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

South West groundwater areas monitoring program

Looking after all our water needs.

Department of Water

Water resource allocation planning series

Report no. 32

December 2008

Department of Water
168 St Georges Terrace
Perth Western Australia 6000
Telephone +61 8 6364 7600
Facsimile +61 8 6364 7601
www.water.wa.gov.au

December 2008

ISSN 1327-8428 (Print)
ISSN 1834-2620 (Online)

ISBN 978-1-921508-33-2 (Print)
ISBN 978-1-921508-34-9 (Online)

Acknowledgements

This report was prepared by Adrian Goodreid.

The author acknowledges the assistance of Department of Water staff of the South West region, Water allocation planning branch and Water resource assessment branch who provided expert advice and comment in the review of this document.

For more information about this report contact:

Adrian Goodreid
Department of Water
Water allocation planning branch

168 St Georges Terrace
Perth WA 6000

Tel: 08 6364 7600
Fax: 08 6364 7601

Contents

Appendices

Figures

Tables

Summary

The Department of Water (the department) has developed the *South West groundwater areas allocation plan*. The purpose of the plan is to provide a management framework for the abstraction of groundwater.

To support the groundwater management plan an accompanying monitoring program is required. The monitoring program describes the approach the department will use to monitor groundwater resources. It is intimately linked to the management plan and management framework through the setting of complementary monitoring objectives and the feedback of monitoring results.

This report also serves as a snapshot of current monitoring and investigations the department is undertaking to improve our understanding of groundwater resources and their dependencies. We have documented these investigations in this report because they inform and influence the monitoring that the department undertakes.

The program is comprised of four sub-programs that cover different areas of groundwater management. These sub-programs are:

- groundwater levels monitoring
- groundwater quality monitoring
- environmental water provisions monitoring
- connected systems investigations and monitoring.

The monitoring and investigations for each sub-program is summarised in below.

Summary table of the South West groundwater areas monitoring and investigation program

Monitoring sub-program	Activities		Location & frequency
	Monitoring	Investigations	
Groundwater levels	Measure and monitor groundwater levels.	• Impacts of groundwater abstraction to other groundwater users. • Aquifer connectivity. • Impacts of climate change. • Impacts to GDE*	The groundwater level network (~450 bores) is measured six times per year to capture maximum and minimum water levels.
Groundwater quality	Parameters to be measured and monitored include groundwater salinity, nutrients, industrial contaminants and acidity arising from the oxidation of PASS*.	• Sea water intrusion investigation. • Myalup horticultural zone salinity monitoring program.	Water quality network and program being developed. Targeted monitoring and assessment for the Myalup horticultural zone.

Monitoring sub-program	Activities		Location & frequency
	Monitoring	Investigations	
Environmental water provisions	Measurement and monitoring of groundwater dependent vegetation condition. Groundwater level measurement and monitoring at representative GDE.	• Eco-hydrological and hydrogeological investigations. • Ecological water requirements studies for vegetation. • Shallow groundwater systems and GDE drilling program planned for 2008–2010. • Specific study of ecological water requirements for South West groundwater dependent vegetation communities planned for 2008–2010.	Monthly groundwater measurement and annual vegetation condition monitoring at 39 sites across the South West groundwater areas. Triggers and responses for groundwater levels have been established for selected representative GDE. Ecological water requirements determined for 24 of the 39 sites.
Connected surface water and groundwater systems monitoring and investigations	Measurement and monitoring of surface water levels and flow. Groundwater monitoring bores have been installed specifically to measure and monitor water levels at selected sites. The groundwater level monitoring network is utilised to measure and monitor groundwater levels near known connected systems.	• Hydrological and inter-connectivity investigations. • Eco-hydrological studies. • Ecological water requirements studies.	Annual flow snapshots and long term investigations at Blackwood, Capel and Donnelly Rivers. Continuous water level measurement at three pools on the Margaret River just upstream of Ten Mile Brook confluence. Continuous water level measurement at Lake Jasper. Ecological water requirements investigations being conducted on Margaret, Brunswick, Capel and Blackwood Rivers, and Wilyabrup and Cowaramup Brooks.

