflow along the river reach between Darradup and Hut Pool. Stream flow was recorded at 8 sites and water salinity at 21 sites. There was no runoff contribution to stream flow at the time of sampling.

The contribution of groundwater discharge from the Yarragadee Formation along the reach was estimated by extrapolation, using the observed stream flows and length of outcrop. The length of Yarragadee Formation outcrop is about 15 km. Stream flows over this section increased about 0.8 GL/km of river reach/year, or 11.5 GL/year. The entire 64 km added about 0.3 GL/km of river reach/year, or 20.5 GL/year. Accordingly, the Yarragadee Formation groundwater contribution to the total baseflow in the reach is 56%. The total reach contribution of 20.5 GL is higher than the longer-term average from the gauging stations (11.5 GL/year) - a result of seasonal variation.

GEOLOGY

The stratigraphy of the Blackwood Plateau and the Scott Coastal Plain is provided in Table 2. Previous groundwater investigations in this area are shown in the references.

Table 2 Stratigraphy of the Blackwood Plateau and the Scott Coastal Plain. After Baddock (1995).

Age	Formation	Maximum Thickness penetrated (m)	Lithology
CAINOZOIC			
Quaternary			
(Holocene)	Alluvium, lake and swamp deposits Safety Bay Sand	9	Sand, clay, peat
Late Pleistocene	Tamala Limestone	16	Sand, limestone
Middle Pleistocene	Guildford Formation	15	Sand
Early Pleistocene	Yoganup Formation	-	Sand, clay
UNCONFORMITY			
Tertiary			
(Middle Eocene)	Formation undifferentiated	6	Sand, clay
MESOZOIC			
Cretaceous			
(Early)	Warnbro Group	235	Clay, sand, coal
	Bunbury Basalt	103	Basalt
UNCONFORMITY			
Jurassic	Parmelia Formation	167	Shale, sand
(Late Jurassic)			
(Middle Jurassic)	Yarragadee Formation	1,252	Sand, shale
(Early Jurassic)	Cockleshell Gully Formation	775	Shale, sand
Triassic			
	Lesueur Sandstone	860	Sandstone
	Sabina Sandstone	120	Sandstone, clay
PALAEOZOIC			
Permian	Sue Coal Measures	455	Siltstone, shale, sandstone, coal

GROUNDWATER GEOLOGY

Within all formations (except the Bunbury Basalt) under these areas, aquifer zones occur in the sand or sandstone units, which can be very permeable and thick in the Yarragadee Formation and (to a lesser extent) the Leederville Formation (Warnbro Group). These aquifers can yield significant volumes of groundwater to bores and are prospective sources of water supply.

The shales, siltstones and clays in the stratigraphic successions are aquitards that restrict the vertical and lateral flow of groundwater and limit the vertical hydraulic connection between aquifers.

In an east-west direction, the sediments under the areas are divided into a series of north-south trending fault blocks. The hydraulic nature of these faults is not fully understood. In some areas, where sandstones are in contact between adjacent blocks, the faults will be permeable and allow horizontal groundwater movement between fault blocks. In other areas, shales and sandstones may be in contact across block contacts and the faults will be of a low permeability and restrict the horizontal movement of groundwater.

Groundwater Flow and Movement

The hydrogeology of the Blackwood Plateau and Scott Coastal Plain has been previously described by Baddock (1994, 1995), Appleyard (1991) and Water Corporation (2003, *in prep*). For the purpose of this paper, only the hydrogeological aspects of the Yarragadee Formation are described.

The uppermost potentiometric head (confined) and water table (outcrop areas) in the Yarragadee Formation and the surface geology near the Blackwood River are presented in Figure 2. A groundwater mound is located south of the Blackwood River and there is radial groundwater flow towards the Blackwood River valley, where groundwater discharge occurs in an area of depressed groundwater levels.

Recharge to the Yarragadee Formation is commonly via: (i) direct precipitation in outcrop areas under the Blackwood Plateau; and (ii) small subcrop and outcrop areas in the Scott Coastal Plain. Where the formation outcrops in the Blackwood River valley, temporary, short-term recharge may occur from stream flow in the Blackwood River during large, high-level winter flows. Indirect recharge is via downward leakage from the overlying superficial formations and Warnbro Group. An area of "perched" groundwater (Water Corporation, 2003) also occurs in the overlying formations and results in an unsaturated zone at the top of the Yarragadee Formation, suggesting that the overlying Warnbro Group at that location has a low vertical hydraulic conductivity, resulting in limited recharge.

