Government of **Western Australia**
Department of **Water**

Peel Coastal groundwater allocation plan

Groundwater-dependent ecosystems

October 2015

Securing Western Australia's water future

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1 Introduction

1.1 Intent of this document

The Department of Water has published the Peel Coastal groundwater allocation plan (2015a). This document supports the allocation planning process and:

- describes groundwater-dependent ecosystems (GDEs) and sets environmental objectives
- describes how we estimated groundwater use by dependent ecosystems and how we used this to help set allocation limits
- presents a regionally-specific monitoring and management framework for ongoing management of groundwater-dependent ecosystems
- presents a monitoring and reporting framework to support plan evaluation.

1.2 Approach

The Department of Water follows the process show in Figure 1 to develop a water allocation plan and set allocation limits. We have followed this process to support the development of the allocation plan.

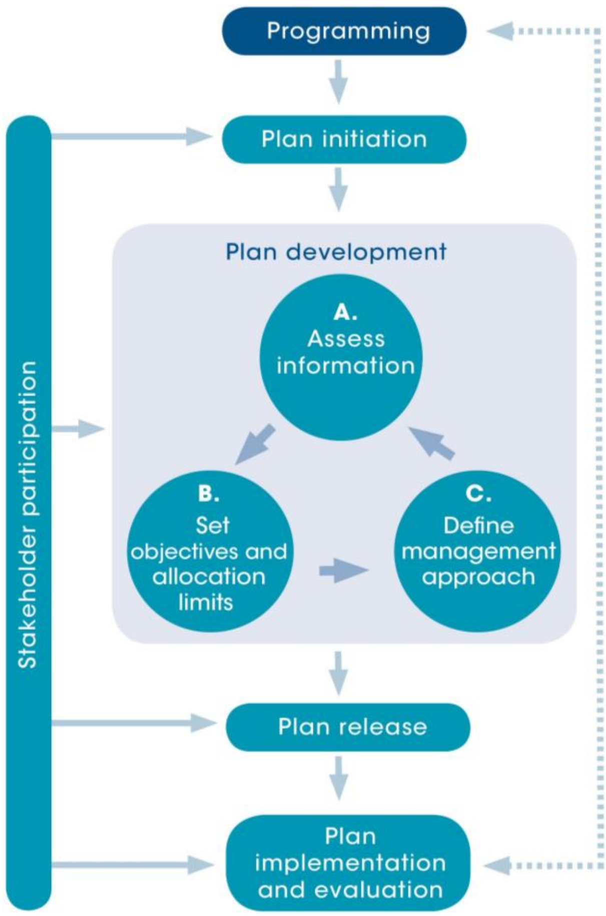

Figure 1 Water allocation planning process during plan development

Assess information on groundwater-dependent ecosystems

We analysed existing information to:

- map areas of potential groundwater dependence
- identify environmental values likely to be associated with the superficial aquifer based on their occurrence on shallow groundwater
- establish the significance of those values at a local, state and national level.

Support the setting of objectives and allocation limits

Based on the outputs from the 'assess information' stage we:

- set environmental management objectives
- estimated the groundwater use – ecological water requirements – of groundwater-dependent vegetation

These outputs were considered when defining the resource yield and allocation limits for the plan area. Our document, *Peel Coastal groundwater area: allocation method report* (Department of Water 2015b) details the methods and reasoning used to determine the allocation limit.

Define management approach

In this last stage we developed our approach for managing risks to environmental values. This included:

- describing the water regime required to meet the management objectives
- identifying reference levels to measure our performance against
- revising the current monitoring program to support management objectives and trigger a management response
- developing a decision support tool for licensing officers and local licensing policies
- developing an adaptive management framework.

1.3 Background

The Peel Coastal groundwater allocation plan area (the plan area) extends along the coast from Mandurah to Myalup, and inland to the Peel-Harvey estuary. It consists of seven management subareas: Mandurah, Falcon, Whitehills, Island Point, Coastal, Lake Clifton and Colburra Downs.

The plan area has unique and significant ecological values. These are mostly associated with the Yalgorup National Park, the largest coastal reserve on the Swan Coastal Plain, and the Yalgorup wetland system which forms part of the Ramsar-listed Peel-Yalgorup wetland system.

With over 170 bird species recorded, the area is recognised to be the most significant on the Swan Coastal Plain for the conservation of wetland and bushland bird species (Dell & Hyder 2009).

Large tracts of intact remnant vegetation remain in the area. This includes Tuart forest and other coastal vegetation types largely cleared or degraded elsewhere on the Swan Coastal Plain. Much of this vegetation is of regional significance, and provides habitat and ecological linkages for fauna movement across the landscape. It also holds value for the potential reintroduction of species which have become locally or regionally extinct (Hyder & Dell 2009).

The plan area supports a diverse range of flora and fauna species including a number of regionally, nationally and internationally threatened species. Of these the living thrombolite community found in Lake Clifton is arguably the most significant. This community is one of only a very few such communities in the world located in inland waters (EPA 2010).

Many of the ecological values in the plan area are associated with ecosystems which rely on groundwater for their existence and health. The occurrence of these groundwater-dependent ecosystems is defined by the local hydrogeological environment where the superficial aquifer is unconfined and often shallow. As a result, groundwater-dependent values are likely to be affected by changes in the quantity or quality of groundwater in the superficial aquifer.

The ecological values are further described at a subarea scale throughout this document. To identify ecological features we have drawn on information provided by the Department of Parks and Wildlife (DPaW, previously (DEC) the Department of Environment and Conservation), the Office of the Environmental Protection Agency Western Australia (OEPA) and from published reports.

2 Assess information

2.1 Understanding the biophysical setting

Climate

The Peel Coastal groundwater allocation plan area (plan area) experiences a Mediterranean type climate with hot dry summers and cool wet winters. Between 1950 and 2010 the average rainfall measured at Mandurah was 819 mm (BoM station 009572). In the last ten years this figure has fallen to 661 mm representing a 19 per cent drop in average yearly rainfall (Figure 2). CSIRO (2009) modelling predicted a drying climate for the whole of the South West of Western Australia suggesting that this pattern of rainfall decline will continue.

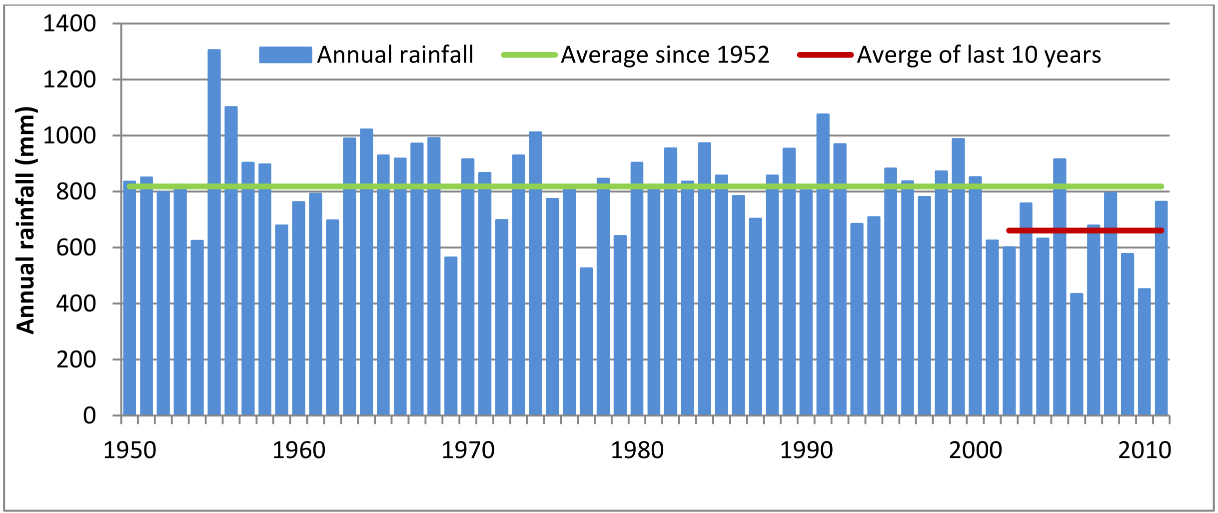

Figure 2 Annual rainfall measured at Mandurah

Average annual evaporation measured at Harvey (BoM station 009812) since 2001 is 1680 mm with an annual rainfall deficit of about 1000 mm/year. Evaporation exceeding rainfall for eight months of the year highlights how limited water is in the plan area (Figure 3).

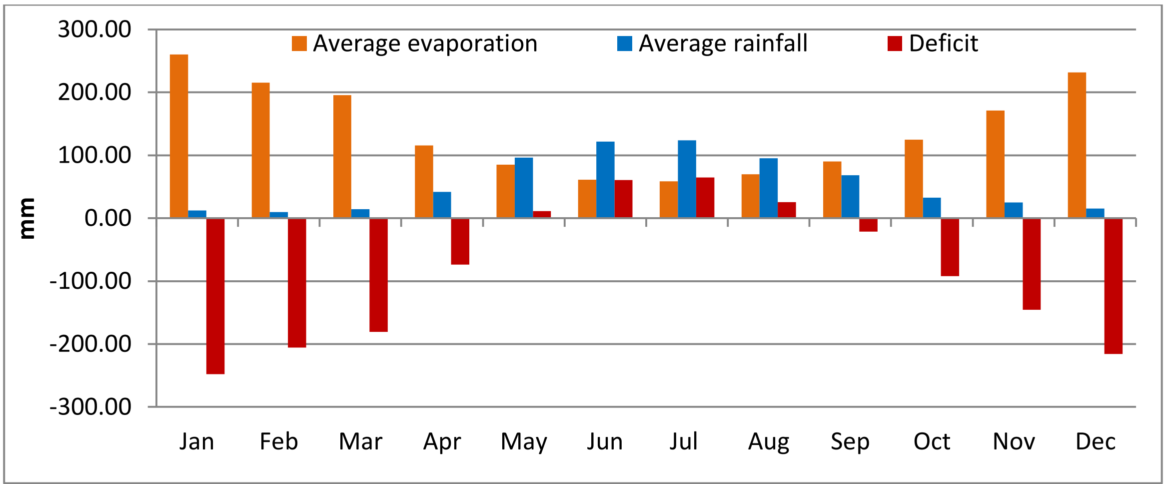

Figure 3 Average monthly rainfall and evaporation and rainfall deficit

Geology

The study area is located on the western edge of the Swan Coastal Plain within the Perth Basin geological formation. The major geological units of the superficial formation are the Safety Bay Sand, Tamala Limestone and Bassendean Sand.

The Safety Bay Sand unit occurs at the surface along the coast in a strip. It is as much as 1 km wide and has a maximum thickness of about 50 m. It consists of medium to coarse grained quartz sand and shells.

The Tamala Limestone is the most extensive formation and consists of interbedded limestone, calcarenite and sand, with subordinate marl and shell beds. Adjacent to the lakes and estuary it often comprises interbedded clay and clayey sand. It has a maximum thickness of 70 m beneath the dunes (Water and Rivers Commission 1999).

The Bassendean Sand unit is in the eastern portion of the study area and has a maximum thickness of about 30 m. It consists of uniform well-sorted coarse grained quartz sand with isolated lenses of limestone (Commander 1988).

The superficial formations have a maximum thickness of 90 m and overlie unconformably the gently west-sloping Leederville Formation.

Geomorphology and hydrogeology

The geomorphology is dominated by the Quindalup and Spearwood Dune landforms that run parallel with the coastline (Figure 4).

The majority of the wetlands and lakes of the study area are located in swales within the Spearwood Dune system and in the interface between the Quindalup and Spearwood Dunes where the unconfined (superficial) aquifer is close to the surface.

The Bassendean Dune landform, also present in the east, consists of low dunes and interwoven wetlands.

The geological units of the superficial formations form a regional unconfined aquifer known as the superficial aquifer. In the study area the saturated thickness in the aquifer ranges from 20 to 40 m. The water table sits at the surface in low-lying areas between the dunes but may be up to 60 m below ground level where overlain by dunes.

Throughflow into the area is limited so rainfall infiltration provides the majority of the recharge to the superficial aquifer. Rainfall recharge forms a lens of fresh water above more brackish/saline groundwater. The saline groundwater is a result of saltwater intrusion from the Indian Ocean which bounds the western edge of the study area, the Peel/Harvey Estuary which bounds a large portion of the eastern edge and leakage from the Yalgorup Lake system.

There are several separate flow systems across the area (Hammond 1989). Groundwater moves slowly from local groundwater mounds and divides to low-lying discharge areas such as the Peel/Harvey Estuary and the coast.

Three of these flow systems are internal and discharge to coastal lakes (Lake Preston, Lake Clifton and Martins Tank). These lakes act as groundwater sinks with little or no outflow except evaporation from the lake surfaces. Because there is no seasonal flushing, evaporative concentration of dissolved salts has resulted in the lakes and underlying groundwater being saline to hypersaline (Figure 4).

There is some leakage into the underlying Leederville aquifer also where hydraulic gradients are downward and confining beds are absent.

Figure 5 shows a conceptual cross section of the study area and illustrates how ecosystems are connected to groundwater.

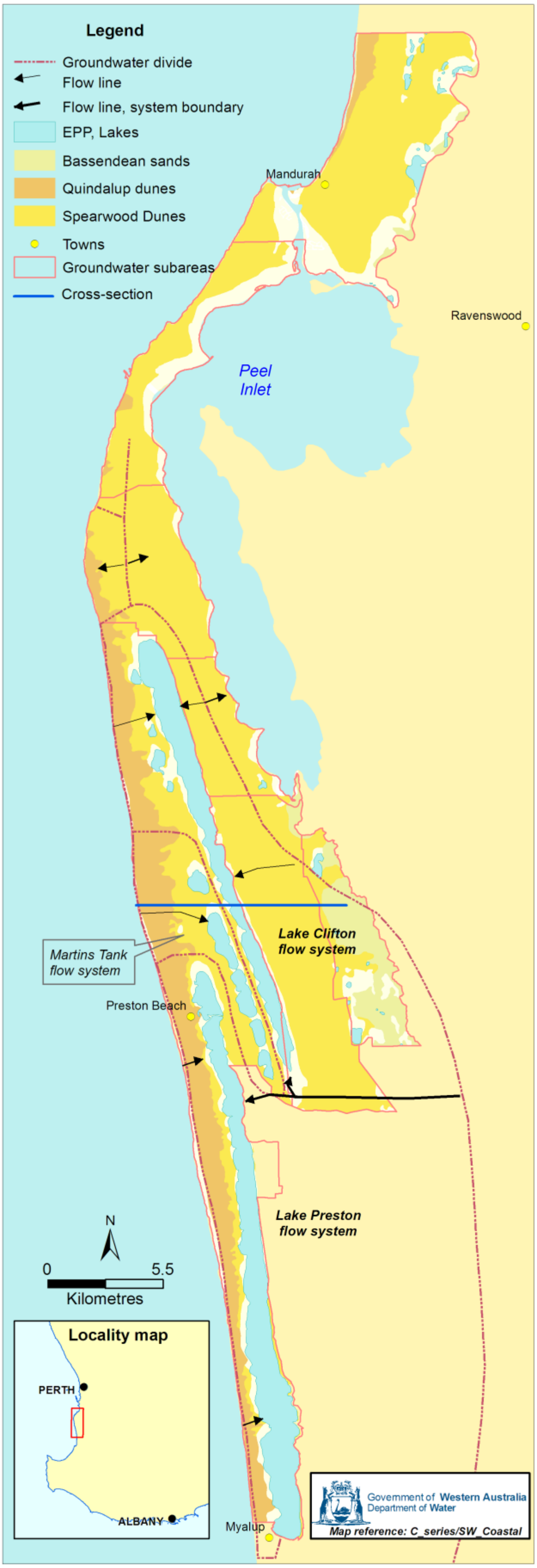

Figure 4 Geomorphology and superficial aquifer flow system (taken from (Commander 1994; RPS 2011)

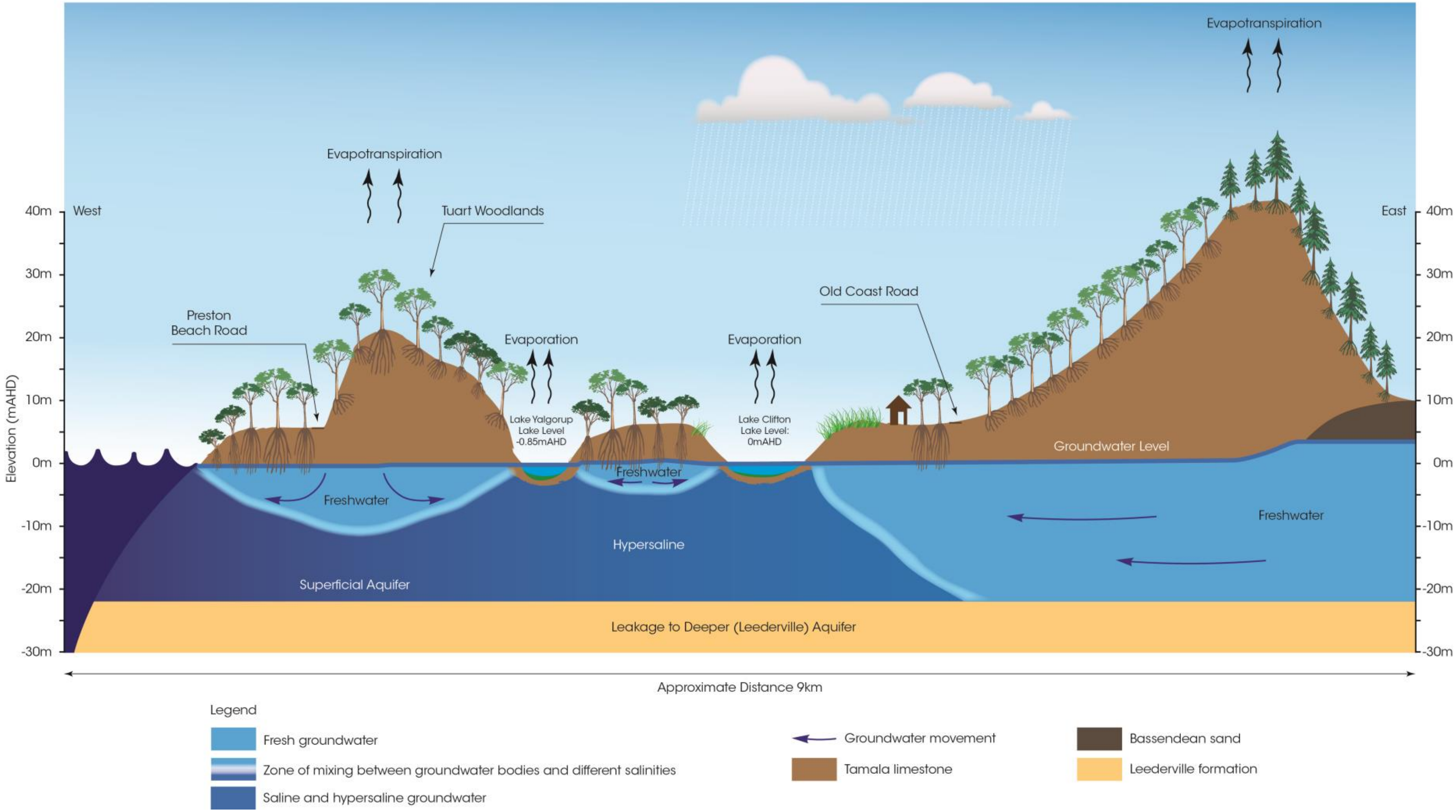

Figure 5 Simplified geomorphology and hydrogeology of the study area (Based on (RPS 2011)

2.2 Identifying groundwater-dependent ecosystems and assessing their values

Groundwater supports many of the unique and significant ecological values in the plan area. Three primary groundwater-dependent ecosystem types are found in the study area:

- Cave and aquifer ecosystems
    - Fauna (stygofauna) that occur in cave pools/streams or within the groundwater itself. These typically include karst aquifer systems, such as those in the Tamala Limestone which are prevalent throughout the study area.
- Ecosystems dependent on the surface presence of groundwater
    - These include the wetland ecosystems that occur throughout the study area where groundwater discharges from the aquifer to the surface for at least part of the year. This type also includes the associated aquatic flora and fauna that inhabit the wetlands and the riparian vegetation that is subject to periodic inundation.
- Ecosystems dependent on subsurface presence of groundwater
    - These include areas of terrestrial vegetation which depend (at least in part) on the subsurface presence of groundwater. This type also includes fauna dependent on the vegetation for refuge, habitat or foraging.

Identification and mapping

In this section we describe how groundwater-dependent ecosystems were identified and mapped across the study area and how we identified their conservation value. As this project is a desktop investigation, the list of features is not exhaustive and is based on currently available information.

The distribution of groundwater-dependent ecosystems across the study area is largely governed by local hydrogeology and geomorphology (Figure 5). We have used this conceptual understanding to help identify and map these ecosystems.

Cave and aquifer ecosystems

Karstic strata such as Tamala Limestone are prevalent throughout the area and are likely to contain suitable habitat for stygofauna and rootmat communities. As such the superficial aquifer is considered to have a high probability of containing rich aquifer ecosystems (EPA 2013).

To date no development proposals have triggered targeted sampling within the study area, and there appears to be no site-specific information on the occurrence, conservation status or habitat requirements of cave or aquifer ecosystems.

Ecosystems dependent on the surface presence of groundwater

Wetlands are the most common type of ecosystem dependent on the surface presence of groundwater. They are generally one of two types: permanent expressions of the groundwater table (lakes) or wetlands that are seasonally inundated or waterlogged (sumplands and damplands) and therefore usually only have a surface presence of groundwater in the winter months.