*Potential acid sulphate soils (PASS); groundwater-dependent ecosystem (GDE)

Review and reporting against the monitoring programs will occur annually. The primary medium for reporting will be the South West groundwater areas annual evaluation statement. This is an annual summary of the performance of the management plan, including monitoring, licensing and investigations. The statement will be available on the department's website. More detailed information may also be available on request.

1 Introduction

1.1 Background

The South West region of Western Australia contains large resources of fresh groundwater that are being tapped for domestic, irrigation, industrial and public water supply use in the region. Water use in this region is increasing, placing pressures on the water resources and the systems that they support. This means that there is a need to increase our knowledge and management, including monitoring, of groundwater resources in this area. In response to this the Department of Water has developed a groundwater management plan for these areas called the *South West groundwater areas allocation plan*.

To support the management plan an accompanying water resource monitoring program is required. The program describes the approach the department will use to measure and monitor groundwater resources. This report documents the key elements of this monitoring program, including the parameters to be measured, sampling frequency, data review and reporting that will occur.

This report serves as a snapshot of some of the work and investigations the department is undertaking to improve our understanding of groundwater resources and their dependencies, and connectivity between groundwater and surface water systems. These investigations will support water resource monitoring and management in the South West groundwater areas.

This monitoring program will be reviewed and improved in line with two key initiatives. The first is a statewide review of the current monitoring programs, particularly the groundwater levels and groundwater quality programs.

The second is a series of projects funded by the Australian Government's Water Smart Australia program. The program offers support for large-scale projects that will contribute to improving water efficiency and environmental outcomes across Australia.

This funding is being used by the department to better understand the hydrological, hydrogeological and ecological systems of the South West groundwater areas. This information will allow the setting of more informed monitoring objectives and an improved management framework for a revised (statutory) groundwater management plan in 2011.

Groundwater resources

The groundwater is contained mainly within the superficial, Leederville and Yarragadee Aquifers of the Southern Perth Basin (see Figure 1 for geology of the area). These aquifers are the most utilised by groundwater users. Some groundwater use also occurs from the Lesueur and Sue Coal Measures aquifers.

The Leeuwin complex and a thin zone of the western margin of the Yilgarn Craton are the only part of the South West groundwater that is a fractured rock hydrogeological environment. In this area groundwater is restricted to fractures in the crystalline basement rocks (i.e. bedrock), and to a thin weathered zone and overlying surficial formations. The nature of the fractured rock restricts the location and volume of water that can be abstracted.

The South West groundwater areas is an administrative area demarked for management of these groundwater resources. The majority of the South West groundwater areas are occupied by four proclaimed groundwater areas. These are the Bunbury, Busselton–Capel, Blackwood and the southern portion of the South West Coastal groundwater areas (Figure 2). On the eastern margin of the South West groundwater areas boundary are some smaller areas which form part of the unproclaimed areas of the state (not illustrated).