Groundwater Levels

Groundwater level trends in the Yarragadee Formation have been established (Gilgallon, 2003) and are relatively stable under the Scott Coastal Plain, with an average seasonal variation of 0.5m to 1.5m. On the Blackwood Plateau, the Karridale line of bores exhibited declining groundwater level trends of 0.3m to 3m between 1989 and 2002, with no apparent seasonal fluctuations.

The depth (below ground surface) to the upper potentiometric head in the Yarragadee Formation in the Blackwood River Valley was calculated by subtracting the upper Yarragadee heads from the digital elevation model (Water Corporation, 2003) for the area (Figure 3) and is shallow (less than 15m) under the Blackwood River and some of the small tributaries that extend up to 5kms from the main channel of the Blackwood River.

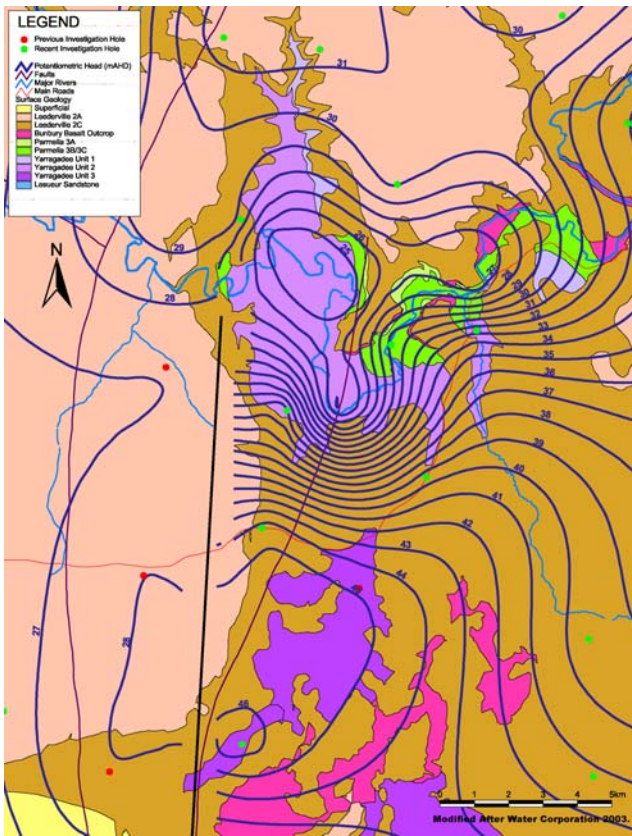


Figure 2 Surface Geology and Upper Potentiometric Head in Yarragadee Formation.

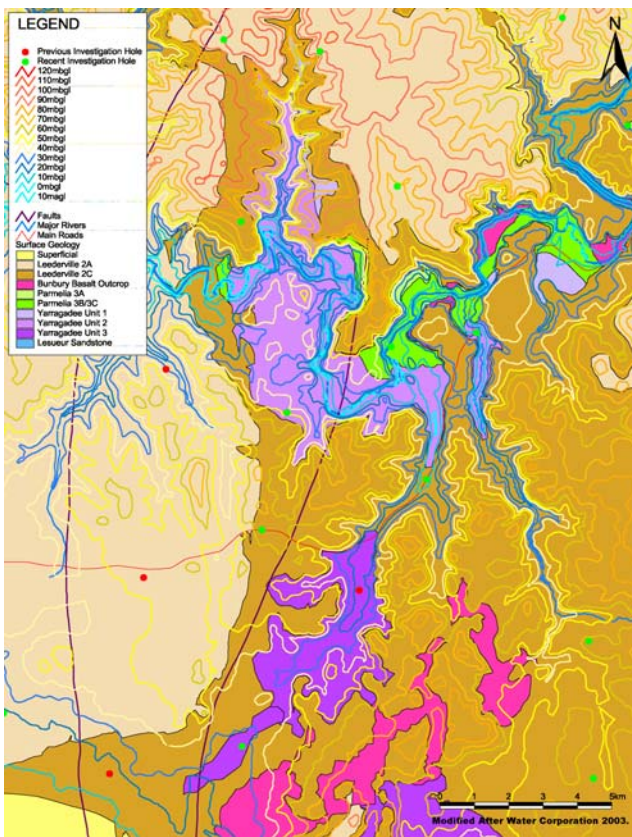


Figure 3 Surface Geology and Yarragadee Formation Depth Below Ground Surface.