Wetlands most often occur in the swales and interdunal areas where the superficial aquifer discharges to the surface and where shallow groundwater is accessible to wetland vegetation (Figure 5).

Chains of lakes are found in the swales within the Spearwood Dune system and in the interface between the Quindalup and Spearwood Dunes where the unconfined aquifer is close to the surface. Fresh groundwater discharges into these lakes, maintains water levels and water quality, and supports the associated ecosystems.

Seasonally inundated sumplands and waterlogged damplands mostly occur in low-lying areas as a winter surface expression of the local groundwater table. These wetlands dry out during summer as the water table recedes and evaporation and plant water use dries out the soil profile. Over the dry period, riparian vegetation around the wetlands most likely relies on access to groundwater within 3 m of the land surface (Froend & Loomes 2004).

Based on this relationship, we developed maps for each subarea (e.g. Figure 7-bottom) showing where depth to groundwater (dtgw) is less than 3 m and have overlaid this with the Environmental Protection Policy wetlands dataset (EPA 1992) and the Geomorphic wetlands dataset (Department of Environment and Conservation 2007).

When we overlaid these datasets, we found very limited areas where mapped wetlands do not correspond with the less than 3 m dtgw map. Based on this, vegetation situated on less than 3 m dtgw beyond areas mapped as wetlands is considered to be terrestrial vegetation that is reliant on shallow groundwater (0–3 m).

Ecosystems dependent on subsurface presence of groundwater

The presence of vegetation reliant on the subsurface presence of groundwater can be inferred if groundwater, or the capillary fringe, above the water table is present within the rooting depth of terrestrial vegetation (Eamus 2009).

In this study we referenced the work done by Froend and Loomes (2004) across the Gnangara Mound that identified three categories of groundwater-dependent vegetation:

- 0–3 m dtgw wetland vegetation
- 3–6 m dtgw terrestrial vegetation
- 6–10 m terrestrial vegetation.

The relationship between these three categories and groundwater on a landscape scale is shown conceptually in Figure 6.

Where the depth to groundwater is greater than 10 m ecosystems may only use groundwater opportunistically or to a very limited extent. Therefore 10 m was used as a key criterion in our subarea groundwater-dependent ecosystem mapping (e.g. Figure 7-top).

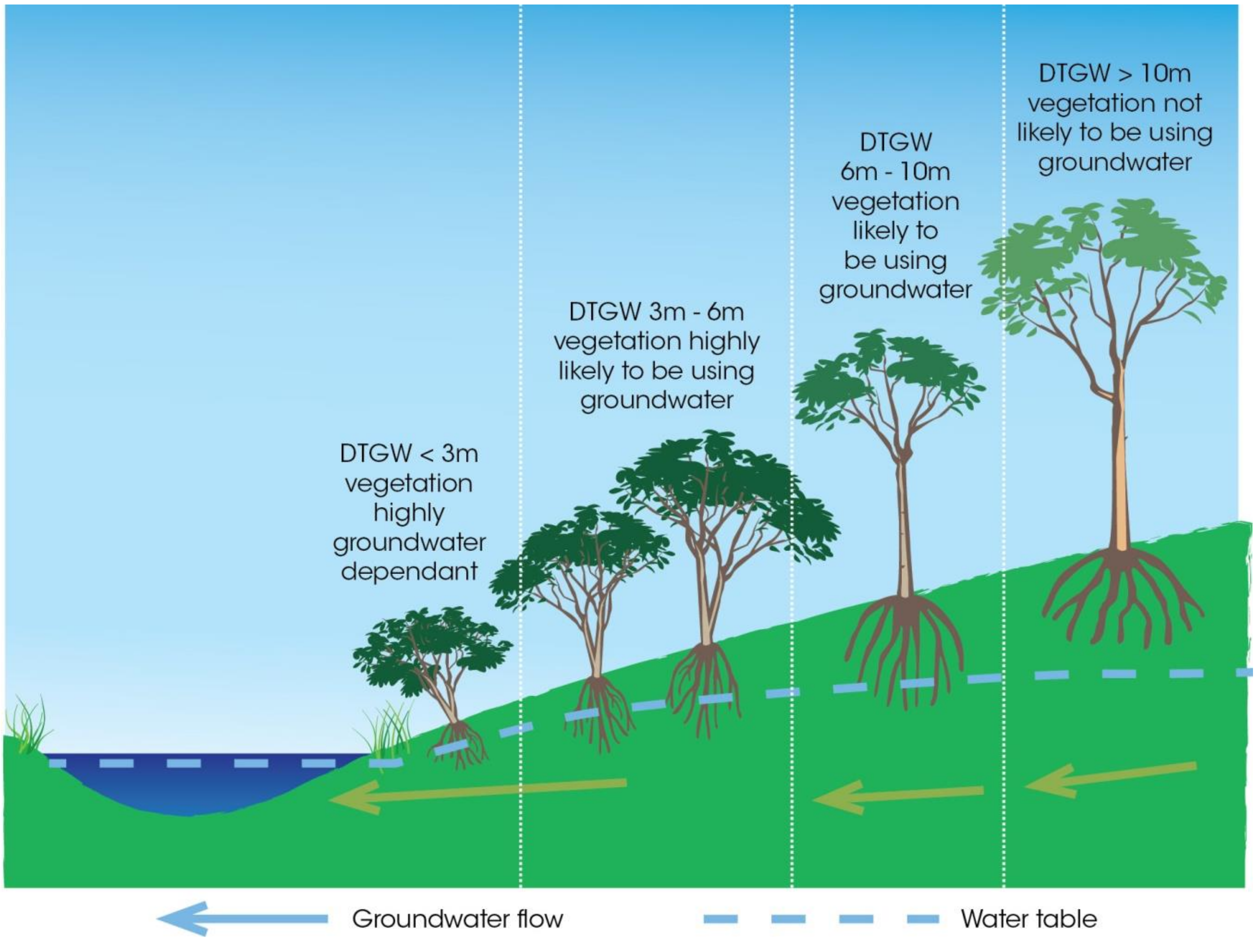

Figure 6 Conceptual model of ecosystem dependence on subsurface presence of groundwater

Identify the environmental values of groundwater-dependent ecosystems

We take the advice of the OEPA and the DPaW when defining key environmental values. Environmental features are considered to be of high conservation significance if they have legislated or documented environmental values as detailed in Table 1.

Other environmental features which may have value but are not formally identified for conservation are considered to be of moderate conservation value. Further details on the conservation codes used to define Threatened Ecological Communities (TECs), Rare and Priority Flora are presented in Appendix 1.

Table 1 Legislation and guidance used to determine conservation significance.

Legislation/ guidance	Protection
International agreements	
Ramsar	The Peel-Yalgorup system is listed as a Ramsar wetland and includes the Peel-Harvey Estuary, the 10 lakes within the Yalgorup National Park and a significant proportion of the non-wetland areas of the National Park.
CAMBA and JAMBA (China-Australia and Japan-Australia Migratory Birds Agreement)	The Yalgorup Lakes are covered by international agreements for the protection of migratory birds in danger of extinction and their environment.
Commonwealth	
EPBC[1] Act 1999	Provides protection for matters of 'national environmental significance', including wetlands, TECs, threatened flora and fauna species.
Register of National Estate (Commonwealth of Australia 2001b)	The Yalgorup National Park is registered based on the unique values of the wetlands. The list recognises and protects places of outstanding heritage to the nation.
State	
Environmental Protection Act 1986 *Wildlife Conservation Act 1950*	Enforced by DPaW to conserve and protect. Covers natural areas supporting populations of Declared Rare Fauna (DRF) or Specially Protected Fauna or threatened species listed under the Act. Also include System 6 Reserves which protect regionally significant areas of urban bushland to maintain and enhance conservation and recreation values of natural areas
Conservation and Land Management Act 1984	Establishes legislative provisions dealing with state conservation and land management matters. It established a number of statutory bodies including the Conservation Commission of Western Australia, the Marine Parks and Reserves Authority, and the Marine Parks and Reserves Scientific Advisory Committee. Includes those categories defined as critical assets in *EPA Position Statement No 9* (2006). Yalgorup National Park is also vested with the Conservation Commission of Western Australia under this Act
Environmental Protection (Swan Coastal Plain Lakes) Policies	The purpose of this policy is to protect the wetlands of high ecological values on the Swan Coastal Plain. The EPA considers wetlands listed under the EPP Lakes policy as critical environmental assets that must be protected.
DEC – Conservation Category Wetlands (CCW) and Resource Enhancement category wetlands	CCW exhibit a high level of 'naturalness'; they have remained undisturbed, contain a natural suite of species and unaltered hydrology. The EPA considers them as critical environmental assets that must be protected. Due to the extent of clearing on the Swan coastal plain DPaW has advised that wetlands with the potential to be rehabilitated to 'Conservation' category status in this region (i.e. Resource Enhancement category) also have significant ecological value and should be included as a 'key environmental value'.

Legislation/ guidance	Protection
EPA Bulletin 788 and Guidance Statement 28	In recognition of the high conservation values of Lake Clifton the EPA released Bulletin 788 and Guidance Statement 28 which provided information and guidance on critical issues in relation to environmental impacts on Lake Clifton and presented the EPA's position on protection of Lake Clifton (EPA 1995; EPA 1998).
EPA Guidance Statements 10 & 33 (2006; 2008) for the protection of remnant native vegetation	The EPA considers that the following remnant vegetation be considered significant vegetation: • natural areas supporting populations of DRF or Specially Protected Fauna or threatened species • remnant vegetation in predominantly cleared areas • vegetation complexes with < 30% of the complex remaining (using Heddle et al. 1978)[2]
EPA Guidance Statement 12 (2013)	Provides a policy framework outlining how subterranean fauna should be considered in EIA and is designed to promote a more consistent approach to assessment and subsequent approval outcomes

[1] *EPBC – Environmental Protection and Biodiversity Conservation Act.*

[2] *EPA recommends a criterion of < 30%, however due to inaccuracies of vegetation clearing statistics DEC has recommended using a figure of < 40% for the Swan Coastal Plain. We use < 40% to determine the conservation significance of remnant vegetation. The mapping used for identifying the complex of remnant vegetation and the extent remaining was provided by the WALGA (Western Australian Planning Commission and WALGA 2010).*

In the following sections (2.3 to 2.9) we describe the depth to groundwater mapping and identification of potential groundwater-dependent ecosystems in each of the seven subareas within the Peel Coastal plan area. We then describe the conservation significance of each subarea and the type of groundwater-dependent ecosystems that we consider occur there.

Groundwater-dependent ecosystems were classified as follows:

- NA – unlikely to be groundwater-dependent based on position in the landscape or known dependence
- Surface – classification based on association with wetlands/riparian community
- Subsurface – classification based on location in areas where dtgw < 10 m
- In situ – may opportunistically use groundwater.

2.3 Mandurah subarea

Mapping

Depth to groundwater mapping indicates that the water table is close to the surface across much of the subarea. A low-lying dune system running parallel to the coastline represents the only area where depth to groundwater is greater than 10 m.

Figure 7-top shows areas where groundwater is within 10 m of the surface. This area supports about 60 per cent of the remnant vegetation across the subarea.

Figure 7-bottom shows areas where groundwater is within 3 m of the surface. All mapped wetlands are situated on this shallow water table and are likely to be receiving groundwater from the superficial aquifer at least some of the time.

Conservation significance

Vegetation and flora

The Mandurah subarea has undergone significant clearing of native vegetation for residential development and retains only about 25 per cent of its native vegetation.

Seven vegetation complexes as defined by Heddle et al. (1980) are found across the subarea (Table 2). With the exception of the Quindalup Complex, all the vegetation complexes are considered to be unrepresented (< 40 per cent in formal reserves) in the regional context and, therefore, at this level of classification, are considered to be of conservation value.

Table 2 Mandurah subarea – vegetation complexes

Vegetation Complex	Conservation significance	Value	GDE type
Cottesloe Complex (central and south)	< 40% remaining, likely to be disturbed	Moderate	Subsurface
Quindalup Complex	> 40% remaining	Moderate	NA
Karrakatta Complex (central and south)	< 40% remaining	High	Subsurface
Yoongarillup Complex	< 40% remaining, supports priority fauna	High	In situ
Herdsman Complex	< 40% remaining, supports priority flora	High	Surface
Vasse Complex	< 40% remaining	High	Surface
Bassendean Complex (central and south)	< 40% remaining, supports priority flora	High	Subsurface

Within remnant vegetation, five priority flora species have been recorded, four of which are likely to be using groundwater based on their association with wetlands (Table 3; (Department of Environment and Conservation 2011).

Table 3 Mandurah subarea – flora of conservation significance

Species	Habitat	Conservation significance	GDE type
Acacia benthamii		Priority 2	NA
Dillwynia dillwynioides	Salt marsh vegetation with fringing estuarine forest.	Priority 3	Surface
Eucalyptus rudis subsp. cratyantha	Salt marsh vegetation with fringing estuarine forest.	Priority 4	Surface
Ornduffia submersa	Freshwater lake	Priority 4	Surface

Species	Habitat	Conservation significance	GDE type
Parsonsia diaphanophleba	Alluvial soils along rivers	Priority 4	Surface

Fauna

Groundwater-dependent ecosystems provide important habitat for fauna populations and linkages for faunal movement throughout the subarea and region.

Six species of fauna with conservation significance were recorded within the area. Four of these have been identified as being under threat of extinction, rare or otherwise in need of special protection (Table 4). This includes the Priority 5, Southern Brown Bandicoot, with more than 50 sightings concentrated around two small urban wetlands (Department of Environment and Conservation 2011). Across the study area this species is consistently located in wetland vegetation suggesting a strong dependence on groundwater. Recent findings across the Gnangara Mound suggest that any decline in wetland vegetation in response to groundwater or rainfall decline is predicted to severely impact this species (Wilson, Valentine et al. 2012).

Table 4 Mandurah subarea - threatened and priority fauna species

Scientific name	Common name	Conservation significance	GDE type
Calyptorhynchus banksii subsp. naso	Forest Red-tailed Black-Cockatoo	Vulnerable	Subsurface
Calyptorhynchus latirostris	Carnaby's Cockatoo	Endangered	Subsurface
Isoodon obesulus subsp. Fusciventer	Southern Brown Bandicoot	Priority 5	Subsurface
Lerista lineata	Perth Lined Lerista (Skink)	Priority 3	NA
Neelaps calonotos	Black-striped Snake	Priority 3	NA
Numenius madagascariensis	Eastern Curlew	Priority 4 JAMBA/ CAMBA	surface

Wetlands

The southern edge of the Mandurah subarea is bounded by the Ramsar-listed Peel Harvey Estuary (Figure 7- bottom). The area also contains a portion of Goegrup Lake which is a proposed extension to the Peel-Yalgorup Ramsar listing (May & McKenzie 2002; Hale & Butcher 2007). The foreshore of the Serpentine River, which bounds the western edge of the subarea, and several wetlands within the subarea have been identified as CCW on DEC's *Geomorphic Wetlands Swan Coastal Plain dataset* (2007). Several of these are also protected under the *Environmental Protection (Swan Coastal Plain Lakes) Policy 1992*.

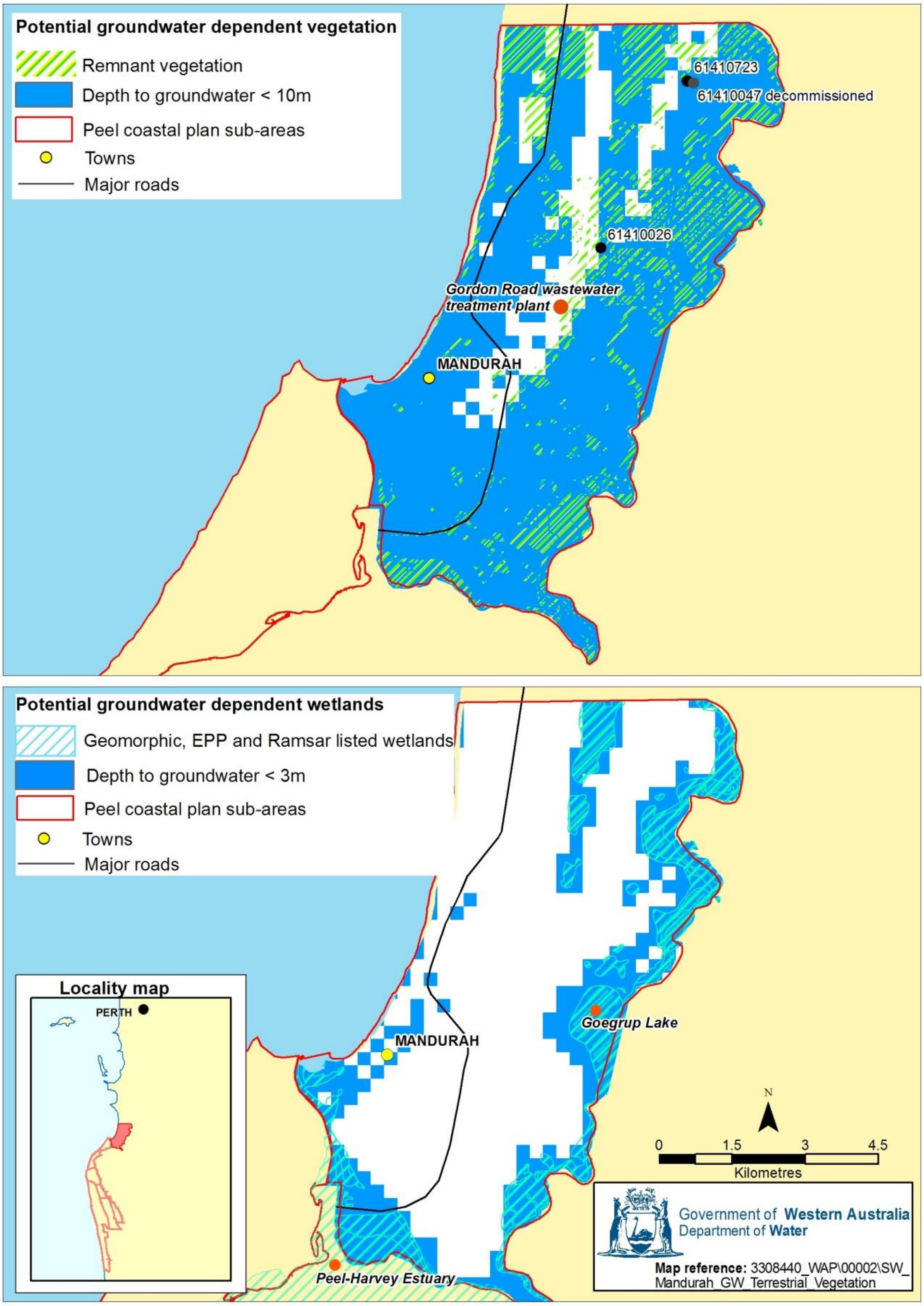

Figure 7 Mandurah subarea: top) remnant vegetation on dtgw < 10 m, bottom) areas with dtgw < 3 m and wetlands of conservation value

2.4 Falcon subarea

Mapping

Depth to groundwater mapping indicates that approximately 70 per cent of the subarea is situated on depths to groundwater less than 10 m (Figure 8-left). This shallow groundwater has the potential to support much of the remnant terrestrial vegetation and provide fauna habitat.

Areas with the potential to support ecosystems dependent on surface expression of groundwater (dtgw less than 3 m) are largely restricted to the areas aligning the Peel-Harvey Estuary (Figure 8-right).

Conservation significance

Vegetation and flora

The Falcon subarea is the most urbanised in the Peel Coastal plan area. It has been largely cleared for residential development, retaining only about 15 per cent of its native vegetation cover. Any remnant vegetation in good condition is therefore likely to have conservation value.

Remnant vegetation may support threatened and priority fauna species, provide a buffer along the perimeter of the Ramsar-listed Peel-Harvey Estuary or aid the movement of fauna.

The southern part of the subarea has a large proportion of native vegetation, including part of Tim's Thicket Reserve. This reserve, vested with the City of Mandurah, has been set aside for recreational use. It is recognised as a regionally significant natural area in the Swan Bioplan – Peel Sector (EPA 2010) and as a System 6 conservation reserve.

Broad scale mapping shows that remnant vegetation in the Falcon subarea belongs to the Cottesloe (central and south), Quindalup and Yoongarillup complexes (Table 5; (Heddle, Havel et al. 1980) .

The Cottesloe Complex is the only one which is potentially groundwater-dependent. Although less than 40 per cent of its natural extent remains, it is moderately degraded and we have therefore ranked it as moderate conservation value.

Table 5 Falcon subarea - vegetation

Vegetation Complex	Conservation significance	Value	GDE type
Cottesloe Complex – Central and South	< 40% remaining –moderately degraded	Moderate	Subsurface
Quindalup Complex	> 40% remaining	Moderate	NA
Yoongarillup Complex	< 40% remaining –moderately degraded	Moderate	In situ

Within these remnants, four near threatened or poorly known flora species have been recorded (Department of Environment and Conservation 2011; Table 6). Of these only *Chamaescilla gibsonii*, a sedge or woody herb, is likely to be groundwater-dependent based on its preference for shallow groundwater near wetlands.