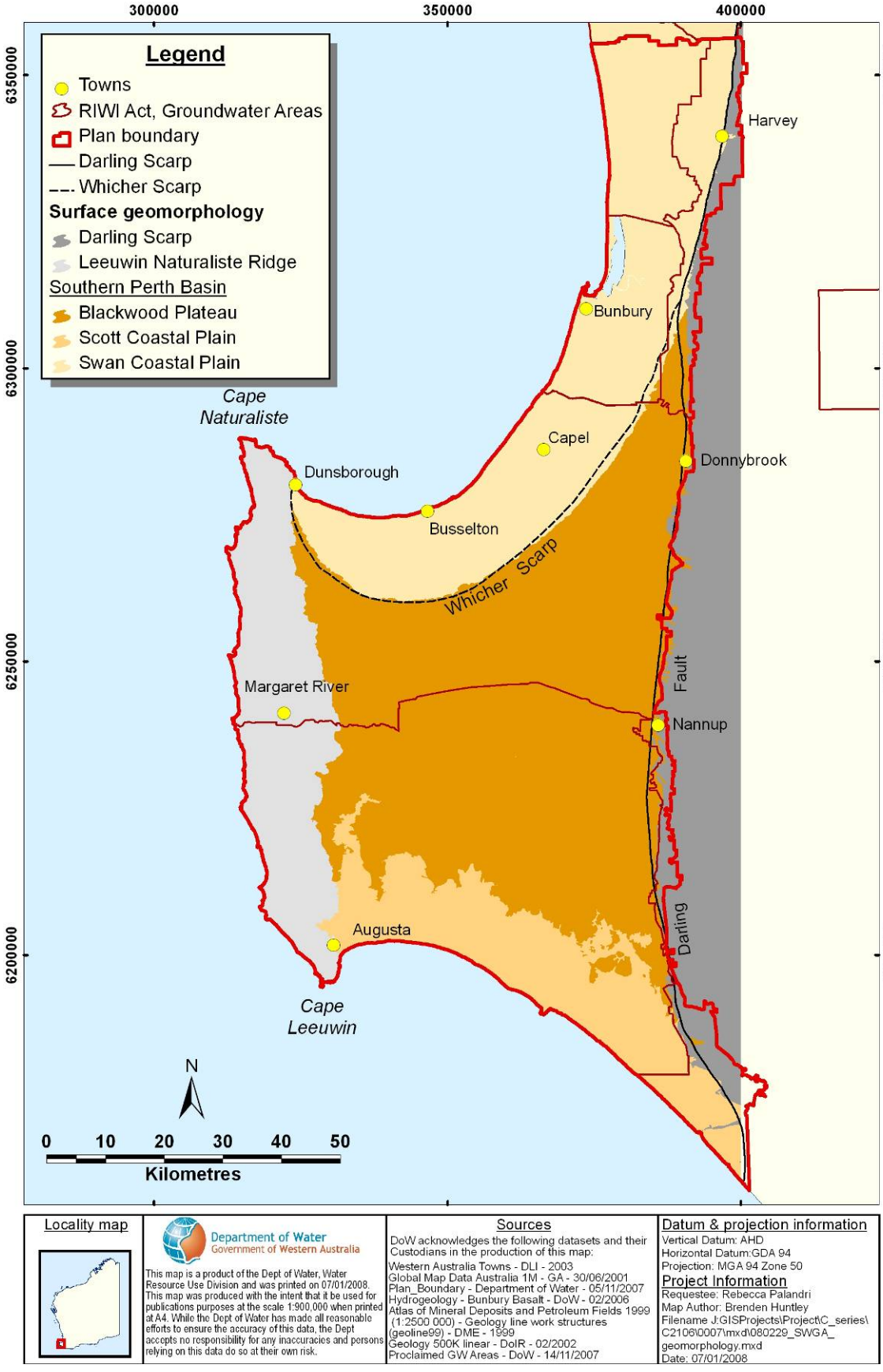

Figure 1 Surface geology of the study area

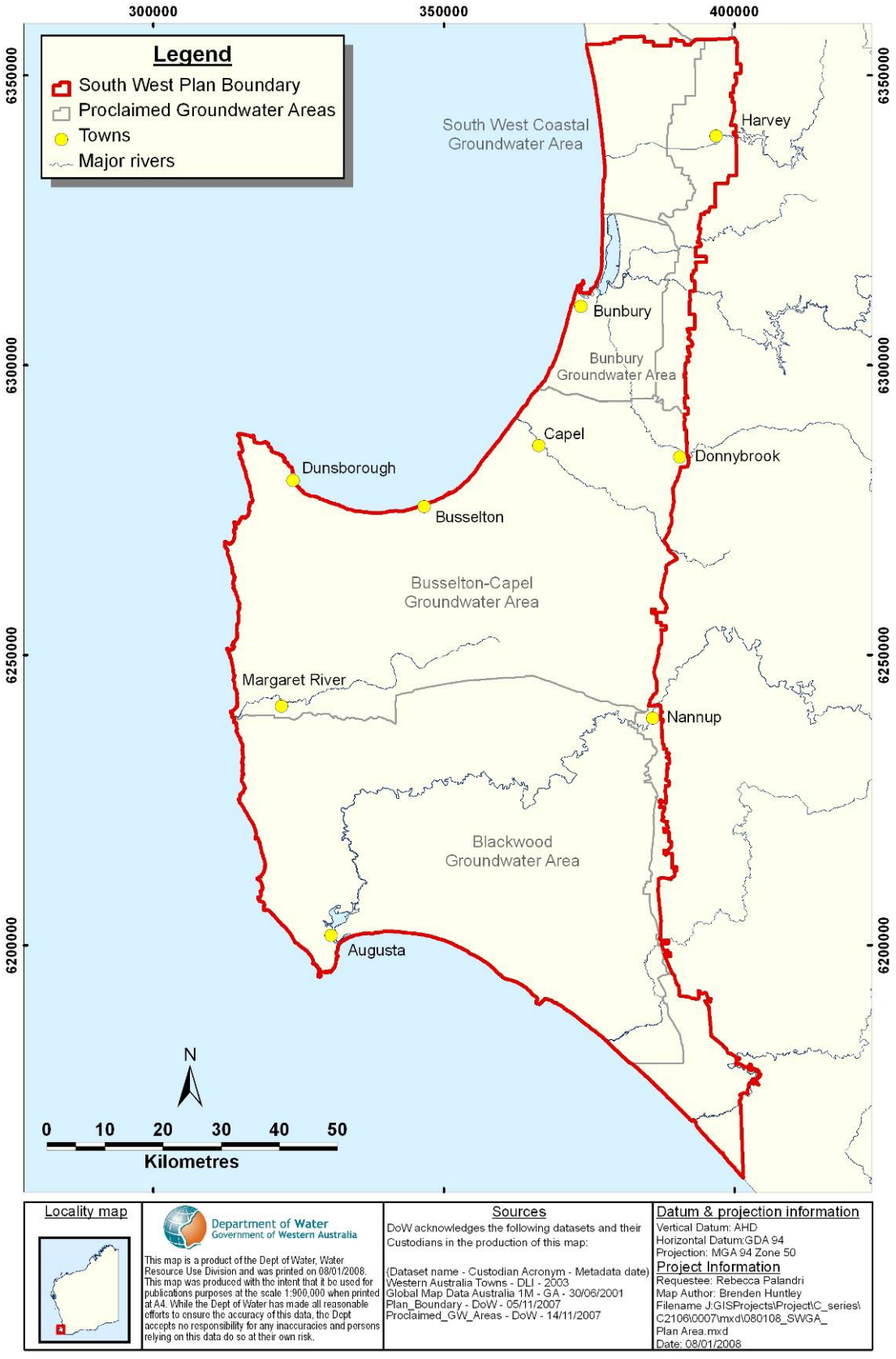

Figure 2 The South West groundwater areas

1.2 Monitoring program context

The monitoring program for the South West groundwater areas has been developed to support the South West groundwater areas allocation plan.

The primary objective of the monitoring program is to monitor and manage the water resources to maintain the integrity of the resource for consumptive use while protecting the social, cultural and environmental values that are dependent on the resource.