ECOLOGICAL DESCRIPTION

Flora and Terrestrial Vegetation

A total of 1486 taxa from some 100 families and 408 genera have been recorded to date. Of these, some 112 taxa are introduced species and this, in part, reflects the degree of human and agricultural activities (Mattiske Consulting, 2003).

For the purposes of GDE and EWR determinations, System 6 mapping by Heddle *et al.* (1980) and Mattiske and Havel (1998) was used because these studies have expanded on the relationships between the underlying geomorphology; the landform and soils; and the resulting vegetation.

As defined by the Wildlife Conservation Act (1950), one Rare (listed as endangered under the EPBC Act 1999), one Priority 1, two Priority 2, three Priority 3 and one Priority 4 flora taxon are currently known to exist within the Yarragadee Formation areas near the Blackwood River. Of the eight rare and priority taxon, 2 are highly dependent, 4 moderately dependent and 2 have a low dependency on groundwater.

Riverine and Riparian Vegetation

Vegetation along the banks of the Blackwood River contain fringing woodland of *Eucalyptus rudis* flanked by tall open forest of *Corymbia calophylla* and *Eucalyptus patens* over *Banksia seminuda*, *Paraserianthes lophantha* subsp. *lophantha* with *Taxandria linearifolia*, *Trymalium floribundum*, *Gahnia trifida* and *Lepidosperma squamatum* on valley floors (Mattiske Consulting, 2003).

Wetland and Phreatophytic Vegetation

The term “wetlands” describes wetlands (damplands and sumplands), floodplain depressions, water-bodies (albeit at times temporary) and lakes within this paper. They have been mapped and described previously by the Semeniuk Research Group (1997). Four wetlands were found within the Yarragadee Formation outcrop area.

Freshwater Fish

In a survey of freshwater fish in south-western Australia (Morgan *et al.*, 1998) a total of eight species of fish were collected/observed from the Blackwood River that include *Tandanus bostocki* (Freshwater Cobbler); *Galaxias occidentalis* (Western Minnow); *Bostockia porosa* (Nightfish); *Leptatherina wallacei* (Hardey Head); *Pseudogobius olorum* (Goby); *Afurcagobius suppositus* (Goby) including the introduced species *Gambusia holbrooki* (Mosquitofish) (University of Western Australia, 2003).

Frogs

Four of the sixteen species of frogs present in the area are of conservation significance (West Australian Museum Fauna List, 2003). These species include *Geocrinia alba* (White-Bellied Frog), *Geocrinia vittelina* (Orange-Bellied Frog) (CS1), *Geocrinia rosea* (Roseate Frog) and *Metacrinia nichollsi* (Nicholls' Toadlet).

Reptiles

Four of the forty-three species of reptiles present in the area are of conservation significance (West Australian Museum FaunaList, 2003). These species include *Morelia spilota imbricata* (Carpet Python), *Egernia pulchra* (skink), *Glaphyromorphus gracilipes* (skink) and *Elaphognathus minor* (Short-Nosed Snake).

Birds

A total of 160 species of birds may be present in the Blackwood Groundwater area, with a further 6 locally extinct species. The majority of species of conservation significance are listed as migratory under conservation agreements and acts and are only infrequent visitors. However, there are some threatened waterbirds (bitterns) that may use seasonal wetlands in all areas. In addition, there are threatened owls and cockatoos, also located in the area (Bamford Consulting Ecologists, 2003).