Table 6 Falcon subarea – flora of conservation significance

Species	Habitat	Conservation significance	GDE type
Chamaescilla gibsonii	Erskine estuary – flat wetland. Damp, open light grey sandy-loam over limestone.	Priority 3	Surface
Conostylis pauciflora subsp. pauciflora		Priority 4	NA
Hakea oligoneura	Tim's Thicket	Priority 4	NA
Lasiopetalum membranaceum	Tuart woodland. Sand	Priority 3	NA

Fauna

A number of birds, mammals and reptile species of conservation significance inhabit the area. Five of these species are under threat of extinction, rare or otherwise in need of special protection (Table 7). The majority of these were sighted in the Mandurah Estuary, or within remnant vegetation (heathland) along the Peel-Harvey foreshore.

Table 7 Falcon subarea – threatened and priority fauna species

Scientific name	Common name	Conservation significance	GDE type
Calyptorhynchus latirostris	Carnaby's Cockatoo	Endangered	Subsurface
Caretta caretta	Loggerhead Turtle	Endangered	NA
Charadrius rubricollis	Hooded Plover	Priority 4	Surface
Falco peregrinus	Peregrine Falcon	Specially protected	NA
Lerista lineata	Perth Lined Lerista (Skink)	Priority 3	NA
Macronectes giganteus	Southern Giant Petrel	Endangered	NA
Numenius madagascariensis	Eastern Curlew	Priority 4	Surface
Phascogale tapoatafa subsp.	Brush-tailed Phascogale	Vulnerable	NA
Thalassarche chlororhynchos	Atlantic Yellow-nosed Albatross	Vulnerable	NA

Wetlands

The eastern and southern edge of the Falcon subarea is bounded by the Mandurah estuary and the Ramsar-listed Peel-Harvey estuary. Other than these, the subarea only contains two small CCW listed on DEC's *Geomorphic Wetlands Swan Coastal Plain dataset* (2007). These wetlands are situated on dtgw of less than 3 m and are considered to be surface-type groundwater-dependent ecosystems.

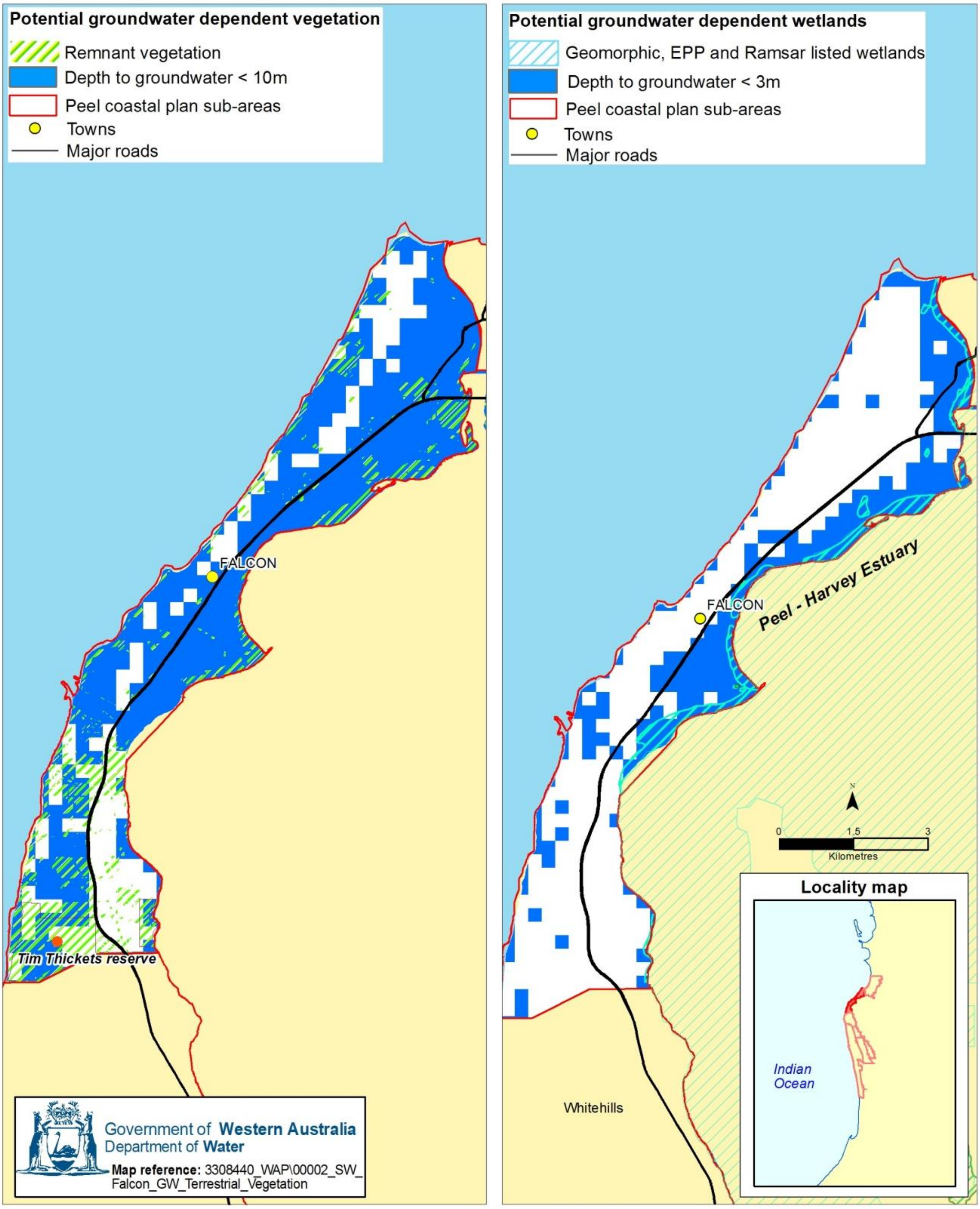

Figure 8 Falcon subarea; left) top) remnant vegetation on dtgw < 10 m, bottom) areas with dtgw < 3 m and wetlands of conservation value

2.5 Whitehills subarea

Mapping

Depth to groundwater mapping (at the end of summer) shows that about 49 per cent of the subarea is sitting on dtgw of less than 10. These areas of potential groundwater dependence occur along a 3 km wide strip running south–north (Figure 9-top) at the interface of the Quindalup and Spearwood Dune System.

A relatively small portion of this area (8%), largely made up of a 250 m strip aligning the Peel-Harvey Estuary, sits on dtgw of less than 3 m (Figure 9-bottom).

Conservation significance

Vegetation and flora

This subarea has high conservation value. About 70 per cent of the subarea is in the Yalgorup National Park, and it is recognised as a regionally significant natural area in the Swan Bioplan – Peel Sector (EPA 2010). The south-east corner is also part of the Peel-Yalgorup Ramsar site. This area is also part of the strongest north–south ecological linkage remaining on the southern Swan Coastal Plain (Molly, Wood et al. 2009).

Large tracts of Tuart (*Eucalyptus gomphocephala*) forest with canopy densities of 30–49 per cent and good native understorey condition (Government of Western Australia 2003) occur across the subarea. The Tuart tree is the only eucalyptus endemic to the Swan Coastal Plain. A marked decline in the health and vitality of Tuart trees in the Yalgorup National Park requires that healthy tracts are preserved.

Vegetation mapping undertaken by the Department of Environment and Conservation (Freeman, Keighery et al. 2009) as part of the Swan Bioplan Project has described the following plant communities across the Whitehills subarea (Table 8).

Table 8 Whitehills subarea – vegetation

Plant Community Group/ subgroup		Conservation significance	Value	GDE type
Estuarine Samphire Shrublands (ESS)	Estuarine samphire shrubland	Riparian vegetation contiguous with CCW	High	NA*
Juncus kraussii sedgelands (LFC1b/2/3a)	Lake fringing community 1b	Riparian vegetation contiguous with CCW	High	surface
Wet Tuart forest LFC3b	Lake fringing community 3b	Riparian vegetation contiguous with CCW	High	Surface
Coastal grasslands and low shrublands	Quindalup uplands community 1a	Strands with low frequency of weeds should be protected2	High	NA

Plant Community Group/ subgroup		Conservation significance	Value	GDE type
Acacia/Melaleuca coastal heath and shrubland	Quindalup community uplands community 1b	Major ecological linkage that should be protected2	High	NA
Eucalyptus/Banksia open low woodland	Spearwood uplands community 1		Moderate	NA
Tuart/Peppermint forests and woodlands	Spearwood uplands community 2	Tuart woodlands in good or better condition should be protected1	High	In situ
Limestone woodlands and heaths	Spearwood uplands community 3		Moderate	Subsurface

1 based on mapping and conservation priorities recommendation in Freeman et al. (2009)

Four near-threatened or poorly known flora species (Department of Environment and Conservation 2011; Table 9) have been identified in the subarea. Of these only *Styidium maritmum*, a low lying shrub, shows a preference for habitat on shallow groundwater.

One threatened ecological community, Acacia shrublands on taller dunes, has also been identified in the subarea (Department of Environment and Conservation 2011), but is unlikely to be accessing groundwater because of its high position in the landscape.

Table 9 Whitehills subarea – threatened and priority flora species

Species	Habitat	Conservation significance	GDE type
Conostylis pauciflora subsp.	Jarrah-marri woodland.	Priority 4	NA
Hibbertia spicata subsp. leptotheca	Heath B.	Priority 3	NA
Lasiopetalum membranaceum		Priority 3	NA
Stylidium maritimum	With *Acacia cyclops, Acrotriche cordata, Astroloma microcalyx, Melaleuca* sp	Priority 3	Subsurface

Fauna

A number of birds, mammals and an insect of conservation significance inhabit the area (Table 10). Of these, four species show a preference for groundwater-dependent habitat. This includes the Western Ringtail Possum which was reintroduced into the area between 1995 and 2005.

The area now supports a viable population of the vulnerable-listed species (Hyder & Dell 2009) with the majority of sightings in remnant vegetation (heathland) along the Peel-Harvey Estuary foreshore.

Table 10 Whitehills subarea - threatened and priority fauna species

Scientific name	Common name	Conservation significance	GDE type
Calyptorhynchus banksii subsp. Naso	Forest Red-tailed Black-Cockatoo	Vulnerable	sub-surface
Calyptorhynchus baudinii	Baudin's Cockatoo	Endangered	NA
Calyptorhynchus latirostris	Carnaby's Cockatoo	Endangered	NA
Dasyurus geoffroii	Western Quoll	Vulnerable	sub-surface
Isoodon obesulus subsp. Fusciventer	Southern Brown Bandicoot	Priority 5	sub-surface
Pseudocheirus occidentalis	Western Ringtail Possum	Vulnerable	sub-surface
Synemon gratiosa	Graceful Sunmoth	Endangered	NA

Wetlands

The Ramsar listed Peel-Harvey estuary runs along the eastern boundary of the Whitehills subarea. The south-east corner of the subarea forms part of the functional area for Lake Clifton and is included under the Peel-Yalgorup Ramsar listing. No EPP wetlands or wetlands of conservation value occur within the subarea.

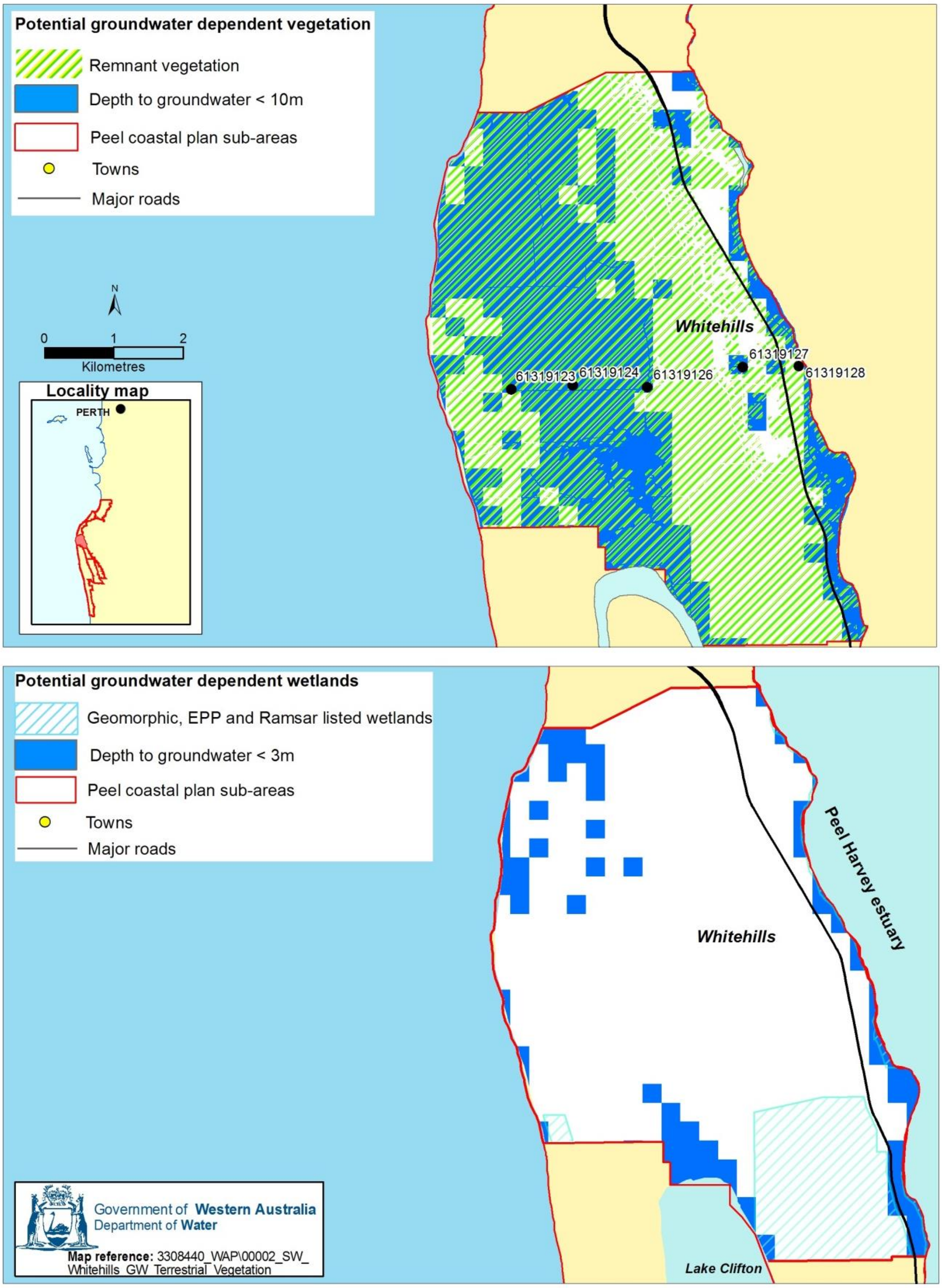

Figure 9 Whitehills subarea: top) areas of dtgw < 10 m and remnant vegetation, bottom) areas of dtgw < 3 m and mapped wetlands

2.6 Island Point subarea

Mapping

The Spearwood Dune System runs north–south through the Island Point subarea resulting in a generally deep water table. The area of groundwater dependence is limited to a zone approximately 500 m wide running along the western boundary of Lake Clifton and a 250–500 m zone along the Peel-Harvey Estuary on the eastern boundary (Figure 10).

Conservation significance

Vegetation and flora

The Island Point subarea retains approximately 60 per cent of its remnant vegetation. Vegetation mapping undertaken by DEC (Freeman, Keighery et al. 2009) as part of the Swan Bioplan Project has identified four plant communities (Table 11).

Tuart woodlands, with canopy density ranging from 10–40 per cent, occur across the subarea. Much of this remnant vegetation is on grazing land and the understorey is often highly degraded. The conservation value of these areas is likely to be moderate.

Much of the remnant vegetation is riparian vegetation associated with the Ramsar-listed Lake Clifton and Peel-Harvey Estuary. This vegetation plays an important role in moderating the chemistry of groundwater and surface water inputs into the wetlands. It is also important in maintaining ecological linkages in this highly fragmented and disturbed area and has been identified as regionally significant in the Swan Bioplan – Peel Sector (EPA 2010).

Table 11 Island Point subarea – vegetation

Plant Community Group/subgroup		Conservation priority	Value	GDE type
Juncus kraussii sedgelands (LFC1b/2/3a)	Lake fringing community 1b	Riparian vegetation contiguous with Conservation Category Wetlands	Critical	Surface
Eucalyptus/Banksia open low woodland	Spearwood uplands community 1		Moderate	NA
Tuart/Peppermint forests and woodlands	Spearwood uplands community 2	Recommended: Tuart woodland if in good or better condition[1]	Moderate	In situ
Limestone woodlands and heaths	Spearwood uplands community 3		Moderate	In situ

1 based on mapping and conservation priorities recommendation in Freeman et al. (2009)

One critically endangered species of flora occurs within the area but it is not considered to be reliant on groundwater based on its location (Table 12).

Table 12 Island Point subarea – flora of conservation significance

Species	Habitat	Conservation significance	GDE type
Caladenia huegelii	Deep sandy soils in low mixed woodlands of Coast Banksia	Critically endangered	NA

Fauna

Three species of fauna with conservation significance have been recorded within the area (Table 13). All three show a preference for habitat supported by shallow groundwater and are therefore considered to be groundwater dependent.

Table 13 Island Point subarea – threatened and priority fauna species

Scientific name	Common name	Conservation significance	GDE type
Pseudocheirus occidentalis	Western Ringtail Possum	Vulnerable	Subsurface
Calyptorhynchus banksii subsp. *naso*	Forest Red-tailed Black-Cockatoo	Vulnerable	Subsurface
Calyptorhynchus baudinii	Baudin's Cockatoo	Endangered	Subsurface

Wetlands

Island Point is bounded on the west by Lake Clifton and on the east by the Peel-Harvey Estuary, both of which are part of the Ramsar-listed Peel-Yalgorup wetland system (Figure 10).

While Lake Clifton does not lie within the subarea the processes that support the development of the internationally significant thrombolite community are reliant on groundwater originating from this subarea. Similarly the Peel-Harvey Estuary which aligns (outside) the subarea is also likely to be receiving groundwater discharge from Island Point.

Two small conservation category wetlands also occur in the south-east corner of the subarea on shallow groundwater.

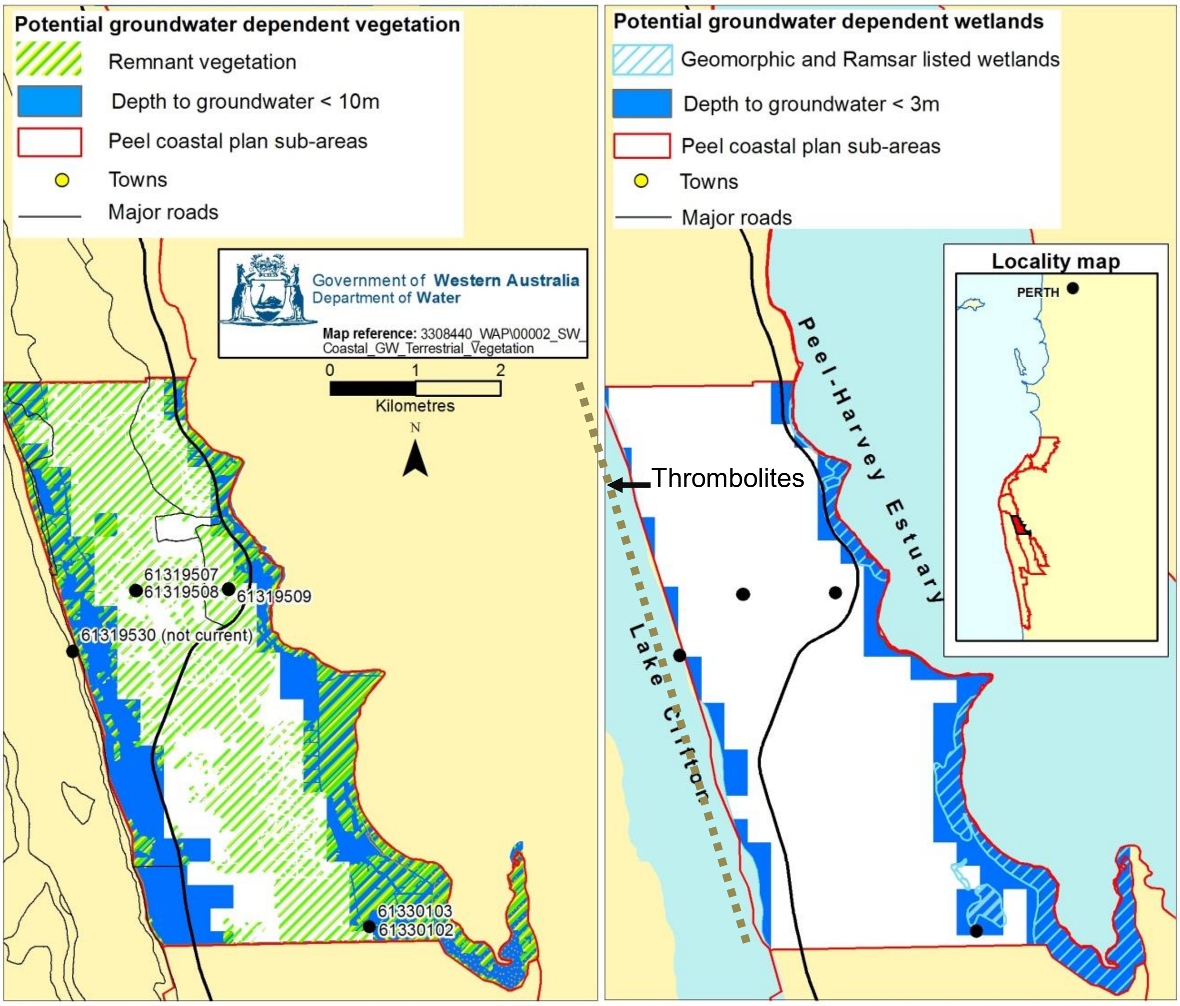

Figure 10 Island Point subarea: left) areas of dtgw < 10 m and remnant vegetation, right) areas of dtgw < 3 m and significant wetlands

2.7 Coastal subarea

Mapping

Across the subarea, depth to groundwater is dominated by the Quindalup and Spearwood dune systems running north–south through the subarea. This dune system restricts areas of shallow groundwater to the interdune swales.