Within the program are four sub-programs (Figure 3). The measurement, analysis and review of data within each sub-programs is used to measure the performance of groundwater resource management by the department against its objectives, and thus advises necessary changes to the management strategies employed by the department.

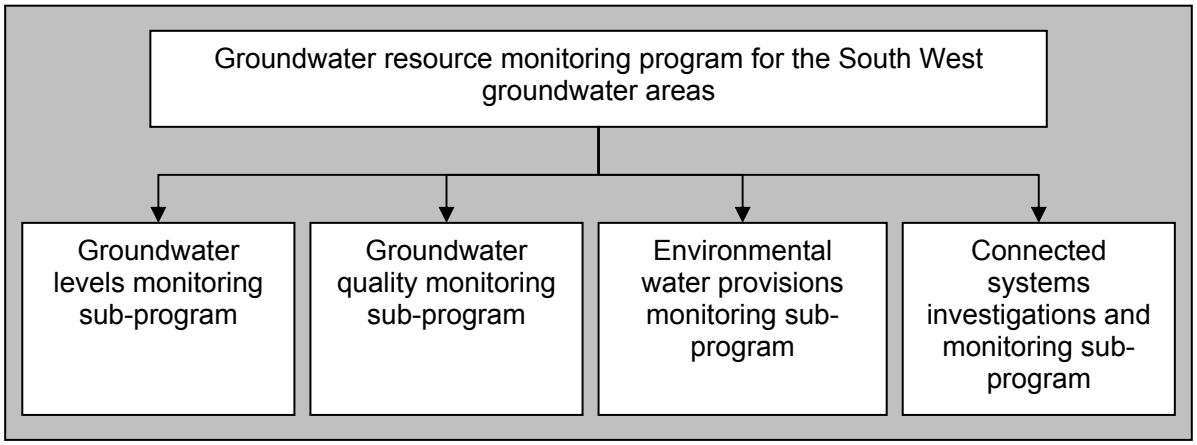

Figure 3 Simplified model of the groundwater resource monitoring program for the South West groundwater areas and supporting sub-programs