Mammals

Thirty-four mammal species may be present in the Blackwood Groundwater area. Seven of these are introduced and a further five species are locally extinct. A high proportion of native mammals are of conservation significance, as defined at the Federal level under the EPBC Act (1999), at the State level by the Wildlife Conservation Act (1950), by Maxwell *et al.*, (1986) and Duncan *et al.* (1999).

Macroinvertebrate Fauna

Six species of macroinvertebrate fauna are located within the Blackwood River and its tributaries (University of Western Australia, 2003).

Threatened Ecological Communities

There are no threatened ecological communities (TECs) known within the Yarragadee outcrop areas, however there are several communities that potentially occur within the Yarragadee outcrop area, typically on one of the tributaries (within Leederville Formation) of the Blackwood River (a proposed TEC).

GROUNDWATER DEPENDANT ECOSYSTEMS

In defining the groundwater and surface water regimes in the project area, it is believed that the Yarragadee Formation may form a single hydro-stratigraphic unit. If this is the case, the hydraulic connection and interaction between groundwater in this formation and the environment is fundamental in determining the locations of all high priority GDEs associated with the Yarragadee Formation.

Any consideration of water regime changes must be in the context of: (i) the wider framework of future lower rainfall, (although not necessarily lowered local water tables); (ii) different influences on the local systems from human activities; and (iii) consequently, the different ecological values.

To some degree, selected flora and fauna species and plant communities will probably be influenced by local water regime changes and many native species, rare species, priority species, endangered species and plant communities appear to be groundwater

dependent. In addressing the delineation of GDEs, it was decided to take a conservative approach by determining the GDEs in a series of areas and sub-areas that reflect inherent differences in geology, geomorphology, landforms, soils, climate and ecological values. The data summarised in the previous section highlight the range of values that exist in the area and as part of the development of the GDEs the water regimes and the influence of these water regimes on the ecological values had to be studied.

Terrestrial GDEs

These vegetation complexes include a range of plant communities that could potentially be GDEs, including: (i) fringing woodlands on the drainage lines and terraces of the main river systems, (ii) woodlands, shrublands, heaths and sedgeland in wetlands and along minor gullies of tributaries, (iii) woodlands, shrublands, heaths and sedgeland in wetlands and seasonally inundated or water-logged areas and (iv) halophytic complexes and woodlands on the fringes of estuarine areas. The different vegetation communities, with a high dependency on groundwater, were defined as fringing vegetation on rivers, minor gullies, and seasonally water-logged (Figure 4). A cross sectional view showing the GDE relationship with the underlying geology and upper potentiometric head within the Yarragadee Formation is presented in Figure 5.

All frogs are likely to be dependent upon groundwater, but the four significant species may be especially dependent because of their breeding biology. However, they may be more reliant on surface water than groundwater. Several other frog species are dependent upon peak water levels for successful breeding (Bamford Consulting Ecologists, 2003).

The majority of reptiles are not groundwater dependent, although the long-term impact of groundwater level changes on upland vegetation may be significant to them (Bamford Consulting Ecologists, 2003).

Over a third of the bird fauna comprises waterbirds that are groundwater dependent, while 10% of species rely on the dense vegetation of wetland margins around streams and wetlands. These include honeyeaters that may rely seasonally on flowering plants close to wetlands (Bamford Consulting Ecologists, 2003). The groundwater dependence of birds in upland habitats is currently unknown.

Only 1 aquatic mammal and 2 closely associated with wetland vegetation occur, but many species tend to be most abundant low in the landscape. The majority of species of conservation significance are groundwater dependent to some degree (Bamford Consulting Ecologists, 2003).

To date, wetlands and macroinvertebrates in the area have not been studied in detail to determine their faunistic values (Edith Cowan University). Vertebrate fauna are considered to be very sensitive to changes in groundwater levels, typically within seasonal wetlands. Interactions of these wetlands with groundwater in the Yarragadee Formation require specific investigations to establish these relationships (i.e. perched or direct connection).

In-Stream GDEs

Macroinvertebrates, like most of the aquatic fauna found within the Blackwood River, are stenohaline, and as such are intolerant to elevated water salinity (University of Western Australia, 2003). With the onset of secondary-salinisation in the upper sections of the

catchment, species may now be restricted to fresher tributaries and localised pools within the Yarragadee Formation outcrop area. Tributaries such as Milyeannup Brook (near the confluence with the Blackwood River) are likely to be refuge areas to aquatic fauna at all times of the year, however water quality sampling and fauna surveys would be required to determine this.