The area of potential groundwater-dependent vegetation (dtgw < 10 m) mirrors the lake system and extends out from the lakes perimeters about 250 m to 1 km (Figure 11-left).

All the wetlands within this subarea are situated in areas where dtgw is less than 3 m and are likely to be intercepting groundwater (Figure 11-bottom). This area is a delineation of the riparian vegetation which, where present, surrounds the lakes and uses the shallow groundwater.

Conservation significance

Vegetation and flora

The Coastal subarea is the largest in the South-West Coastal groundwater area and currently retains about 80 per cent of its vegetation cover. Because of the relative intactness of the vegetation and diversity of habitats available the environmental values of the area are very significant.

In a regional context, the site contains significant vegetation which also provides significant fauna habitat and the most important north–south ecological linkage between fragmented areas of the coast between Dawesville and Binningup (EPA 2011). A large proportion of the remnant vegetation has also been identified in the Swan Bioplan as a regionally significant natural area (EPA 2010).

Vegetation mapping undertaken by DEC (Freeman, Keighery et al. 2009) as part of the Swan Bioplan Project has identified the following plant communities (Table 14).

Table 14 Coastal subarea – vegetation

Plant Community Group/subgroup		Conservation value	Value	GDE type
Juncus kraussii sedgelands	Lake fringing community 1a	Riparian vegetation contiguous with Conservation Category Wetlands	High	Surface
Juncus kraussii sedgelands (LFC1b/2/3a)	Lake fringing community 1b	Riparian vegetation contiguous with Conservation Category Wetlands	High	Surface
Melaleuca cuticularis low forest	Lake fringing community 2	Riparian vegetation contiguous with Conservation Category Wetlands	High	Surface
Melaleuca rhaphiophylla low forest	Lake fringing community 3a	Riparian vegetation contiguous with Conservation Category Wetlands	High	Surface
Wet Tuart forest LFC3b	Lake fringing community 3B	Of conservation value if Tuart woodland in good or better condition[1]	High	Surface
Coastal grasslands and low shrublands	Quindalup uplands community 1a	Stands with low frequency of weeds considered to be of conservation value[1]	High	NA
Acacia/Melaleuca coastal heath and shrubland	Quindalup community uplands community 1b	Stands with low frequency of weeds considered to be of conservation value[1]	High	NA
Eucalyptus/Banksia open low woodland	Spearwood uplands community 1		Moderate	NA
Limestone woodlands and heaths	Spearwood uplands community 3		Moderate	In situ
Island vegetation	Island vegetation	Riparian vegetation contiguous with Conservation Category Wetlands also supports TEC SWCFT29a	Moderate	Surface
Tuart/Peppermint coastal forests and woodlands	Quindalup uplands community 2	Of conservation value if Tuart woodland in good or better condition[1]	Moderate	In situ
Quindalup wetlands	*Juncus kraussii* and *Baumea juncea* sedgelands	Riparian vegetation contiguous with Conservation Category Wetlands	Moderate	Surface

1 based on mapping and conservation priorities recommendation in Freeman et al. (2009)

Within the subarea is the state and federally-listed critically endangered *Thrombolite (stromatolite) Community of a Coastal Brackish Lake*. In addition one endangered, one vulnerable and five priority TEC species have been recorded for the area (Table 15). This includes an occurrence of FCT SCP30b which is significant as it is now the northernmost known occurrence of this community (Freeman, Keighery et al. 2009).

Table 15 Coastal subarea – threatened ecological communities

Community ID	Common Name	Conservation significance	GDE type
SCP18	Shrublands on calcareous silts	Vulnerable[1]	NA
SCP25	Southern *Eucalyptus gomphocephala – Agonis flexuosa* woodland	Priority 3[1]	In situ
SCP26a	*Melaleuca huegelii – Melaleuca acerosa* shrublands on limestone ridges	Endangered[1]	NA
SCP29b	Acacia shrublands on taller dunes	Priority 3	NA
SCP29a	Acacia shrublands on shallow sands	Priority 3	Subsurface
SCP30b	Quindalup *Eucalyptus gomphocephala* and/or *Agonis flexuosa* woodland	Priority 3[1]	In situ
Pamelup Pond	Living microbial mats in hypersaline ponds	Priority 2	Surface
Clifton-microbialite	Stromatolite-like freshwater microbialite community of coastal brackish lakes	Critically endangered	Surface

[1] identified in EPA (2011)

Nine flora species of conservation value are recorded in the subarea (Table 16).

Table 16 Coastal subarea – flora of conservation significance

Species	Habitat	Conservation significance	GDE type
Eucalyptus argutifolia		Vulnerable	NA
Hakea oligoneura	Lower slopes of limestone ridge	Priority 4	Subsurface
Haloragis aculeolata	Valley, black coarse shelley sand over limestone	Priority 2	Subsurface
Haloragis scoparia		Priority 1	Subsurface
Hibbertia spicata subsp. leptotheca	On limestone soil	Priority 3	Subsurface
Lasiopetalum membranaceum	Sand over limestone	Priority 3	NA
Platysace ramosissima	Pale grey brown sand, over limestone	Priority 3	NA
Sphaerolobium calcicola	Damp clay soil	Priority 3	Subsurface
Stylidium maritimum	On consolidated dunes	Priority 3	Subsurface

Fauna

Ten fauna species with conservation significance have been recorded within the area. This includes four endangered species and two vulnerable species facing a high to very high risk of extinction in the wild (Table 17). Of all of these species we have identified four species of bird that rely on habitat that is groundwater dependent.

Table 17 Coastal subarea – threatened and priority fauna species

Scientific name	Common name	Conservation status	GDE type
Calyptorhynchus baudinii	Baudin's Cockatoo	Endangered	Subsurface
Calyptorhynchus latirostris	Carnaby's Cockatoo	Endangered	Subsurface
Charadrius rubricollis	Hooded Plover	Priority 4	Subsurface
Dasyurus geoffroii	Western Quoll	Vulnerable	Subsurface
Falco peregrinus	Peregrine Falcon	Specially protected	Subsurface
Lerista lineata	Perth Lined Lerista (Skink)	Priority 3	NA
Macronectes giganteus	Southern Giant Petrel	Endangered	NA
Numenius madagascariensis	Eastern Curlew	Priority 4	NA
Synemon gratiosa	Graceful Sunmoth	Endangered	NA
Thalassarche chlororhynchos	Atlantic Yellow-nosed Albatross	Vulnerable	NA

The populations of many species that inhabit this subarea may be among the largest and most significant on the southern Swan Coastal Plain. Habitat clearing has resulted in generally scarce populations elsewhere continuing to decline or becoming locally extinct (EPA 2011).

Wetlands

The Coastal subarea contains ten wetlands that make up the Yalgorup Lakes System (*Figure 11*-right). Together they cover about 50 km^2 and represent a nationally and globally distinct and unique suite of wetlands (V & C Semeniuk Research Group 2009).

This system of wetlands is recognised internationally under the Ramsar Convention due to its importance for migratory birds and is recognised as nationally important under the Directory of Important Wetlands in Australia and the Register of National Estate.

At a state level the lakes are protected under the *Environmental Protection (Swan Coastal Plain Lakes) Policy 1992* and have a management classification of 'conservation category' according to the *Geomorphic Wetlands of the Swan Coastal Plain.*

The predominant attributes of the Yalgorup Lake system (chemistry and water levels) are defined by their hydrology. They receive virtually no surface water runoff and are maintained by direct rainfall and groundwater inflow. As such, any change to the volumes or quality of groundwater discharging into the lakes could have significant impacts on the system's ecology through changes in patterns and extent of inundation (Hale & Butcher 2007).

Lake Clifton and Lake Preston are considered to be groundwater sinks which means they intercept the regional groundwater flow lines and have very little outflow other than evaporation. Although an investigation by Noble (2010) suggests that Lake Clifton many show some throughflow characteristics at times with water inflow from the east and outflow to the west.

Lake Clifton is unique because it supports the largest known population of living non-marine microbialites (thrombolites) in the Southern Hemisphere, and is one of only two sites known where microbialites occur in water less salty than sea water (Hale & Butcher 2007). These thrombolite structures are considered to be around 3000 years old and hold an invaluable record of water chemistry and climate history in their internal structures (V & C Semeniuk Research Group 2009).

In additional to rainfall they rely on the inflow of fresh groundwater rich in $CaCO_3$ to maintain lake levels, prevent desiccation and to keep the system hyposaline throughout the year.

While the thrombolites are located in the Coastal subarea they rely on groundwater discharge that originates from the Island Point and Lake Clifton subareas.

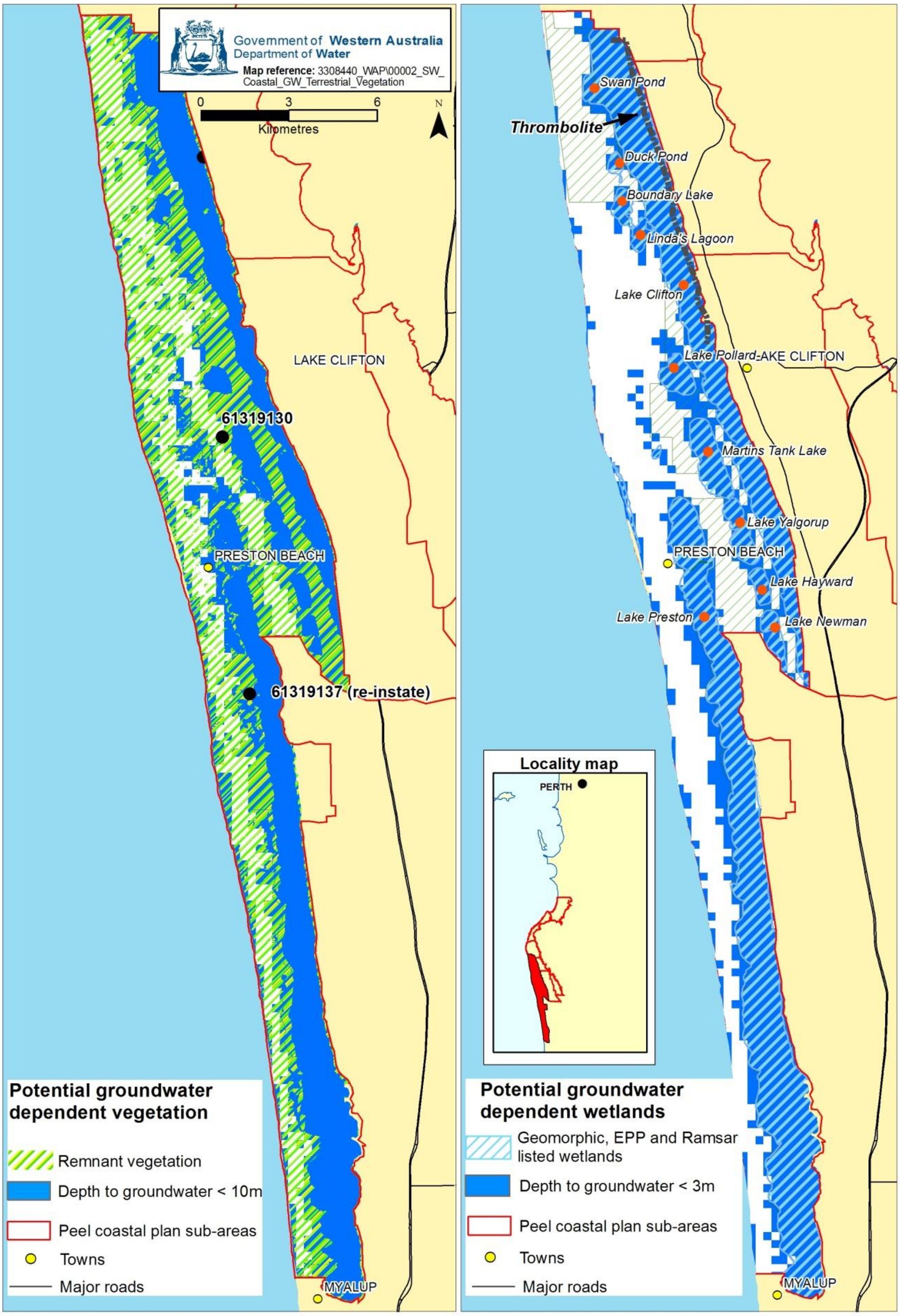

Figure 11 Coastal subarea; left) areas of dtgw < 10 m and remnant vegetation, right) areas of dtgw < 3 m and significant wetlands

2.8 Lake Clifton subarea

Mapping

The depth to groundwater map (end of summer) shows that the dune systems running north-south through the subarea restrict areas of shallow groundwater to the interdunal swales (Figure 12).

Shallow dtgw (<10 m) occurs along the perimeter of Lake Clifton extending out about 1.5 km. Another zone is present along the eastern boundary. Areas of likely wetlands and dependent ecosystems are restricted to a small section in the north-east corner of the study area and a narrow strip bordering Lake Clifton.

Conservation significance

Vegetation and flora

Lake Clifton retains less than 50 per cent of its native vegetation with large areas cleared for tree plantations, small scale agriculture and rural blocks.

Remnant vegetation in the Lake Clifton subarea belongs to the Cottesloe Complex (central and south), Karrakatta Complex (central and south), Yoongarillup Complex, Vasse Complex and Bassendean Complex (central and south).

All of these complexes have high conservation value with less than 40 per cent of their pre-European extent remaining (EPA 2006). The area contains a large System 6 Conservation reserve managed by DPaW. The remnant vegetation has been identified in the Swan Bioplan as a regionally significant natural area (EPA 2010) and makes up part of a regionally significant ecological linkage (Molloy, Wood et al. 2009).

Table 18 details plant communities present across the subarea as mapped by Freeman et al. (2009), their conservation value and potential groundwater dependence.

Table 18 Lake Clifton subarea – vegetation

Plant Community[1]		Vegetation of conservation value	Value	GDE type
Juncus kraussii sedgelenads	Lake fringing community 1b	Riparian vegetation contiguous with Conservation Category Wetlands	High	Subsurface
Melaleuca rhaphiophylla low forest	Lake fringing community 3a	Riparian vegetation contiguous with Conservation Category Wetlands	High	Surface, subsurface
Wet tuart forest	Lake fringing community 3b	Riparian vegetation contiguous with Conservation Category Wetlands	High	Surface, subsurface

Plant Community[1]		Vegetation of conservation value	Value	GDE type
Tuart/Peppermint forests and woodlands	Spearwood upland community 2	Recommended: Tuart woodland in good or better condition[1]	High	In situ
Limestone woodlands and heaths	Spearwood upland community 3		High	NA

[1] *based on mapping and conservation priorities recommendation in Freeman et al. (2009)*

Several occurrences of the endangered TEC, *Melaleuca huegelii – Melaleuca acerosa* shrublands on limestone ridges, were recorded and one occurrence of the Priority 3, Southern *Eucalyptus gomphocephala – Agonis flexuosa* woodlands (Table 19). Of these, *M. huegelii – M. acerosa* shrubland often occurs where depth to groundwater is about 10 m and they may be accessing groundwater.

Table 19 Lake Clifton subarea – threatened ecological communities

Community ID	Common Name	Conservation significance	GDE type
SCP 26a	*Melaleuca huegelii – Melaleuca acerosa* (currently *M. systena*) shrublands on limestone ridges (Gibson, Keighery et al. 1994)	Endangered	Subsurface
SCP25	Southern *Eucalyptus gomphocephala – Agonis flexuosa* woodlands	Priority 3	In situ

Occurrences of two Priority 4 and two Priority 3 species have been recorded in the subarea (Table 20). Only one of these, *Sphaerolobium calcicola,* a small flowering shrub, shows a preference for interdunal swaps and low-lying areas indicating groundwater dependence.

Table 20 Lake Clifton subarea – flora of conservation significance

Species	Conservation significance	GDE type
Acacia semitrullata	Priority 4	NA
Caladenia speciosa	Priority 4	NA
Hibbertia spicata subsp. leptotheca	Priority 3	NA
Sphaerolobium calcicola	Priority 3	Subsurface

Fauna

The endangered Carnaby's Cockatoo and the priority Western Brush Wallaby have been recorded within the subarea (Table 21). A recent study of the Western Brush Wallaby on the Gnangara Mound has found that due to their habitat preferences this species has a strong dependence upon groundwater and should be considered susceptible to declining groundwater levels (Wilson, Valentine et al. 2012).

Table 21 Lake Clifton subarea – threatened and priority fauna species

Scientific name	Common name	Conservation significance	GDE type
Macropus irma	Western Brush Wallaby	Priority 4	Subsurface
Calyptorhynchus latirostris	Carnaby's Cockatoo	Endangered	Subsurface

Wetlands

The Lake Clifton subarea is bounded on the west by Lake Clifton. There are several small wetlands in the north-east and south-east corners. These are recognised as EPP lakes and/or have a ‘conservation category’ management classification.

The wetlands present in the north-east corner of the subarea are situated on dtgw of less than 3 m and are likely to be receiving groundwater (Figure 9-right).

As discussed in Section 5.4, while Lake Clifton is outside the subarea boundary, the hydrology of the subarea will have a direct effect on the lake and the critically endangered thrombolite community.

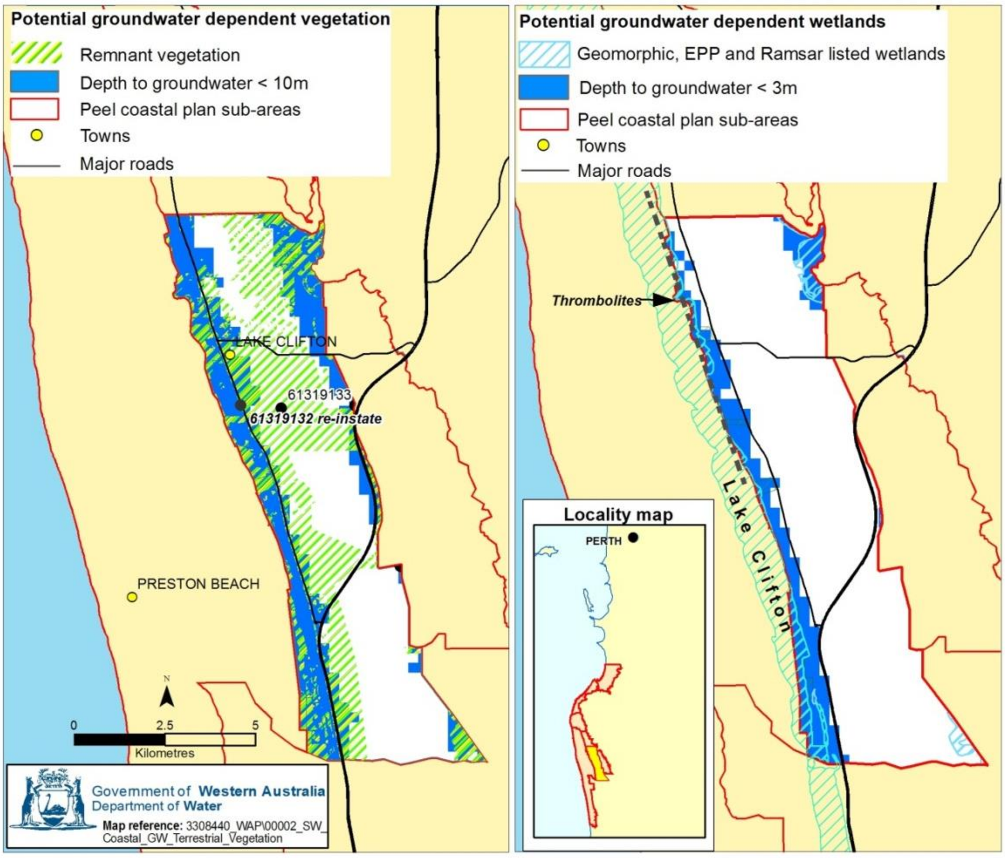

Figure 12 Lake Clifton subarea: left) areas of dtgw < 10 m and remnant vegetation, right) areas of dtgw < 3 m and significant wetlands

2.9 Colburra Downs subarea

Mapping

About 95 per cent of Colburra Downs sits on dtgw of less than 10 m (Figure 13-left) and could support GDE. The occurrence of dtgw of less than 3 m is largely restricted to the northern half of the subarea (Figure 13-right).

Conservation significance

Vegetation and flora

Colburra Downs has been largely cleared for pasture and has less than 15 per cent remnant vegetation cover. Remnant vegetation belongs to the Karrakatta Complex (central and south), Yoongarillup Complex, Vasse Complex and Bassendean Complex (central and south) and Serpentine River Complex (Table 22). They all have < 40 per cent of their pre-European extent remaining.

Table 22 Colburra Downs subarea – vegetation

Vegetation Complex	Conservation significance?	Value	GDE type
Karrakatta Complex (central and south)	Yes < 40% remaining – likely to be disturbed	Moderate	Subsurface
Yoongarillup Complex	Yes < 40% remaining – likely to be disturbed	Moderate	Subsurface
Vasse Complex	Yes < 40% remaining – likely to be disturbed	Moderate	Subsurface
Serpentine River Complex	Yes < 40% remaining – likely to be disturbed	Moderate	Subsurface
Bassendean Complex (central and south)	Yes < 40% remaining – dependent on condition		Subsurface

The critically endangered *Caladenia huegelii* and Priority 3 *Angianthus drummodii* have both been identified at one site within the subarea (Table 23).