The sub-programs are described below:

1 Groundwater levels monitoring sub-program.

This sub-program details the objectives and management framework for the groundwater level monitoring network in the South West groundwater areas, which forms part of the Department's State Reference Network. Groundwater level trends, aquifer performance, spatial and temporal connection between aquifers and impact to other users and the environment are some of the key parameters to be measured and evaluated through this sub-program.

2 Groundwater quality monitoring sub-program.

This sub-program will detail the objectives and management framework for the groundwater quality monitoring network in the South West groundwater areas. Movement of the seawater interface, aquifer salinity, nutrients, and acid

generation due to the oxidation of acid sulphate soils are some of the parameters to be measured and evaluated through this sub-program.

An area of special interest to the department is groundwater quality in the intensive horticultural belt in the Myalup and Lake Preston subareas. Groundwater salinity is increasing and is thought to be the result of localised recycling of fertiliser salts and incursion of saline water. To manage groundwater quality in this area the department has implemented a standardised monitoring procedure for all licence holders in these areas and is conducting regular review of the measurement data.

Development of the groundwater quality monitoring program is a longer term goal for the department.

3 Environmental water provisions (EWP) monitoring sub-program.

This sub-program details the objectives and management framework for the monitoring of environmental water provisions. The relationship between groundwater levels and vegetation condition at representative groundwater-dependent ecosystems (GDE) is the primary focus of the monitoring. For GDE that have a surface water component (connected systems), for example the Blackwood River, measurement of streamflow and water levels is also a part of this sub-program.

4 Connected systems investigations and monitoring sub-program.

This sub-program details the investigations of connected surface water and groundwater systems being conducted by the department. In some of these systems regular measurement of streamflow and water levels occurs. A management framework for connected systems is defined. However, further investigative work is required to better understand these systems before a monitoring program complete with management triggers and responses can be developed.

2 Groundwater levels monitoring sub-program

2.1 Introduction

Water level measurements from observation bores are the principal source of information about the hydrologic stresses acting on aquifers and how these stresses affect groundwater recharge, storage, and discharge (Taylor and Alley, 2001). These are key indicators of the groundwater resource condition.

The department measures groundwater levels to assess the success of management strategies to protect environmental and social values that depend on water and maintain the integrity of the resource for consumptive use.

2.2 Monitoring, assessment and reporting framework

The department has developed a framework for groundwater level measurement that illustrates the process for monitoring, assessment and reporting (Figure 4). Implicit is the linkage between the monitoring objectives and the objectives of the management plan. Discussion of the key components of the framework follows.