ECOLOGICAL VALUES

The ecological values were assessed on the basis of available information and the likelihood of groundwater level declines impacting on management objectives that are required for: (i) the respective ecological values; (ii) the potential consequences of the impact; and (iii) the risk of the impact occurring. This analysis enabled the grouped ecological values to be ranked as High, Medium or Low and the identification of the key areas that need further investigation.

DETERMINATION OF EWRs

The following process was followed for identifying interim (R2) EWRs – defined as the water regime required to maintain a dependent environment at a low level of risk:

- GDE types were defined within areas and sub-areas,
- Management objectives were defined for the GDE types within each area and sub-area,
- Groundwater attributes were defined for the GDE types within each area and sub-area,
- Conservation and ecological values were determined (as far as practical),
- Degree of groundwater dependency was defined for the respective values and ecosystems,
- Susceptibility of the values to changes in groundwater levels were defined for each GDE type.

GDEs were then ranked on the basis of the integrated ecological values and the degree of significance of these values.

Reducing the amount of groundwater flow to GDEs can lead to a proportional decline in water level and consequently the condition or extent of the GDE values can also decline. The interim EWRs were determined in relation to magnitude, duration and rate of water level and water quality changes.

In the absence of sufficient data for delineating interim EWRs in the Blackwood River area, the criteria defined for the phreatophytic and wetland categories on the Gnangara Mound (about 60 km north of Perth) were utilised (Water Corporation, 2002) as an initial guide for phreatophytic and wetland categories in the study area. This was then modified to define the interim EWRs for the highly-ranked GDEs within these areas. Based on the uncertainty associated with the types of ecosystems in different wetlands throughout the study area, a conservative approach was required to determine threshold values. It was assumed that faunistic values would be maintained if the vegetation values were maintained.

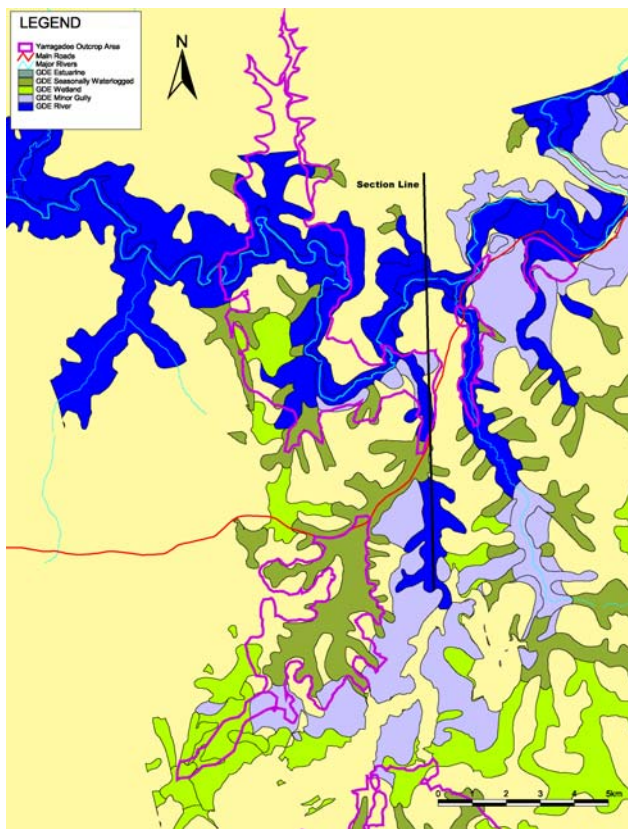


Figure 4 Distribution of GDE Locations.

At a local scale, Yarragadee groundwater discharge contribution may have a disproportionately large impact on stream salinity concentrations in the Blackwood River. The groundwater discharge from the Yarragadee Formation occurs over a short length (15km) and dilutes stream flow salinities over that length. Reducing the amount of fresh groundwater discharge could cause water salinity in that part of the river to increase substantially. Salinity concentrations downstream are not likely to be significantly affected because the contribution of the Yarragadee groundwater discharge to overall stream flows in the Blackwood River is small.