Table 23 Colburra Downs subarea – flora of conservation significance

Species	Conservation significance	GDE type
Angianthus drummondii	Priority 3	NA
Caladenia huegelii	Critically endangered	NA

Fauna

There are no reported occurrences of conservation significant fauna species within the Colburra Downs subarea.

Wetlands

The Colburra Downs subarea is bounded on the eastern and northern edges by the Harvey River. In addition, 20 wetlands in the subarea are recognised as EPP lakes and/or have a management category classification of 'conservation category' (Figure 13).

The majority of wetlands are situated on dtgw less than 3 m and are likely to be groundwater dependent. Across the southern half of the subarea there is a suite of wetlands situated on dtgw 3.2–5 m. These wetlands have been classified as sumplands (Department of Environment and Conservation 2007) and while there may be some perch water, are likely to be interacting with the autumn water table.

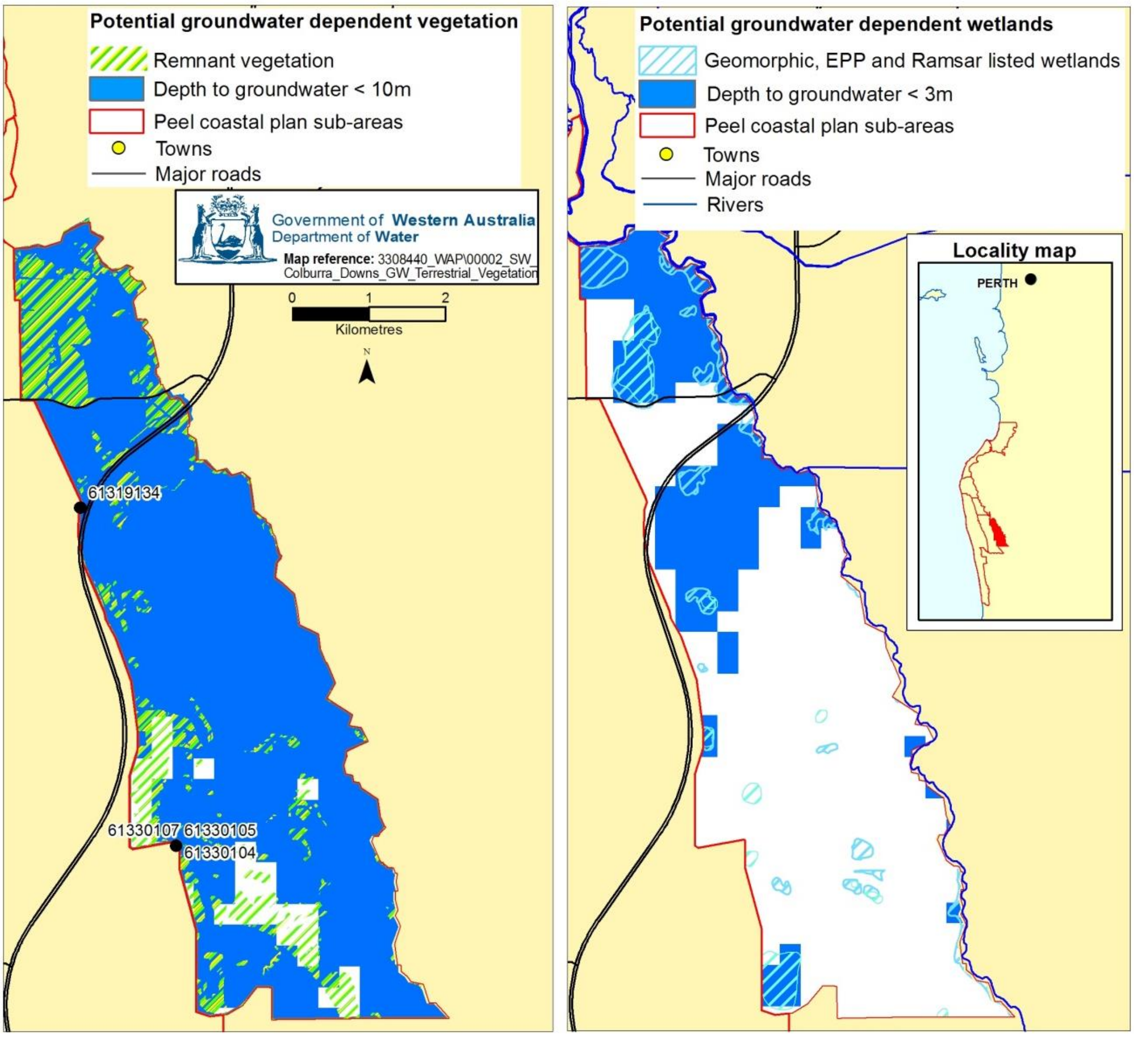

Figure 13 Colburra Downs subarea: left) areas of dtgw < 10 m and remnant vegetation, right) areas of dtgw < 3 m and wetlands

2.10 Summary of subarea environmental values

- Mandurah subarea

While the majority of the native vegetation was cleared for urban development the remaining vegetation supports a number of flora and fauna species of conservation value. This subarea is considered to be of moderate environmental value.

- Falcon subarea

Much of the Falcon subarea (70 per cent) sits over shallow groundwater (< 10 m). The Falcon subarea is the most urbanised in the Peel Coastal plan area, retaining only about 15 per cent of its native vegetation cover. The subarea is of low environmental value.

- Whitehills subarea

Approximately half of the subarea is sitting on shallow groundwater (< 10 m). The area has high environmental values as much of it is within the Yalgorup National Park, the Peel-Yalgorup Ramsar site is nearby and large tracts of Tuart (*Eucalyptus gomphocephala*) forest remain intact.

- Island Point subarea

Only a relatively small section of the subarea is across shallow groundwater. However, it has high environmental values as it is bounded on the west by Lake Clifton and on the east by the Peel-Harvey Estuary, both of which are part of the Ramsar-listed Peel-Yalgorup wetland system. In addition, the internationally significant Thrombolite community at Lake Clifton is reliant on groundwater originating from this subarea. Similarly, the Peel-Harvey Estuary is also likely to be receiving groundwater discharge from Island Point.

- Coastal subarea

The environmental values of the Coastal subarea are very significant. It is the largest in the Peel Coastal area and currently retains about 80 per cent of its vegetation cover and therefore diverse habitats. The subarea contains the Yalgorup Lakes System which is recognised internationally under the Ramsar Convention and nationally under the Directory of Important Wetlands in Australia and the Register of National Estate. Lake Clifton is unique because it supports the largest known population of living non-marine microbialites (Thrombolites).

- Lake Clifton subarea

The Lake Clifton subarea retains less than 50 per cent of its native vegetation with large areas cleared for tree plantations, small-scale agriculture and rural blocks. Despite the area's low in-situ environmental values, groundwater from the subarea supports Lake Clifton and the critically endangered Thrombolite community.

- Colburra Downs subarea

The Colburra Downs subarea has low environmental values. About 95 per cent sits over shallow groundwater (< 10 m) but it is largely cleared for pasture and has less than 15 per cent remnant vegetation cover.

2.11 Water for the environment

As part of our planning process we consider the volume of water that needs to remain in the system to support groundwater-dependents ecosystems and their identified values. This was considered by the project team during allocation limit setting.

Determining environmental water

We estimated groundwater use by dependent vegetation using diurnal water-table fluctuations. These daily fluctuations are a direct product of plant water use during the day and recovery of groundwater levels overnight when vegetation water use is minimal (Figure 14). The pattern of drawdown and recovery can be analysed to estimate the evapo-transpiration rate of groundwater (ET_G) by the overlying vegetation.

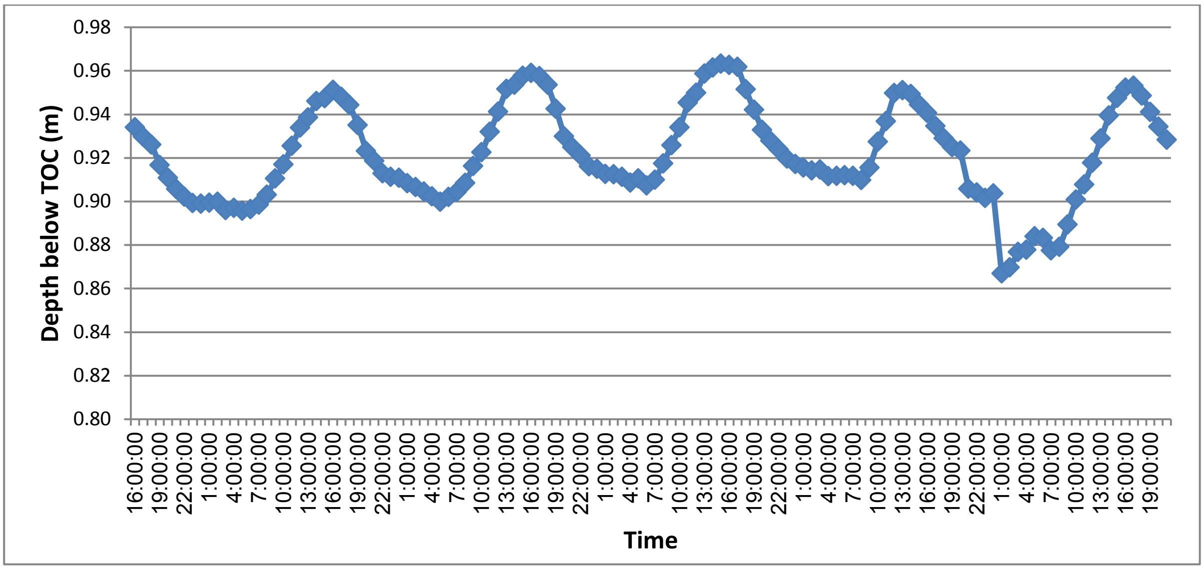

Figure 14 Hydrograph of hourly water level data in bore YSH3 showing diurnal fluctuations from 30/11/2012 to 06/12/2012

ET_G is defined as evapotranspiration from the saturated zone including the capillary fringe water zone. Estimates of ET_G were calculated using the method proposed by White (1932) and the original equation with exceptions as detailed.

$ET_G = S_y(24r_{GW}\pm s)$ (1)

where:

S_y = specific yield: the volume of water released per unit of water table fluctuation. We have varied S_y to account for the shorter drainage times as detailed below.

r_{GW} = groundwater recovery: normally calculated from the rate of water table rise between 00:00 and 04:00 and extrapolated out to 24 hours. This has been adjusted to be extrapolated from the minimum groundwater level between 02:00 and 06:00 to suit the conditions in the study area.

S = net change in water table elevation during 24 hours. This takes account of changes in water table due to throughflow.

The four key assumptions of the White (1932) method are:

1. Daily water table fluctuations are due to ET by vegetation.
2. The rate of groundwater inflow into the site is constant throughout the day.
3. ET is small during the time used to calculate the groundwater recovery.
4. Specific yield represents the volume of water extracted from the saturated zone, per drop in the water table per unit area of the site.

To address assumptions 1 and 2, barometric pressure, temperature and precipitation were recorded. Data were removed or compensated for as necessary based on these measurements. Groundwater abstraction can affect the rate of inflow into the site but around the loggers is expected to be minimal and so we have not compensated for this variable.

To address assumption 3, we must assume that ET_G rates are very low for the four hours preceding daily minimum groundwater levels. Improved field techniques (sapflow) show that night-time transpiration often occurs but at rates lower than in the daytime (Fisher, Baldocchi et al. 2007; Mereu, Gerosa et al. 2009). We have not compensated for night-time evaporation. This may result in an underestimate of ET_G, both by failing to count night-time ET and by underestimating recharge.

The value used for specific yield (assumption four) is the most significant source of potential error in this technique. As discussed in Loheide et al. (2005), specific yield calculated from traditional methods (i.e. pump tests) does not take account of the various properties of the aquifer nor the shorter drainage times that are necessary for quantifying drainage at a daily rate. In this study, values of specific yields were selected based on the guidelines presented in Loheide et al. (2005) or by using other data.

Data collection and results

Loggers were deployed into three bores across the study area and set to log at hourly intervals. We also used data collected from an additional logger site outside the study area (bore EWB05; Table 4).

ET_G was calculated using data collected from all four bores (results for YSH3 are shown in Figure 15). We discarded all negative values and values from days with rain, following a visual inspection of outliers.

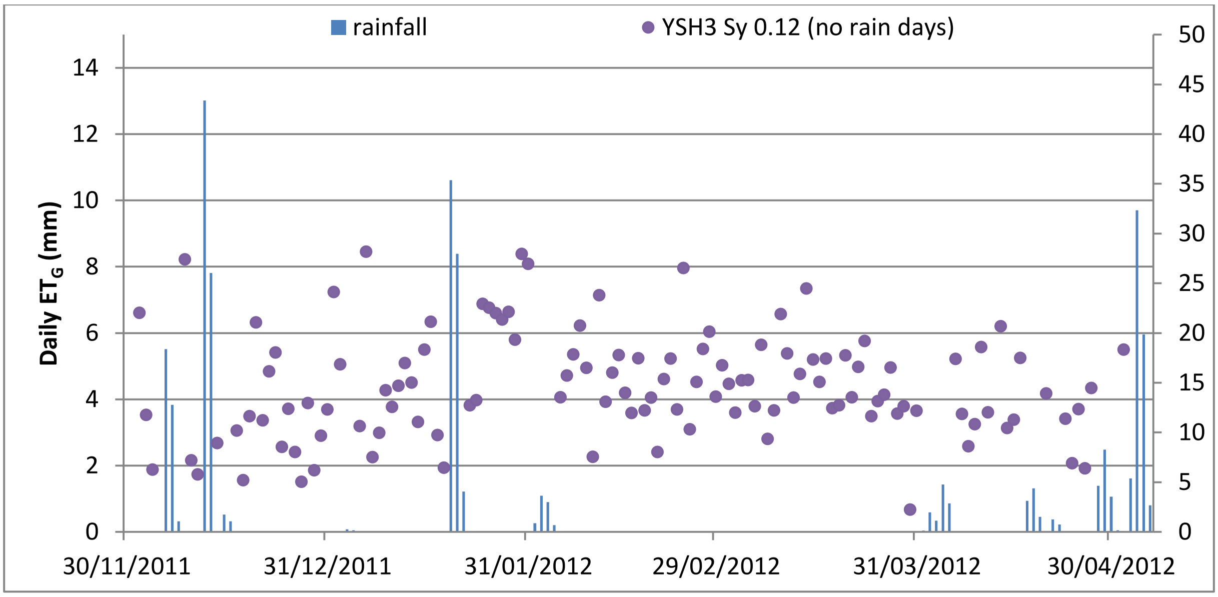

Figure 15 Daily ET_G at YSH3 excluding rainy days

Summary results from all sites are shown in Table 24. From these results we have categorised ET_G rates into the depth to groundwater categories of 0–3 m, 3–6 m and 6–10 m (Table 25).

Table 24 Bores equipped with loggers and summary details, including calculated average daily ET_G

Details	YSH4 61319530	YSH3 61319529	EWB05 (outside study area)	Y24B 61319507
Depth to groundwater (range)	0.90 to 1.5 m	0.70 to 1.1 m	2.8 to 3.5 m	11.8 to 12.0 m
Sediment texture	Sand	Carbonate mud	Sand	Silty sand
Readily available specific yield	0.18	0.12	0.18	0.14
Mean calculated daily ET_G	4.36 mm	4.39 mm	2.52 mm	0 mm No distinct diurnal fluctuation

Table 25 Depth to groundwater (dtgw) categories and estimated daily ET_G rates

DTGW category	Daily ET_G
0–3 m	4.38 mm
3–6 m	2.52 mm
6–10 m	1.25 mm
> 10 m	0.00 mm

There was no distinct diurnal fluctuation evident in bore Y24B where groundwater was deeper than 10 m. From this we have assumed that ET_G at depths greater than 10 m is minimal. Also, no daily ET_G results were available for the 6–10 m depth category so we have used the midpoint between the 3–6 m and > 10 m category.

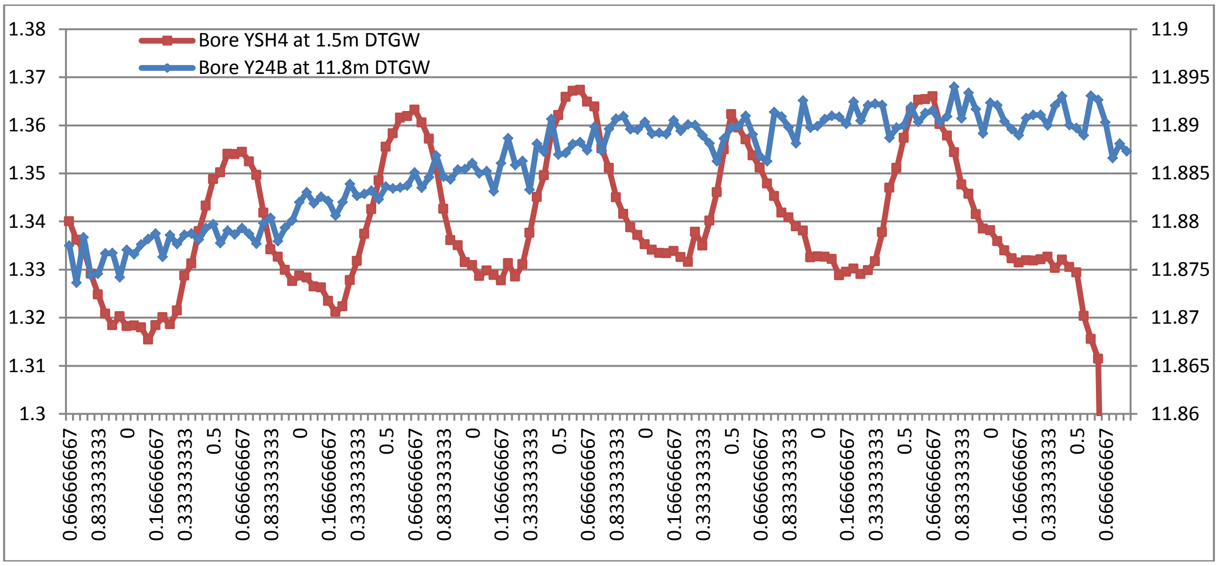

Figure 16 Comparison of diurnal fluctuation patterns between shallow (YSH4) and deep bores (Y24B)

Upscaling to total vegetation groundwater use

ET_G represents a measure of the volume of water being used by vegetation at a particular point in the landscape. To use this in developing allocation limits a volumetric measure of groundwater use is needed. To do this we used a simplistic approach to scaled up the point source calculated ET_G by extrapolating the results across the subareas based on the depth to groundwater categories; i.e. an assumption that all vegetation where groundwater is 0–3 m deep will be using groundwater at a rate of 4.38 mm/day.

We further refined the process by excluding saline wetland vegetation communities (Table 26). We have also excluded 50 days per year: the approximate number of days per year with significant rainfall (> 20 mm). We have done this to take into account the lower evapotranspiration demand on rainy and overcast days.

Tuarts (*Eucalyptus gomphocephala*) have been mapped across dtgw ranges of 0 m to greater than 40 m, suggesting they are not highly groundwater dependent. This is supported by a recent investigation of the water-source partitioning of Tuarts which concluded that they may use groundwater opportunistically rather than having a dependence on it (Drake, Froend et al. 2011).

We have calculated ET_G for Tuart dominated communities and classified them as being groundwater dependent when situated on dtgw less than 10 m. This may be an area where further refined of ET_G can be undertaken.

This technique does not take into account any spatial or temporal variability in plant water use and assumes that vegetation structure and groundwater use is homogenous based solely on depth to groundwater. As we only have seven months of data we are assumed that ET_G will remain constant within the year and across years.

Due to the uncertainties inherent in this approach, we did not use the results presented here as a stand-alone method to describe water requirements of the groundwater-dependent ecosystems. We did, however, consider this information as we developed a risk-based approach to calculating allocation limits.

Table 26 Mapped communities, their depth to groundwater (dtgw) range and inclusion in ET_G calculation

Plant community		DTGW range	ET_G inclusion
Estuarine Samphire Shrublands	Estuarine Samphire Shrublands	< 3 m	No
Island Vegetation	Island Vegetation	< 3 m	Yes
Lake Fringing Community 1a	Lakeside Samphire Shrublands	< 3 m, often <1 m	No
Lake Fringing Community 1b	*Juncus kraussii* Sedgelands	< 3 m, often <1 m	No
Lake Fringing Community 2	*Melaleuca cuticularis* Low Forest	< 3 m	No
Lake Fringing Community 3a	*Melaleuca rhaphiophylla* Low Forest	< 3 m	Yes
Lake Fringing Community 3b	Wet Tuart Forest	Generally < 3 m	Yes
Mixed Shrub Calcareous Flat Wetlands	Mixed Shrub Calcareous Flat Wetlands	< 3 m	Yes
Quindalup Uplands Community 1a	Coastal Grasslands and Low Shrublands	along coast <10 m up to > 20 m	No
Quindalup Uplands Community 1b	Acacia/Melaleuca Coastal Heath and Shrublands	often >10 m	No
Quindalup Uplands Community 2	Tuart/Peppermint Coastal Forests and Woodlands	< 3 to 20 m	In situ
Quindalup Wetlands	*Juncus kraussii* and *Baumea juncea* Sedgelands, Scattered *Melaleuca viminea*	often < 3 m	Yes
Spearwood Uplands Community 1	Eucalyptus/Banksia Open Low Woodland	10 to >20 m	No
Spearwood Uplands Community 2	Tuart/Peppermint Forests and Woodlands	3 to > 20 m	In situ
Spearwood Uplands Community 3	Limestone Woodlands and Heaths	3–20 m	In situ

2.12 Groundwater used by vegetation for subareas

Mandurah subarea

About 17 per cent of the Mandurah subarea is covered by remnant vegetation situated on dtgw of less than 10 m. We have excluded 3 per cent of this from the ET_G calculation as it has been classified as Quindalup complex and is considered unlikely to be groundwater dependent. Calculated ET_G for the Mandurah subarea is shown in Table 27.