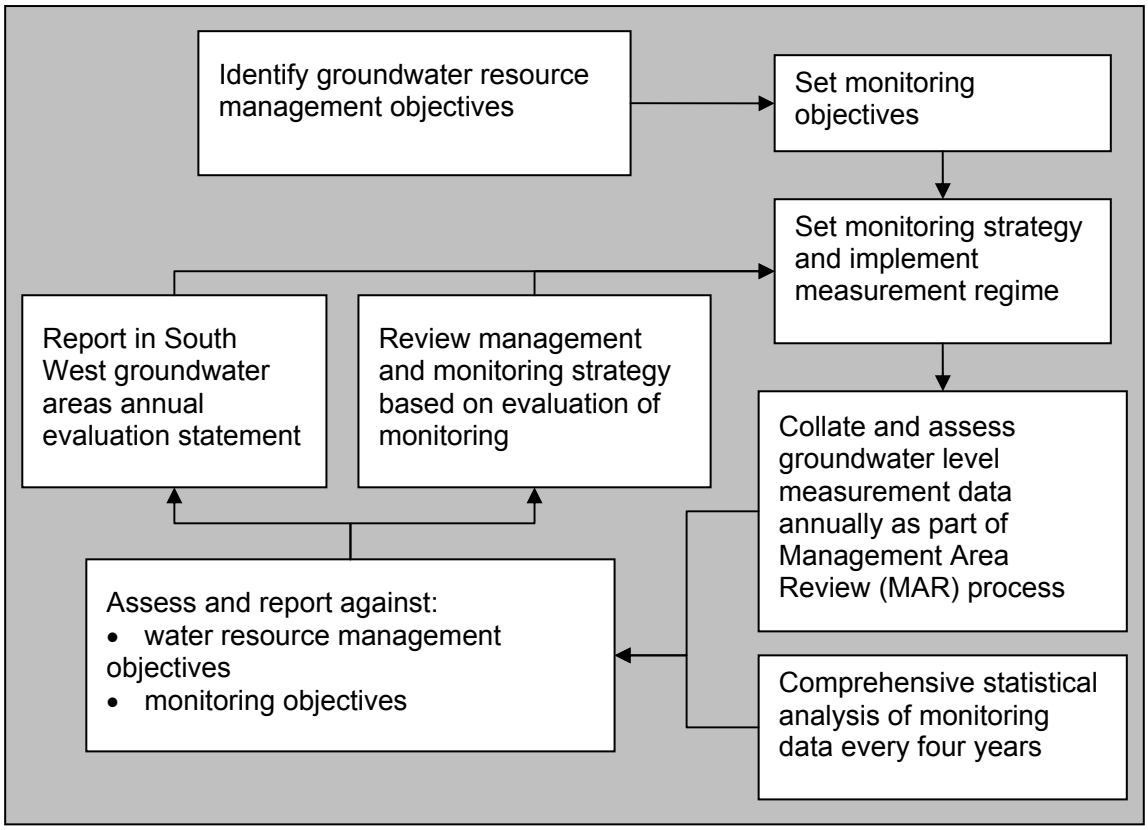

Figure 4 Groundwater levels monitoring, evaluation and reporting framework for the South West groundwater areas

Identify water resource management objectives

The key groundwater resource management issues in the South West groundwater areas that have driven the development of management objectives are:

- Understand aquifers in the South West groundwater areas and determine long-term aquifer performance.
- There are many groundwater users in the South West groundwater areas. Protecting and minimising impacts between users is a key management issue for the department.
- There are many groundwater dependent ecosystems and places of high cultural and social value that are dependent on groundwater in the plan area. Monitoring groundwater levels in and around these sites is a key part of our management strategy to protect these environments from the impacts of groundwater abstraction.
- There is potential for the seawater interface to move inland and alter the quality of groundwater in aquifers. Measuring groundwater levels near the coast (and groundwater salinity) helps the department assess the direction of groundwater flow in aquifers and monitor any changes.

Set monitoring objectives

The monitoring objectives of the groundwater levels sub-program were set by a review group comprising water resource managers, hydrogeologists, licensing officers, and eco-hydrologists. The objectives defined by this group are to monitor groundwater levels to assess:

- aquifer and water resource performance, and verify and improve the South West Aquifer Modelling System (SWAMS) groundwater model
- the impacts of abstraction on other users
- the impacts of climate change on the groundwater resource
- the location of the seawater interface
- the spatial and temporal connection between aquifers
- interconnectivity with surface water systems
- the impacts of consumptive water use, climate change and other factors on GDE water regimes.

Set monitoring regime and strategy

The monitoring network

The current groundwater level monitoring network consists of around 460 observation bores drilled since 1974 (Table 2 and Figure 5). Biannual measurement of most of the bores has occurred over the past 20 years.

The monitoring bores are located in the sedimentary aquifers of the Southern Perth Basin. The department does not operate any groundwater monitoring bores on the Leeuwin Complex due to the discontinuous nature of the fractured rock aquifer.

Other groundwater monitoring bores of interest to the department include the Blackwood Plateau (BP) bore series that were installed by the Water Corporation in 2003 and 2004. These bores have been measured monthly since installation (Figure 6, Table 2). The bores were used to investigate the hydrogeology of the Blackwood Plateau as part of the Water Corporation's proposal to withdraw 45 GL/a from the Yarragadee Aquifer. These bores may become part of the department's groundwater level monitoring network in 2008.

There are approximately 610 groundwater monitoring bores in the South West groundwater areas, including the Water Corporation's Blackwood Plateau bores, with the potential for more through future drilling programs. This is detailed in the department's *Investigating Western Australia's groundwater resources: A 15 year plan of action (2005 –2020)* (DoW 2005) document.