Standard salinity guidelines for river systems (ANZECC/ARMCANZ, 2000) were adopted for the Blackwood River and associated tributaries. An exceedence (median value) of the current 80th percentile is the recommended ANZECC “trigger value” for the assessment of salinity for partly degraded systems. However, this can only be applied where long-term monitoring data are available (e.g. Hut Pool Gauging Station). Using a mass balance approach, the estimated increase in surface water salinity due to a reduction in discharge was determined. Although the greatest increase in water salinity will occur in December and January, it is only minor. In areas where long-term monitoring data do not exist, a conservative approach was used, allowing for an overall increase of 10% in current stream flow salinity. This was based on the average salinity increase at Hut Pool when the 80th percentile was applied to the data. However, in the Blackwood River, there may be fundamental changes in biodiversity and ecological processes at lower levels of variance from this value.

Minimum flow connectivity required for macroinvertebrates is 5cm over riffles and for fish, 20cm over riffle zones during reproductive migrations in the months September to October. At all other times, these levels can be reduced to 5cm (University of Western Australia, 2003).

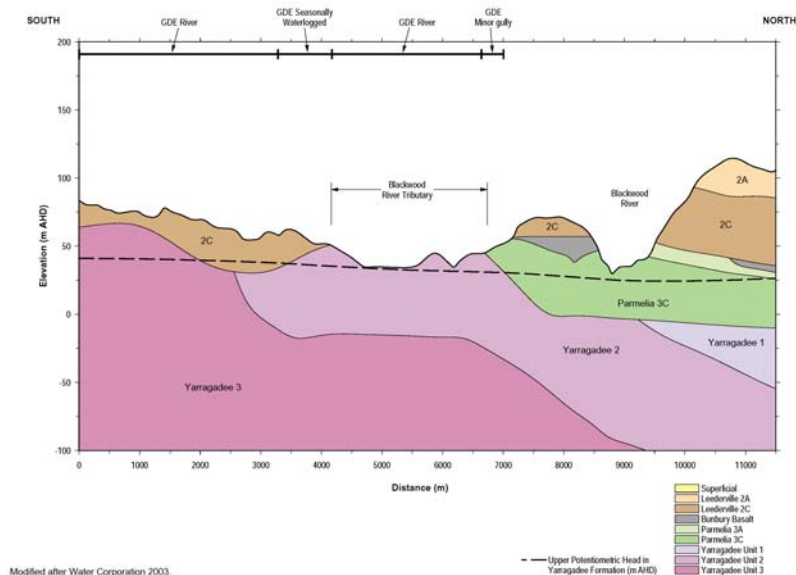


Figure 5 Hydrogeological Relationship to GDEs

Conceptual scenarios for minimum flows across riffle zones were calculated using observed data from Hutt Pool. Flow data during the period 1984 to 2003 for the lowest flow month (assumed as March) were used to establish the sensitivity of surface flow within the Blackwood River to groundwater discharge from the Yarragadee Formation.

For the purpose of determining the minimum flow requirements of 5cm over riffle zones for all months, (except during September and October - minimum of 20 cm), the 10th percentile from the available flow data at Hutt Pool was adopted as the minimum baseline flow in the Blackwood River.

CONCLUSIONS

The methodologies for determining interim (R2) EWR criteria for an area with complex hydrogeology and a high biodiversity value have been outlined. These have been developed primarily by a systematic approach utilising vegetation mapping, the hydrogeological environment in relation to groundwater dependent ecosystems and the perceived ecological values in the area.

The general lack of detailed ecological data in the area has necessitated the selection of conservative EWRs, which have largely been based on historical GDE/EWR studies in the Gnangara Mound. The sandy nature of the soils in both the Gnangara Mound and the Yarragadee outcrop area in the Blackwood River valley suggest that this approach may be reasonable at a preliminary level, but it is not satisfactory for the next level (R3) of EWR assessment and the determination of meaningful EWPs for the area.

As a result, extensive baseline monitoring is required before the next step in EWR evaluation can be completed. Monitoring transects and baseline data requirements have been identified and this work will presumably commence in the short-term.

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