Table 27 Calculated ET_G by groundwater-dependent vegetation across the Mandurah subarea

Depth (m)	Subarea (m^2)	Vegetation cover (%)	ET_G (mm/day)	Yearly ET_G (less rain days)	Areal ET_G (GL/yr)
0 to 3	61482335	0.05	4.38	1379.70	4.24
3 to 6	61482335	0.03	2.52	793.80	1.46
6 to 10	61482335	0.06	1.25	393.75	1.45
					7.16

Falcon subarea

About 14 per cent of the Falcon subarea is covered by remnant vegetation situated on dtgw less than 10 m. We have excluded four per cent of this from the ET_G calculation as it has been classified as Quindalup complex and is considered unlikely to be groundwater dependent. Calculated ET_G for the Falcon subarea is shown in Table 28.

Table 28 Calculated ET_G by groundwater-dependent vegetation across the Falcon subarea

Depth (m)	Subarea (m^2)	GDE cover (%)	ET_G (mm/day)	Yearly ET_G (less rain days)	Areal ET_G (GL/yr)
0 to 3	35608259	0.02	4.38	1379.70	0.98
3 to 6	35608259	0.03	2.52	793.80	0.85
6 to 10	35608259	0.05	1.25	393.75	0.70
					2.53

Whitehills subarea

About 39 per cent of the Whitehills subarea is covered by remnant vegetation situated on dtgw of less than 10 m. We have excluded five per cent of this from the ET_G calculation as it has been classified as Quindalup or Spearwood upland plant community and is considered unlikely to be accessing groundwater. Calculated ET_G for this subarea is shown in Table 29.

Table 29 Calculated ET_G for groundwater-dependent vegetation in the Whitehills subarea

Depth (m)	Subarea (m^2)	GDE cover (%)	ET_G (mm/day)	Yearly ET_G (less rain days)	Areal ETg (GL/yr)
0 to 3	35050107	0.03	4.38	1379.70	1.45
3 to 6	35050107	0.15	2.52	793.80	4.17
6 to 10	35050107	0.16	1.25	393.75	2.21
					7.83

Island Point subarea

About 20 per cent of Island Point subarea is covered by remnant vegetation situated on dtgw of less than 10 m. We have excluded three per cent of this from the ET_G calculation as it has been classified as Quindalup or Spearwood upland plant community or saline wetland vegetation. Calculated ET_G for this subarea is shown in Table 30.

Table 30 Calculated ET_G for groundwater-dependent vegetation in the Island Point subarea

Depth (m)	Subarea (m^2)	GDE cover (%)	ET_G (mm/day)	Yearly ET_G (less rain days)	Areal ET_G (GL/yr)
0 to 3	18962546	0.07	4.38	1379.70	1.83
3 to 6	18962546	0.05	2.52	793.80	0.75
6 to 10	18962546	0.05	1.25	393.75	0.37
					2.96

No work has been done to quantify groundwater discharge into Lake Clifton. EPA Bulletin 788 (1995) recommended that 1.1 GL/yr remain in situ as discharge into Lake Clifton to maintain lake levels and the salt water interface on the eastern side of the lake.

Lake Clifton subarea

About 17 per cent of Lake Clifton subarea is covered by remnant vegetation situated on dtgw of less than 10 m. We have excluded six per cent of this from the ET_G calculation as it has been classified as Quindalup or Spearwood upland plant community or saline wetland vegetation. Calculated ET_G for Lake Clifton is shown in Table 31.

Another important component of groundwater use is discharge into Lake Clifton. EPA Bulletin 788 (1995) recommended that 1.6 GL/yr remain in situ as discharge into Lake Clifton to maintain lake levels and the salt water interface on the eastern side of the lake.

Table 31 Calculated ET_G for groundwater-dependent vegetation in the Lake Clifton subarea

Depth (m)	Subarea (m^2)	GDE cover (%)	ET_G (mm/day)	Yearly ET_G (less rain days)	Areal ET_G (GL/annum)
3 to 6	54057065	0.04	2.52	793.80	1.72
6 to 10	54057065	0.07	1.25	393.75	1.49
					3.21

Coastal subarea

About 26 per cent of the Coastal subarea is covered by remnant vegetation situated on dtgw of less than 10 m. We have excluded eight per cent of this from the ET_G calculation as it has been classified as Quindalup or Spearwood upland plant community or saline wetland vegetation. Calculated ET_G for groundwater-dependent vegetation is shown in Table 32.

Table 32 Calculated ET_G for groundwater-dependent vegetation in the Coastal subarea

Depth (m)	Subarea (m^2)	GDE cover (%)	ET_G (mm/day)	Yearly ET_G (less rain days)	Areal ET_G (GL/annum)
0 to 3	148402279	1	4.38	1379.70	2.05
3 to 6	148402279	8	2.52	793.80	9.42
6 to 10	148402279	9	1.25	393.75	5.26
					16.73

Colburra Downs subarea

About 13 per cent of the Colburra Downs subarea is covered by remnant vegetation situated on dtgw of less than 10 m. Calculated ET_G for this groundwater-dependent vegetation is shown in Table 33.

Another important component of groundwater use in the Coastal subarea is discharge into the Yalgorup Lake system. EPA Bulletin 788 (1995) recommended that 1.9 GL/yr remain in situ as discharge into Lake Clifton to maintain lake levels and the salt water interface on the western side of the lake. More recent investigations suggest that Lake Clifton does not receive groundwater from the Coastal subarea, rather that this groundwater discharges into the chain of minor lakes to the east of Lake Clifton and into Lake Preston (Noble 2010; RPS 2011)

Shams (Water and Rivers Commission 1999) calculated groundwater discharge into Lake Preston from the west to be about 2 GL/yr while RPS (2011) estimated groundwater discharge to be in the order of 6.1 GL/yr.

Table 33 Calculated ET_G for groundwater-dependent vegetation in the Colburra Downs subarea

Depth (m)	Subarea (m^2)	GDE cover (%)	ET_G (mm/day)	Yearly ET_G (less rain days)	Areal ET_G (GL/annum)
0 to 3	24311953	0.03	4.38	1379.70	1.01
3 to 6	24311953	0.05	2.52	793.80	0.96
6 to 10	24311953	0.05	1.25	393.75	0.48
					2.45

3 Support setting of plan objectives and allocation limits

The Department of Water must provide for both the sustainable use and development of water resources and the protection of ecosystems associated with them.

3.1 Setting objectives

Plan outcomes and resource objectives

Plan outcomes are what we aim to achieve by implementing water resource management. We considered the ecological values described in this report when determining the following outcome for the Peel Coastal groundwater allocation plan:

> *Protect valuable ecosystems dependent on groundwater, including those of the Peel-Yalgorup wetland system, from impacts of abstraction.*

To ensure we meet the outcomes we manage to a number of resource objectives. They must be measurable so that progress against them can be assessed during regular plan evaluations.

We set objectives by taking into account numerous issues including environmental requirements and objectives.

Environmental objectives

We set environmental objectives at selected reference sites (Table 34). These objectives relate to how we expect the water resource to change, or remain, over time at reference sites across the plan area.

We used the mapping of groundwater-dependent ecosystems and their environmental values, as described in this report, to set the environmental objectives and to guide how we manage risks to the GDE.

The reference site environmental objectives were set by considering the:

- water-dependent ecological values
- water resource objectives of the water allocation plan
- predicted impacts of climate change.

Table 34 Ecological reference sites and objectives

Subarea	Reference site environmental values	Reference site environmental objectives
Mandurah	Remnant groundwater-dependent vegetation – high value	1. Maintain groundwater levels to support groundwater-dependent vegetation.
Whitehills	Estuary riparian vegetation – critical value	2. Maintain groundwater quality to support groundwater-dependent vegetation
	Tuart woodlands – high value	
Island Point	Ramsar-listed Lake Clifton – critical value	3. Maintain groundwater discharge into Lake Clifton.
	Riparian vegetation and Ramsar-listed Lake Clifton – critical value	4. Maintain groundwater level to support riparian vegetation and groundwater discharge into Lake Clifton.
	Riparian vegetation and EPP wetland – critical value	5. Maintain groundwater level to support EPP wetland.
	Ramsar-listed Lake Clifton – critical value	Recommendation only: Maintain surface water level above trigger for rapid salinity increase.
Coastal	Riparian vegetation and Ramsar-listed Martins Tank Lake – critical value	6. Maintain groundwater level to support riparian vegetation and maintain discharge into Martins Tank Lake.
	Riparian vegetation and Ramsar-listed Lake Preston – critical value	7. Maintain groundwater level to support riparian vegetation and maintain discharge into Lake Preston.

The ecological objectives were used to formulate resources objectives in the plan (Table 35).

Table 35 Ecological objectives and equivalent resource objective

Ecological objective (from Table 34)	Resource objective in the Plan
1, 2, 4, 5	3. maintain groundwater levels in the Superficial aquifer that minimise risk to groundwater-dependent ecosystems
3, 4, 6, 7	4. maintain fresh groundwater discharge into Lake Clifton, Lake Preston and Martin’s Tank to minimise risk to dependent ecological values.

Reference sites and the water regime that should be maintained to meet the environmental objectives are discussed in more detail in section 4.1

Proposed strategies to achieve these objections are discussed in sections 4.2, 4.3 and 4.4.

3.2 Allocation limits

An allocation limit is the annual volume of water set aside from a water resource for consumptive use such as household, urban, irrigation, stock, mining or industrial use. Allocation limits are a balance between current and future groundwater use, and the volume of water that we choose to retain in the aquifer for environmental and resource-protection purposes.

Due to the relatively low use of groundwater (compared to other areas of the state) the department does not have an extensive monitoring program in the plan area. As a result, the extensive data needed to support quantitative methods for setting allocation limits, such as a numerical model, were not available.

We therefore used a risk-based approach to set allocation limits. This typically involves understanding how current levels of use have affected the resource and calculating whether more or less water can be allocated while still achieving the plan's outcomes and objectives.

To allow us to consider the possible future impacts of abstraction on groundwater-dependent values, we estimated the amount of groundwater – environmental water requirements – used by the dependent ecosystems in each subarea. This was based on ET_G as discussed in section 4.2. For further detail on how this information was used refer to the allocation methods report (DoW 2014b).

The outcomes of this risk based approach resulted in reduced allocation limits across the plan area from 17.3 GL to 8.8 GL (Table 36).

Table 36: Allocation limits for the Superficial aquifer (by subarea) in the Peel Coastal plan area

Subarea	Previous allocation limit (kL)	New allocation limit *(current use)* (kL)
Mandurah	5 000 000	4 653 729
Falcon	1 800 000	2 321 923
Island Point	1 600 000	568 375
Whitehills	200 000	335 909
Lake Clifton	3 000 000	661 440
Coastal	4 100 000	192 550
Colburra Downs	1 600 000	70 000
TOTAL	**17 300 000**	**8 803 926**

4 Define the management approach

This section describes the management approach we will use to address our ecological objectives and which will be set in the allocation plan. Our approach includes:

- GDE reference sites across the plan area, with management triggers
- monitoring program and a management response framework
- local licensing policies
- local licensing strategy for licensing officers.

4.1 Groundwater-dependent ecosystem reference sites and management framework

To better manage the resource we described ecological water requirements, in the form of minimum groundwater reference levels, for selected sites in the plan area.

It is expected that ecosystems can tolerate some change to average minimums and remain at a low level of risk (Froend & Loomes 2004). These groundwater levels will therefore maintain the regional water regime necessary to achieve the plan objectives and maintain key groundwater-dependent environmental features. They will alert the department of reductions in groundwater levels that may affect the groundwater-dependent environment.

We have developed reference levels as a way of highlighting changes to water regimes that might affect groundwater-dependent ecosystems. We have taken this approach rather than setting hard criteria (not to be breached) as there is still some uncertainty over which groundwater source some ecosystems are using and what their ecological thresholds (to water regime change) may be.

We selected representative sites: wetlands of high conservation value and areas of terrestrial vegetation, using wetland and vegetation mapping and analysis of aerial photography. Generic ecological water requirements, in the form of maximum drawdown (m), were established for each site.

We used long-term groundwater monitoring data and published information on vegetation response to groundwater drawdown to develop these minimum levels. They are developed based on our understanding of how the water regime supports the groundwater-dependent ecosystem and indicate the groundwater level that will sustain groundwater-dependent values.

Nine groundwater reference sites and one surface water reference site have been selected. When setting the reference water level we considered the:

- groundwater-dependent values
- presence of groundwater-dependent rare species or communities
- species most vulnerable to water regime change

- infrastructure
- historical data.

Where sufficient historical data were available, an 'average minimum' for the site was calculated using yearly minimum groundwater levels recorded since 1992.

To quantify the magnitude of acceptable water level change, we used findings from research on the response of Banksia species on the Gnangara Mound to changes in groundwater level (Froend & Loomes 2004). This work set generic criteria for maintaining wetland and terrestrial vegetation at low, moderate, and high levels of risk from groundwater level change. The recommended decline rates to maintain vegetation at a low level of risk are summarised in Table 3.

Hydrographs show groundwater levels have only declined slightly in the long term across most plan subareas, despite licensed abstraction and declining rainfall. It is suggested that the Indian Ocean and the Peel Inlet buffer groundwater levels in these subareas, suppressing any large responses to rainfall declines or abstraction (Macaulay 2012).

A suppressed response in groundwater fluctuations may mean that local vegetation is more sensitive to declines than expected. We used more stringent magnitudes of decline to ensure that the reference groundwater levels take account of the smaller natural variations expected at these sites (Table 37).

Table 37 Acceptable magnitude and rate of groundwater decline

Groundwater-dependent ecosystems type	**Magnitude (m) and rate (m/yr) of decline to maintain vegetation at a low level of risk (Froend & Loomes 2004)**		**Magnitude (m) of decline applied to the Peel plan area**
Wetland vegetation 0–3 m depth to groundwater	< 0.25	< 0.10	< 0.25
Terrestrial vegetation 0–3 m depth to groundwater	< 0.75	< 0.10	< 0.25
Terrestrial vegetation 3–6 m depth to groundwater	< 1.00	< 0.10	< 0.25
Terrestrial vegetation 6–10 m depth to groundwater	< 1.25	< 0.10	< 0.50

We have also set reference groundwater levels for representative wetlands that are maintained by groundwater discharge using the same premise.

We recognise that the effects of rainfall and abstraction may be reflected in the thickness of the low salinity lens and the position of the salt water interface/mixing zone rather than in changing groundwater levels (pers. comm. Phil Commander, 2012). Monitoring groundwater levels alone in these instances will not be sufficient because water quality may change significantly without any change in water levels. In these instances, water quality monitoring and criteria will need to be put in place.

Further reductions in rainfall are predicted for the plan area, and that this, as well as groundwater abstraction, may affect the water available to ecosystems. Where possible we have quantified the impact of declining rainfall on groundwater level using historical groundwater and climate datasets. This provides water resource managers with a tool to identify if the previous year's annual rainfall may have contributed to a decline in the following year's maximum groundwater level.

4.2 Reference groundwater levels

Mandurah subarea

We currently monitor groundwater levels in bores 61410723 and 61410026 in the Mandurah subarea superficial aquifer (Figure 17).

Bore 61410723 has been monitored since 2010. Groundwater at this site is about 8.5 mbgl (metres below ground level) and supports an area of remnant vegetation mapped as Yoongarillup Complex, which is likely to be highly disturbed. The existing dataset is too short to define groundwater level trends or recommend reference groundwater levels.

Bore 61410026 has been monitored since 1975. Groundwater at this site is about 7.5 mbgl and supports an area of remnant vegetation mapped as Yoongarillup Complex. Monitoring shows a rising trend in groundwater over this period (Figure 17) not declining as expected based on reduced rainfall. This is likely to be a result of recharge water from the nearby Gordon Road Waste Water treatment plant artificially maintaining groundwater levels.

Ecological values in this subarea are considered moderate and may be affected if waste water recharge does not continue to maintain groundwater levels. To support the values, a reference groundwater level of 0.13 mAHD is recommended. This is based on allowing a maximum decline of 0.5 m below the average minimum of 0.63 mAHD.

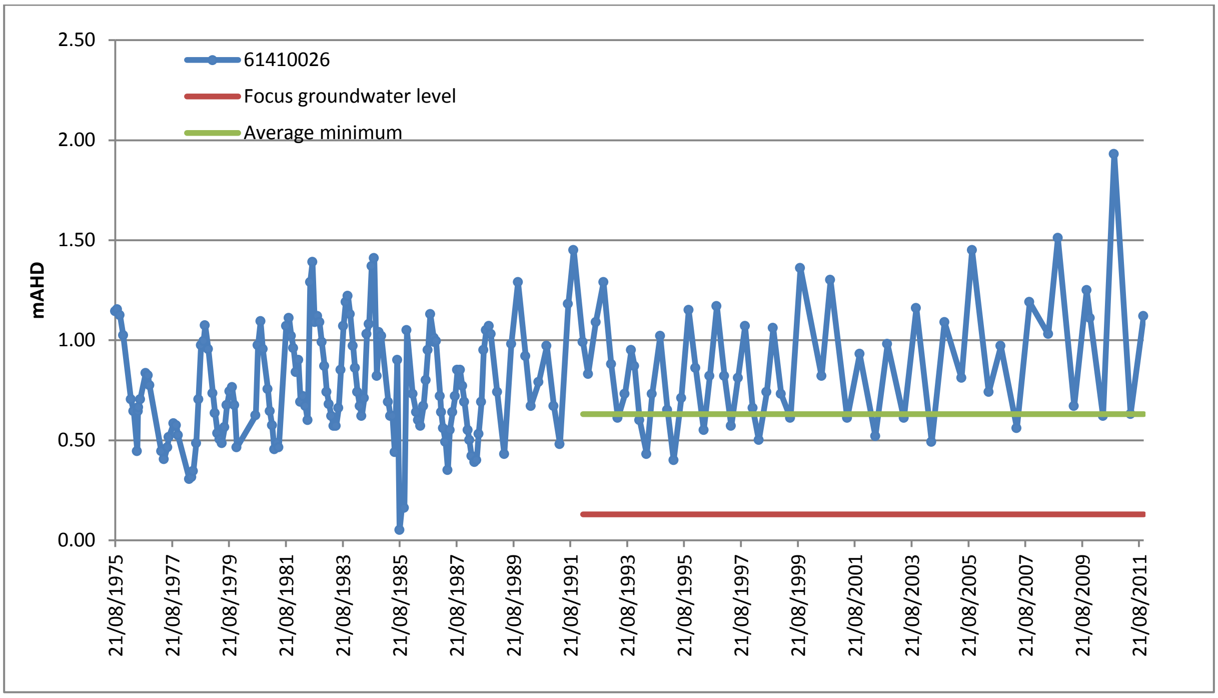

Figure 17 Bore 61410026 hydrograph with average minimum groundwater level calculated on 1992–2011 data, and reference groundwater level

Reference groundwater level for bore 61410026

A reference groundwater level of 0.13 mAHD (8.68 mbgl) is recommended for this site. This is based on allowing a maximum decline of 0.5m from the average minimum recorded since 1992.

Falcon subarea

We currently do not monitor the superficial aquifer in the Falcon subarea and have not set any reference groundwater levels. Groundwater monitoring data from bores located in the Whitehills subarea are likely to be representative of groundwater levels in the lower portion of Falcon.

Recommendation for monitoring

It is recommended that the department implement a strategy through the plan to utilise licensee compliance monitoring to track groundwater level and quality trends in the northern part of the subarea.

Whitehills subarea

We currently monitor five bores across the Whitehill subarea three times each in summer and winter. Details of these bores and of the environment they represent are show in Table 38.

Table 38 Whitehills subarea monitoring bores

Bore	DTGW category	Environment	Value	Period of data	Hydrograph analysis
61319123	6–10 m*	Tuart and Peppermint forest and woodland	High	1982–present	Responds seasonally to rainfall with overall stable dtgw
61319124	6–10 m	Limestone woodlands and Heaths	Medium	2003–present	Stable to slightly declining dtgw
61319126	6–10 m	Tuart and Peppermint forest and woodland	High	1995–present	Responds seasonally to rainfall with overall stable dtgw
61319127	3–6 m	Eucalyptus/Banksia open low woodland	Medium	1995–present	Responds seasonally to rainfall with overall stable dtgw
61319128	0–3 m	Interface with estuary and riparian vegetation	Critical	1982–present	Responds seasonally to rainfall with overall stable dtgw

** Bore 61319123 is situated on > 10 m dtgw but represents a nearby community situated on < 10 m*

Hydrograph analysis for all bores shows a seasonal response to rainfall but no evidence of declining groundwater levels in response to a drying climate or groundwater abstraction. Figure 19 shows hydrographs for the two bores with the longest datasets.

As discussed previously it is likely that the close proximity to both the Indian Ocean and the Peel Inlet is buffering groundwater levels and suppressing any response to declining rainfall (Macaulay 2012).

Therefore we have not set reference groundwater levels for this subarea but rather recommended that profile monitoring be implemented at the most eastern and western bores to record changes in the thickness of the freshwater lens.

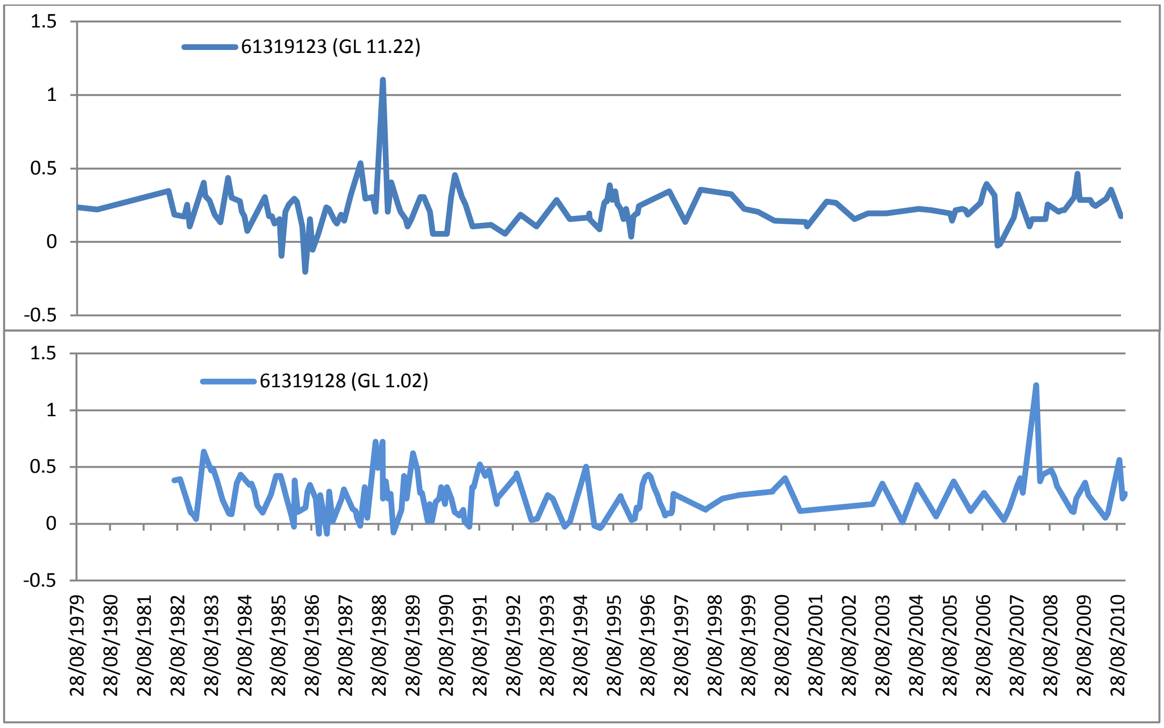

Figure 18 Hydrographs for bore 61319126 (top) and 61319128 (bottom)

Recommendation for monitoring

It is recommended that the Department commences water quality monitoring at the water table and through the water profile in bores 61319123 and 61319128 to monitor the thickness of the freshwater in response to rainfall and groundwater abstraction.

Island Point subarea

We currently monitor five bores in the superficial aquifer at three locations across Island Point. Details of these bores and bore 61319530 (to be reinstated) are shown in Table 39.

Hydrograph analysis indicates that groundwater levels respond seasonally to rainfall with an overall slight declining trend in groundwater level.

Reference groundwater levels were set for bores 61330103, 61319507 and 61319530 as discussed below. A reference surface-water level has also been recommended for Lake Clifton.

Table 39 Island Point groundwater monitoring bores

Bore	DTGW category	Plant community	Value/GDE	Period of data	Hydrograph analysis
61319507 and 61319508	>10 m	Tuart/peppermint forest and woodland with highly disturbed understorey	NA, but represents throughflow into Lake Clifton	1995 to current	Responds seasonally to rainfall with overall stable to slightly declining groundwater level

61319509	>10 m	Eucalyptus/Banksia open Low Woodland	NA	1995 to present	Responds seasonally to rainfall with overall stable to slightly declining groundwater level
61330102 and 61330103	0–3 m	Riparian vegetation in good condition aligning an EPP wetland	Critical groundwater-dependent asset	1982 to present	Responds seasonally to rainfall with overall stable to slightly declining groundwater level
61319530 (not current) YSH4	0–3 m	Riparian community of *Juncus kraussii* sedgeland in moderate condition aligning Lake Clifton and included in Ramsar listing	Critical groundwater-dependent asset	1995–98, to be re-instated	Insufficient data to define groundwater level trends

Reference groundwater level in bore 61330103

In bore 61330103 the average minimum depth to groundwater since 1992 has been 0.26 mAHD (2.65 mbgl). At this location shallow groundwater supports riparian vegetation and an EPP-listed wetland. Using the method discussed in section 4.1, a reference groundwater level of 0.01 mAHD (2.9 mbgl) would be applicable to this site to support these GDEs.

The hydrograph for this site shows groundwater levels dropped below this in 2003, 2007, 2010 and 2011 (Figure 19). Each of these years followed a year in which total annual rainfall fell below the 20th percentile (Figure 20). This demonstrates the impacts of low rainfall on minimum groundwater levels.

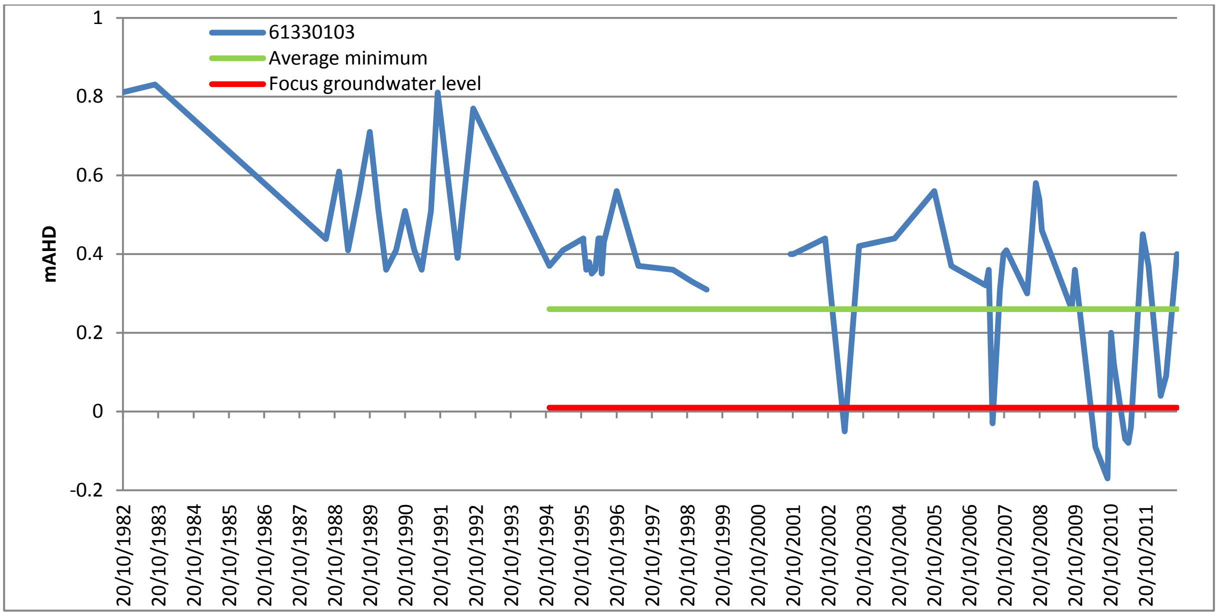

Figure 19 Bore 61330103 hydrograph with average minimum groundwater level calculated on 1992–2011 data, and reference groundwater level

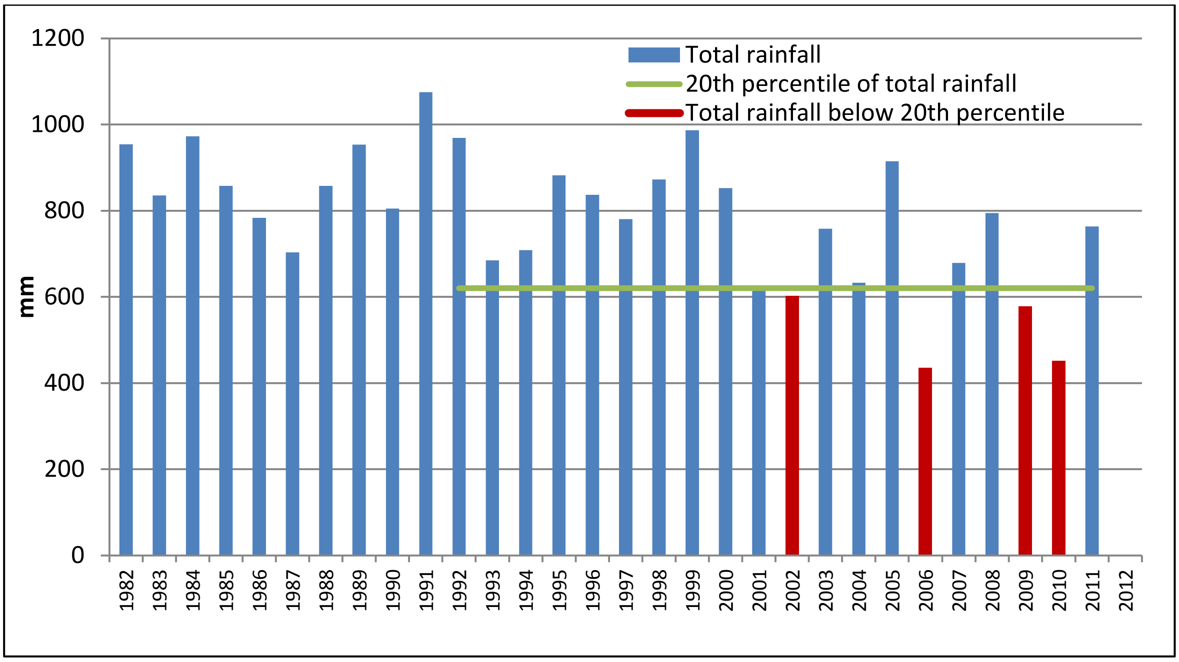

Figure 20 Total annual rainfall and 20th percentile calculated on total rainfall since 1992 with red bars showing occurrence of rainfall below 20th percentile

In bore 61330103 it is recommended that a reference groundwater level of 0.01 mAHD is set with the provision that this can be exceeded when the previous year's total annual rainfall is below the 20th percentile (620 mm).

Recommendation to DPaW for surface-water level trigger at Lake Clifton boardwalk

In addition to supporting riparian vegetation, groundwater discharge from the subarea directly supports the thrombolite community in Lake Clifton by providing fresh groundwater high in calcium and bicarbonate. It also helps maintain surface water levels in Lake Clifton that in turn prevent desiccation of the thrombolites and keep salinity in the system hyposaline.

Since 1985 DPaW has monitored surface water and salinity levels in Lake Clifton twice a year: in September and November. While this dataset represents end of winter levels, it is the most complete and consistent dataset available and is considered adequate for establishing trends in salinity and surface-water levels. Records show a steady decline in the surface-water level of Lake Clifton and a steady rise in salinity, both of which are likely to adversely affect thrombolite communities.

Modelling conducted by CSIRO suggests that the major driver of lake water level and salinity is rainfall, with groundwater abstraction having a comparatively small impact (Barr 2003). Plotting cumulative deviation from the mean rainfall (CDFM) against lake salinity supports the conclusion that rainfall is a strong driver of the current rise in lake salinity (Figure 21).

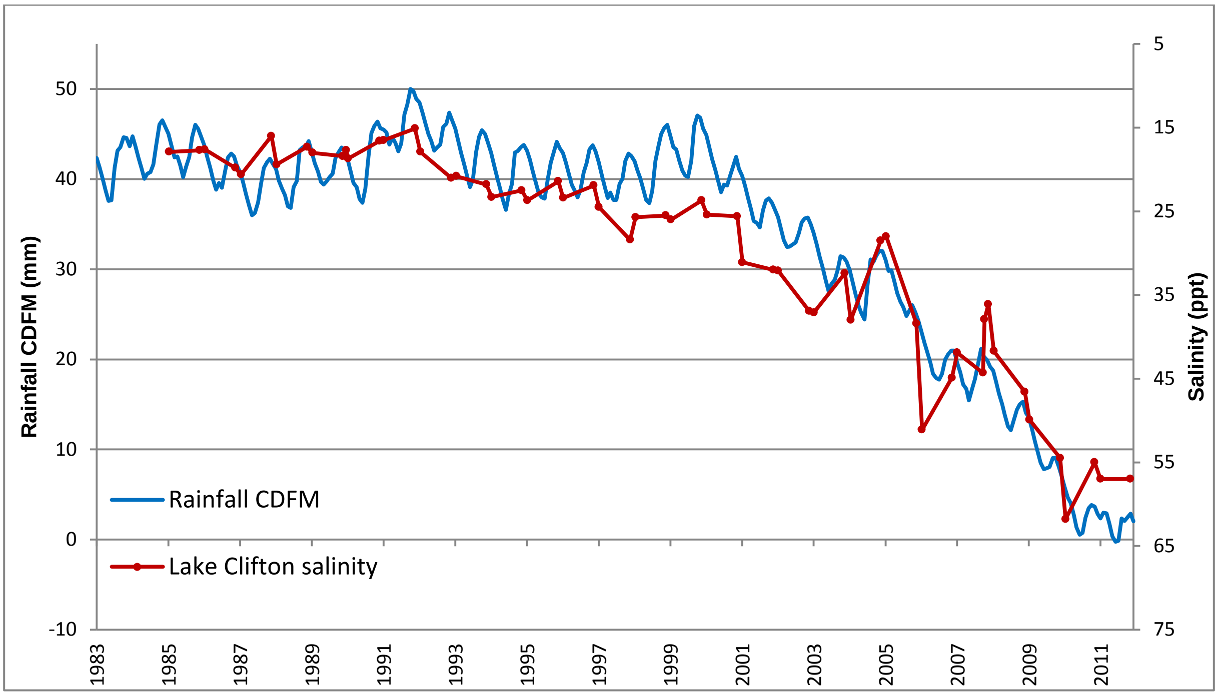

Figure 21 Rainfall CDFM and Lake Clifton salinity measured at the end of spring

Cumulative deviation from the mean rainfall (CDFM) is a simple arithmetical technique used for rainfall evaluation. The actual rainfall over a defined period is subtracted from the long-term mean rainfall of the same period. The deviations are plotted cumulatively in a diagram showing periods of above mean rainfall by the upward tending graph and of below mean rainfall in downward tending graph. Lake Clifton is generally a closed system and so saline water is not flushed from the system but rather accumulates with an overall trend of rising values. For this reason CDFM, which is basically a trending map, is considered to be a comparable analysis technique against salinity. The graph shows that rainfall CDFM is a good fit for salinity trends.

A rapid change in salinity beyond that predicted by rainfall occurred in May 2007 (Figure 21). This is likely to be a result of record low lake levels allowing underlying more saline groundwater to flow into the lake. Based on monitoring data, when Lake Clifton has a surface-water level of –0.165 mAHD there was no significant impact on salinity but salinity spiked when surface-water level was at –0.205 mAHD (Figure 22).

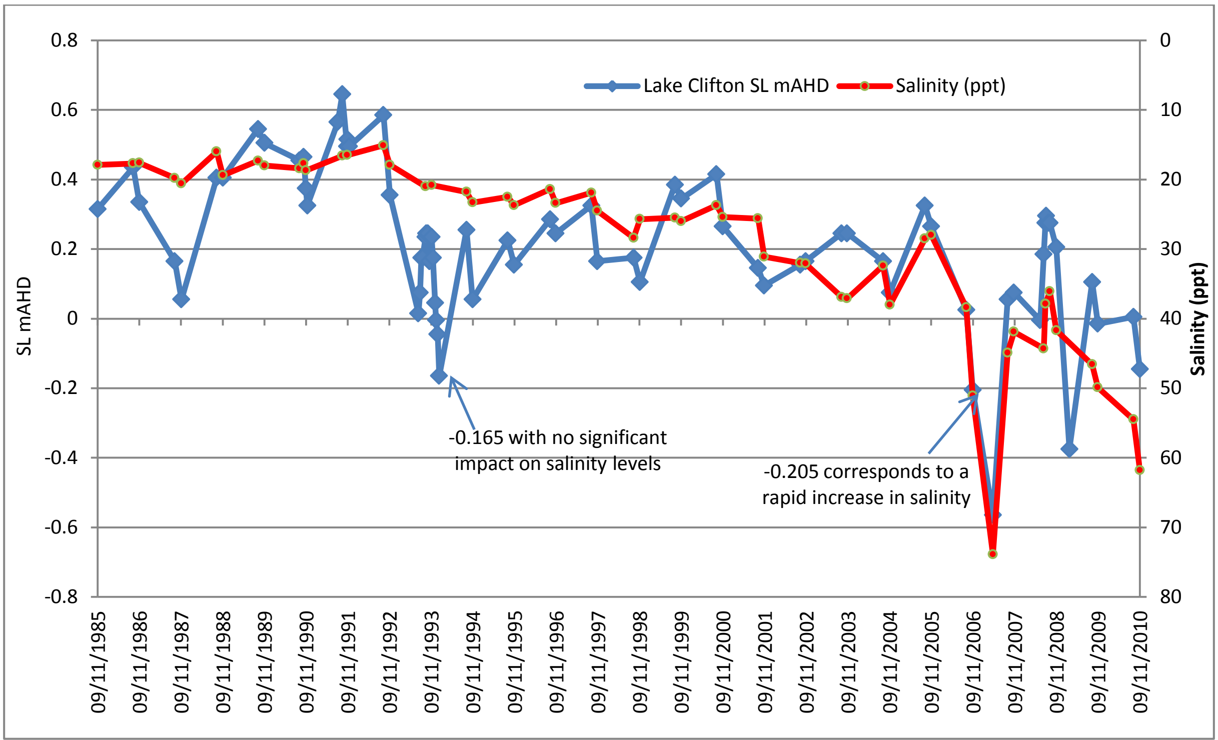

Figure 22 Hydrograph of Lake Clifton surface-water level and salinity

At the boardwalk it is suggested that DPaW could use a surface-water level of –0.165 mAHD to indicate when a rapid change in salinity may occur.

Note: The salinity tolerance of the Lake Clifton thrombolites is currently unknown but it is considered notable that living specimens have only been found where the salinity generally remains lower than 35 parts per thousand (Hale & Butcher 2007). Despite our current lack of understanding it is likely that the thrombolites and the entire lake ecology will be significantly affected by any permanent increase in salinity (Smith, Goater et al. 2010)

Reference groundwater level in bore 61319508

While local groundwater levels do not appear to be the major driver of surface-water level and salinity changes in the lake, any further decline in groundwater level will exacerbate this trend. We have therefore recommended a reference groundwater level for bore 61319508 and re-instatement of monitoring in bore 61319530 to allow us to manage groundwater discharge into Lake Clifton.

In bore 61319508 the depth to groundwater is about 10 m and the average minimum since 1992 has been 0.03 mAHD. Using the method described in section 4 the reference level would be set at –0.47 mAHD. However this correlates to a lake level below the recommended reference lake surface-water level of –0.165 mAHD and is likely to affect the rate of discharge into Lake Clifton.

Based on monitoring data, the surface-water level was not trending downwards until groundwater levels in bore 61319508 were below –0.05 mAHD. From this we can assume that at a groundwater level of –0.05 mAHD, groundwater discharge into Lake

Clifton (as a proportion of total inputs) is adequate to maintain surface-water levels in the lake (Figure 23).

Lower groundwater levels were recorded in 2007 and 2010. These occurrences followed years when the annual rainfall fell below the 20th percentile (Figure 20) suggesting that lower groundwater levels are likely in years following low rainfall.

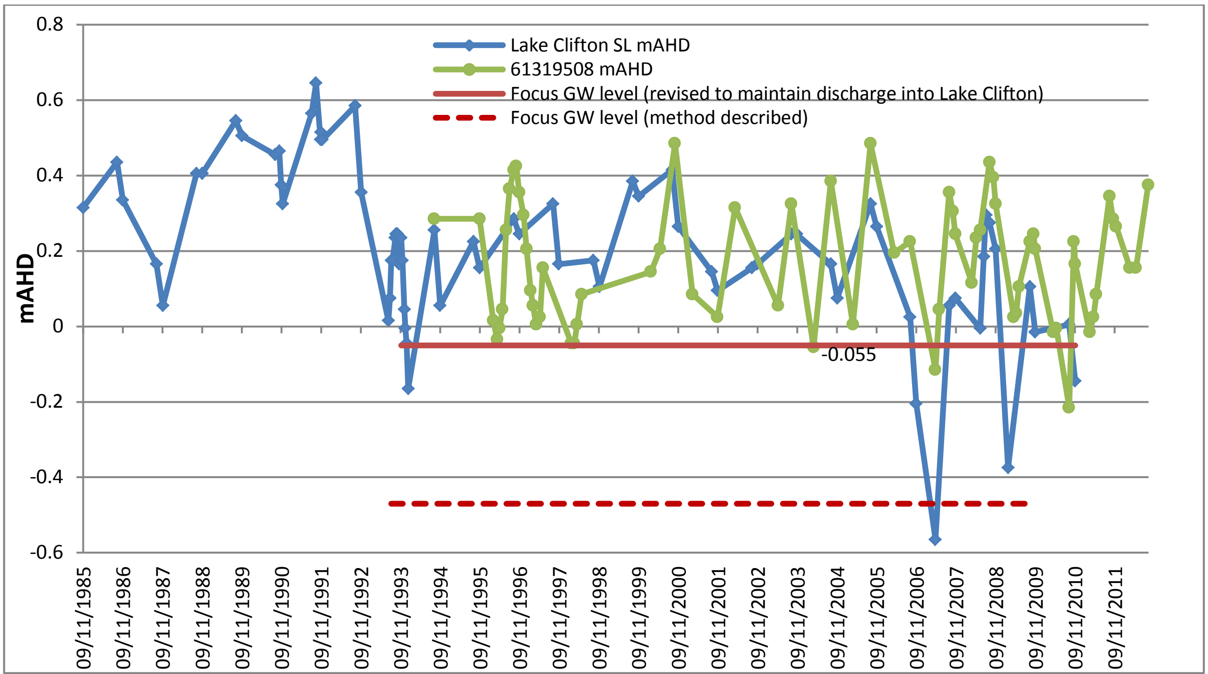

Figure 23 Hydrograph of Lake Clifton surface-water level and groundwater level measured in bore 61319508

For this site it is recommended that a reference groundwater level of –0.05 mAHD is set with the provision that this can be lower when the previous years' total annual rainfall is below the 20th percentile (620 mm).

Reference groundwater level in bore 61319530

Bore 61319530 is situated in a key location in riparian vegetation aligning Lake Clifton. It monitors groundwater levels in the discharge zone adjacent to the critically endangered thrombolite community and forms a rough transect with the Lake Clifton Boardwalk and bore 61319508. There is currently insufficient data to set a reference groundwater level for this site.

It is recommended that this bore is reinstated onto the monitoring program with a view to setting a reference groundwater level to maintain throughflow into Lake Clifton and support riparian vegetation.

Coastal subarea

We currently monitor bore 61319130 in the Coastal subarea, and have set reference groundwater levels for this bore and for bore 61319137, which we recommend be re-instated on the monitoring program (Figure 25).

Reference groundwater level in bore 61319130

The water level in bore 61319130 was measured approximately six times per year since 1982 and has shown a slight declining trend over this period. The levels range between 3.6 and 4.2 mbgl, and support Tuart/Peppermint Forest remnant vegetation. Bore 61319130 is situated in the Martins Tank flow system (Figure 4) and is indicative of groundwater discharge into Martins Tank Lake rather than into Lake Clifton (RPS 2011).

To keep the groundwater-dependent vegetation at a low level of risk, a reference groundwater level of –0.26 mAHD (4.43 mbgl) would be suitable. This is based on allowing a maximum decline of 0.25 m from the average minimum recorded since 1992.

The reported minimum lake level for Martins Tank Lake is -0.73 mAHD (RPS, 2011). This is based on very limited data collected between 2010-11. A reference level of –0.26 mAHD at bore 61613130 will maintain a hydraulic gradient between local groundwater levels and Martins Tank Lake and discharge into the lake from the west side. We do not have sufficient data to quantify inflow.

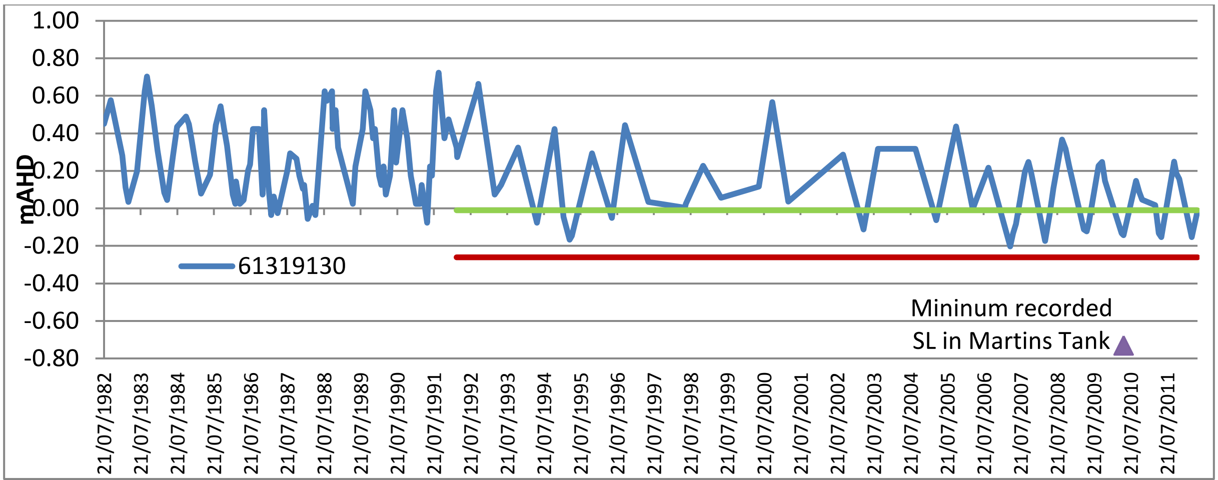

Figure 24 Hydrograph of bore 61319130

For this site it is recommended that a reference groundwater level of –0.26 mAHD is set, with the provision that groundwater levels below this be evaluated with consideration of the rainfall trends.

Reference groundwater level in bore 61319137

Bore 61319137 is currently not monitored but has a dataset from 1982 to 2005 (Figure 25). This site is considered to be in a key location with shallow groundwater (ranging from 1.5 to 2.8 mbgl) supporting lake fringing communities of Samphire shrublands and *M. cuticularis* low forest. Groundwater levels measured in this bore are also indicative of groundwater discharge into Lake Preston.

The average minimum groundwater depth since 1992 has been –0.20 mAHD. Using the method discussed in Section 4.1, a reference groundwater level of –0.45 mAHD

(2.662 mbgl) would be applicable to this site to support groundwater-dependent vegetation.

The reported minimum lake level for Lake Preston is -1.3 mAHD (RPS, 2011). This is based on very limited data collected between 1978-79 and 2010-11. A reference level of -0.45 mAHD at bore 61613137 will maintain a hydraulic gradient between local groundwater levels and Lake Preston and hence discharge into Lake Preston from the west side. We do not have sufficient data to quantify inflow.

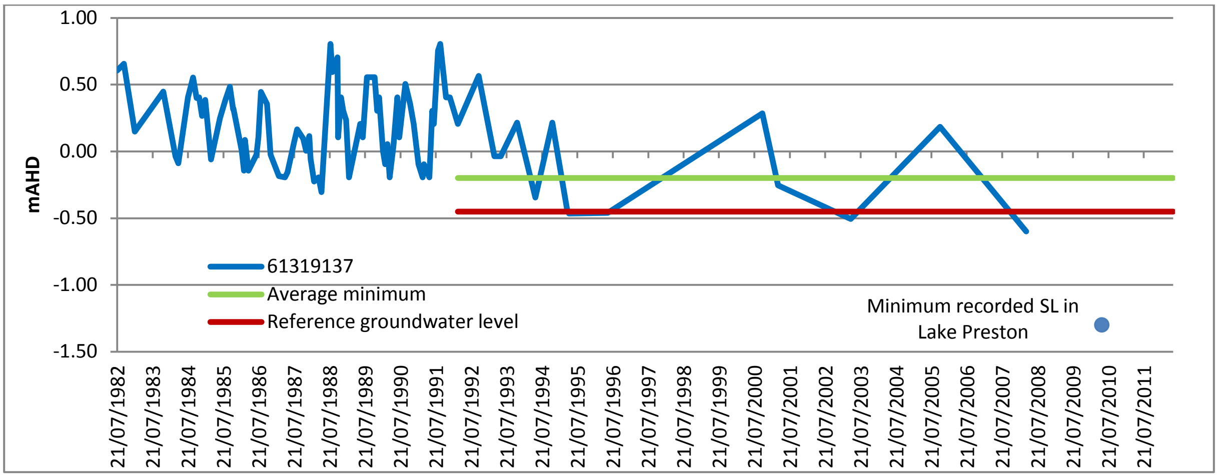

Figure 25 Hydrograph of bore 61319137

Although there is limited data between 1994 and 2008, the hydrograph for this site suggests that groundwater levels have been declining since 1994. This is likely to be attributed to rainfall decline rather than groundwater abstraction which is minimal (estimated 0.2 GL/yr).

For this site it is recommended that a reference groundwater level of –0.45 mAHD is set with the provision that groundwater levels below this be evaluated with consideration of the rainfall trends.

Lake Clifton subarea

There is currently one bore in the Lake Clifton subarea monitoring groundwater levels of the superficial aquifer. Depth to groundwater in this bore is more than 25 m and does not represent an area where GDEs are likely to occur. As such no reference groundwater levels have been set for this subarea.

Recommendation for monitoring

It is recommended that the department implement a strategy through the plan to utilise licensee compliance monitoring to track groundwater level and quality trends in the Lake Clifton subarea.

Colburra Downs subarea

There are four bores at two locations which *monitor* groundwater levels in the Colburra Downs superficial aquifer (Table 40). As these bores do not represent any areas of potential groundwater-dependent values, reference groundwater levels have not been calculated.

Table 40 Colburra Downs groundwater monitoring bores

Bore	DTGW category	GDE	Value	Period of data	Hydrograph analyses
61319134	0–3 m	Cleared		1979–present	Stable to slightly declining dtgw
61330107 (nested with 61330104 & 61330105)	0–3 m	Cleared – adjacent to tree plantation		1982–present	Responds seasonally to rainfall with overall stable dtgw

Summary of reference groundwater levels and recommendations

Detailed below is a summary of the recommended reference groundwater levels for the plan area (Table 41).

Table 41 Recommended reference groundwater level

Subarea	Obj	Bore	Reference groundwater level	Additional recommendation	Climate provision
Mandurah	1	61410026	> 0.13 mAHD		Consider in line with CDFM
Whitehills	2	61319128		Commence profile monitoring	TBD
	2	61319123		Commence profile monitoring	TBD
Island Point	3	61319508	> –0.05 mAHD	Commence profile monitoring	Consider in line with rainfall trend
	4	61319530	Recommence monitoring and develop reference groundwater level	Commence profile monitoring	TBD
	5	61330103	>0.01 mAHD	Commence profile monitoring	Consider in line with rainfall trend
		Boardwalk	>–0.20 mAHD surface level salinity trigger		Consider in line with rainfall trend
Coastal	6	61319130	> –0.26 mAHD	Commence profile monitoring	Consider in line with rainfall trend
	7	61319137	> -0.45 mAHD	Commence profile monitoring	Consider in line with rainfall trend

4.3 Monitoring program

We have developed a monitoring program which has adopted the reference groundwater levels developed previously. These levels represent the performance indicators against which data will be assessed (Table 42).

Table 42 Ecological monitoring program to support the Peel Coastal groundwater allocation plan

Reference site objective	Subarea	Bore	Parameter	Frequency	Performance indicator*
1	Mandurah	61410026	Groundwater level	2 times/year	>0.13 mAHD
2	Whitehills	61319128	Water quality	6 times/year	TBD
		61319123	Water quality	6 times/year	TBD
3	Island Point	61319508*	Groundwater level	6 times/year	>–0.05 mAHD
4		61319530*	Groundwater level	Continuous (logger)	Baseline
5		61330103	Groundwater level	6 times/year	>0.01 mAHD
6	Coastal	61319137*	Groundwater level	Continuous (logger)	>–0.45 mAHD
7		61319130*	Groundwater level	6 times/year	>–0.26 mAHD

** In addition to groundwater level monitoring it is recommended that the department commences water quality monitoring at the water table and through the water profile to detect salinity changes and develop reference levels based on water quality.*

4.4 Local licensing guidance for licensing officers

Although there is currently no new water available for licensing in the Peel Coastal plan area, from time to time some volumes may become available through the relinquishment or recouping of entitlements. Water is also available through trading and transfers. We will assess any application for new water or trades to ensure that any possible adverse effects on groundwater-dependent ecosystems and water quality can be managed.

We will do this using the overarching processes the department has in place to help evaluate the acceptability of licence applications which may affect groundwater-dependent ecosystems.

Because the area covered by the Peel Coastal groundwater allocation plan supports many groundwater-dependent ecosystems of international, regional and local significance, we have developed local licensing guidance to support licensing officers during assessment of new groundwater licences or licence renewals and trading.

This local licensing guidance is designed to tie-in with:

- Operational policy no. 5.12 – *Hydrogeological reporting associated with a groundwater well licence*: which details the level of hydrogeological assessment that needs to be undertaken for a groundwater well licence.
- The nature of advice given by the department's Environmental Water Planning section and the *GDE guideline* (Department of Water, 2015c) which details the level of environmental assessment that needs to be undertaken for a groundwater well licence.

This guidance feeds directly into policy 5.12 by providing a decision making framework for deciding what score to assign to 'Potential for unacceptable impacts to GDE'. It has been developed to mirror the assessment process described in the GDE guideline but uses the specific information available for the Peel Coastal groundwater plan area.

The *Environmental water guidance to support Peel Coastal region licensing* (Department of Water, 2015d) provides a step by step process for licensing officers to determine if a license application poses a risk to groundwater-dependent ecosystems. It makes use of the depth to groundwater map and environmental values layers that have been developed for this project. In summary the strategy:

Step 1: Defines the area that needs to be considered in the groundwater-dependent ecosystems assessment.

Step 2: Evaluates and scores how important are the environmental values within that area.

Step 3: Evaluates and scores the depth to groundwater associated with the ecological values.

Step 4: Uses this information to complete the risk template and determine how you should score potential effects to groundwater-dependent ecosystems when determining the level of assessment under Operational Policy no. 5.12.

4.5 Plan scale adaptive management

The adaptive management framework ties together the reference groundwater levels (section 4.2) and the ecological monitoring program (Section 4.3) and defines how management responds if trigger levels are reached or objectives are not met.

Monitoring results will be assessed annually as part of the plan evaluation process to check if water levels to support groundwater-dependent ecosystems have remained at or above the reference groundwater levels. If groundwater levels fall below the minimum set level then further investigation will be required.

Further investigation will include firstly comparing the monitoring bore hydrograph with rainfall to assess if the trend is likely related either to drying climate or to a particularly low rainfall year (a year below the 20th percentile). If the decline follows the rainfall trend, it can be assumed that rainfall recharge to the aquifer is likely the causal factor affecting water level decline, and the department will consider management options.

If the decline in water level is not consistent with rainfall trends, further investigation will be necessary to find the cause for the decline and the impacts on groundwater-dependent ecosystems. Management options would be considered based on findings, and could include increased compliance activity by the department for licensees in the affected areas, and an assessment of the health of the groundwater-dependent ecosystems associated with the monitoring location.

Appendix A Conservation codes for Western Australian flora and fauna

The Department of Parks and Wildlife website currently provides the following listing for threatened native plants and threatened native animals that need to be specially protected because they are under identifiable threat of extinction, are rare, or otherwise in need of special protection.

T: Threatened species – Specially protected under the *Wildlife Conservation Act 1950,* listed under Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice for Threatened Fauna and Wildlife Conservation (Rare Flora) Notice for Threatened Flora (which may also be referred to as Declared Rare Flora).

Species* which have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such.

X: Presumed extinct species – Specially protected under the *Wildlife Conservation Act 1950,* listed under Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice for Presumed Extinct Fauna and Wildlife Conservation (Rare Flora) Notice for Presumed Extinct Flora (which may also be referred to as Declared Rare Flora).

Species* which have been adequately searched for and for which there is no reasonable doubt that the last individual has died, and have been gazetted as such.

IA: Migratory birds protected under an international agreement – Specially protected under the *Wildlife Conservation Act 1950,* listed under Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Birds that are subject to an agreement between governments of Australia and Japan, China and The Republic of Korea relating to the protection of migratory birds and birds in danger of extinction.

S: Other specially protected fauna – Specially protected under the *Wildlife Conservation Act 1950,* listed under Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Threatened Fauna and Flora are further recognised by the Department according to their level of threat using IUCN Red List criteria. For example, Carnaby's Cockatoo *Calyptorynchus latirostris* is specially protected under the *Wildlife Conservation Act 1950* as a threatened species with a ranking of endangered.

Threatened Ecological Communities and Ranking:

CR: Critically Endangered – considered to be facing an extremely high risk of extinction in the wild.

EN: Endangered – considered to be facing a very high risk of extinction in the wild.

VU: Vulnerable – considered to be facing a high risk of extinction in the wild.

Species that have not yet been adequately surveyed to be listed under Schedule 1 or 2 are added to the Priority Flora and Priority Fauna Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened flora or fauna. Species that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list for other than taxonomic reasons, are placed in Priority 4. These species require regular monitoring. Conservation Dependent species are placed in Priority 5.

1: Priority One: Poorly-known species

Species that are known from one or a few collections or sight records (generally fewer than five), all on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, Shire, rail reserves and Main Roads WA road, gravel and soil reserves, and active mineral leases and under threat of habitat destruction or degradation. Species may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes.

2: Priority Two: Poorly-known species

Species that are known from one or a few collections or sight records, some of which are on lands not under imminent threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, State forest, unallocated Crown land, water reserves. Species may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes.

3: Priority Three: Poorly-known species

Species that are known from collections or sight records from several localities not under imminent threat, or from few but widespread localities with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Species may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and known threatening processes exist that could affect them.

4: Priority Four: Rare, Near Threatened and other species in need of monitoring

(a) Rare. Species that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These species are usually represented on conservation lands.

(b) Near Threatened. Species that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable.

(c) Species that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.

5: Priority Five: Conservation Dependent species

Species that are not threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years.

Shortened forms

AHD	Australian height datum
BoM	Bureau of Meteorology
CCW	Conservation Category Wetlands
CDFM	Cumulative deviation from the mean
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEC	Department of Environment and Conservation
DoW	Department of Water
DoP	Department of Planning
DPaW	Department of Parks and Wildlife
DRF	Declared Rare Fauna
dtgw	Depth to groundwater
DWAID	Divertible water allocation information database
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
ESS	Estuarine Samphire Shrublands
ET	Evapo-transpiration
ET_G	Evapo-transpiration rate of groundwater
FPC	Forest Products Commission
GDE	Groundwater-dependent ecosystem
IWSS	Integrated Water Supply Scheme
LFC	Lake fringing community
mbgl	Meters below ground level
OEPA or EPA	Office of the Environmental Protection Authority
TBD	To be decided

TEC	Threatened Ecological Community
WAPC	Western Australian Planning Commission
WIN	Water Information Network
WRC	Water and Rivers Commission

Glossary

Abstraction	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.
Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock. Aquifer types include
Australian Height Datum	(AHD) The datum used for the determination of elevations in Australia. The determination used a national network of bench marks and tide gauges, and set mean sea level as zero elevation.
Bore	A narrow, normally vertical hole drilled in soil or rock to monitor or withdraw groundwater from an aquifer.
Discharge	The water that moves from the groundwater to the ground surface or above, such as a spring. This includes water that seeps onto the ground surface, evaporation from unsaturated soil, and water extracted from groundwater by plants or engineering.
Ecological linkage	A series of patches of remnant vegetation which act as stepping stones of habitat which facilitate the maintenance of ecological processes and the movement of organisms within and across a landscape. Can be used as a measure of the biodiversity conservation value of a patch of native vegetation
Groundwater	Water which occupies the pores and crevices of rock or soil beneath the land surface.
Hydrogeology	The hydrological and geological science concerned with the occurrence, distribution, quality and movement of groundwater, especially relating to the distribution of aquifers, groundwater flow and groundwater quality.
Licence	A formal permit which entitles the licence holder to ‘take’ water from a watercourse, wetland or underground source.
Recharge	Water that infiltrates into the soil to replenish an aquifer.
Spring	A spring is where water naturally rises to and flows over the surface of land.
Subarea	A sub-division within a Surface or Groundwater Area, defined for the purpose of managing the allocation of groundwater resources. Subareas are not proclaimed and can therefore be changed internally without being gazetted.

Map sources

The Department of Water acknowledges the following datasets and their custodians used for this report:

Native vegetation mapping (Beeston et al. 2001; DAFWA 2009)

Vegetation Complexes (CALM 1998; DCE 1990)

DEC managed lands (CALM 2005c)

DEC TEC locations (CALM 2011 and updates)

DEC Declared Rare and Priority Flora (CALM 2011; Western Australian Herbarium 1998)

System 6 and System 1 areas (DCE 1976, 1983)

Estuary and Coast Boundaries (DLI 2005a)

Major Rivers of Western Australia (DLI 2005b)

Tuart mapping (Government of Western Australia 2003)

WA Coastline, WRC (Poly) – DoW – 20/07/2006

State Roads – DOLA – 06/01/1999

Towns

Geomorphic Wetlands Swan Coastal Plain (DoE 2004)

Wetlands EPP 2004

DWAID Groundwater Subareas (DoW 2011)

Datum and projection information

Vertical datum: Australian Height Datum (AHD)

Horizontal datum: Geocentric Datum of Australia 94

Projection: MGA 94 Zone 50

Spheroid: Australian National Spheroid

Project information

Map Author: M Antao

Filepath: J:\gisprojects\Project\330\80000_89999\3308440_WAP\00002

Filenames: SWCoastal_Wetlands.mxd & SWCoastal_Terrestrial_Vegetation

Compilation date: December 2011

Disclaimer

These maps are a product of the Department of Water, Water Allocation Planning Division and were printed in December 2014. The maps were produced with the intent that they be used for information purposes at the scale as shown when printing.

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