Measurement frequency

Until recently, most bores in the department's groundwater monitoring network have been measured twice per year. Since March 2007 measurement of the bores has increased to six times per annum to better identify the seasonal minimum and maximum water levels. The department is currently reviewing measurement frequency to align with the monitoring objectives of the groundwater levels sub-program.

The majority of bores in the network are measured manually, but the department will assess the use of automated data loggers and telemetry (collected data is relayed automatically to the department via radio or telephone) to determine the most efficient method of monitoring.

Data storage

Groundwater level data is stored in the department's Water Information Network (WIN) database. Time series data from the department's groundwater monitoring network is available on request.

Analysis, assessment and reporting

The department will assess the groundwater level data through two processes:

1. annual assessment of the groundwater level data
2. comprehensive statistical analysis of the groundwater level data every four years.

The Water Resources Assessment Branch with the South West region will assess the groundwater level data annually. This review will report on groundwater level

trends as they relate to the key groundwater resource management objectives in the South West groundwater areas.

The assessment is an integral part of the Management Areas Review (MAR) (Johnson 2005) process that the department uses for the regular review of groundwater resources in the state.

The annual groundwater data assessment will be summarised in the web based South West groundwater areas annual evaluation statement. The statement is an annual report on the performance of the management plan, including the monitoring programs.

The department will conduct a comprehensive statistical analysis of the measurement data every four years. The first of these assessments is due for completion in June 2008. The types of analyses that will make up the review are:

- Analysis of groundwater level data from monitoring bores in unconfined conditions against long term rainfall using a technique similar to the cumulative deviation from mean annual rainfall (CDFM).
- Analysis of groundwater levels to detect trends, and correlate against groundwater abstraction in the area
- Correlation of groundwater levels from nested bores to help ascertain the interconnectivity between aquifers.
- Provide recommendations on monitoring (measurement frequency, location etc.) to improve such analyses in the future.

The first analysis will be used to help determine the impact of climate change. The outcomes of these analyses will assist in the future decisions about the frequency of monitoring undertaken in the South West groundwater areas and performance review of meeting the water resource condition objectives.

Table 1 Groundwater monitoring bore# information by aquifer and major physiographic unit (see Figure 1) in the South West groundwater areas

Area	Groundwater monitoring line	Aquifer						
		Superficial	*Leederville*	*Yarragadee*	*Cockleshell*	*Lesueur*	*Sue*	*Total*
Swan coastal plain	Binningup Line (BLP)	-	3	-	3	-	-	6
	Boyanup (BL)	1	4	9	2	-	-	16
	Bunbury Shallow (BY)	18	12	18	-	-	-	48
	Busselton Shallow (BN)	28	64	6	-	-	2	100
	Donnybrook (DNB)	-	8	-	-	-	-	8
	Environmental Water (EW) Bores***	16	-	-	-	-	-	16
	Harvey Shallow (HS)**	55	-	-	-	-	-	55
	Jindong Project (BJM)	-	4	3	-	-	-	7
	Kemerton (KE)	-	2	-	2	-	-	4
	Lake Clifton (D)	4	-	-	-	-	-	4
	Lake Clifton (E)	14	-	-	-	-	-	14
	Lake Clifton (F)	9	-	-	-	-	-	9
	Lake Clifton (G)	7	-	-	-	-	-	7
	Leschenault Peninsula	-	2	-	-	-	-	2
	Picton (PL)	-	1	4	-	-	-	5
	Quindalup (Q)*	-	3	10	-	-	-	13
	Yalgorup Lakes (Y)	1	-	-	-	-	-	1
Blackwood Plateau	Cowaramup (CL)	-	10	10	3	-	4	27
	Cowaramup (CW)	-	14	-	-	-	-	14
	Environmental water bores***	10	-	-	-	-	-	10
	Karridale (KL)	-	4	11	2	7	-	24
Scott coastal plain	Environmental water bores***	8	-	-	-	-	-	8
	Scott Coastal (SC)*	16	18	21	-	7	-	62
Total (DoW monitoring bores)		**187**	**149**	**92**	**12**	**7**	**4**	**460**
Blackwood Plateau	Water Corporation Blackwood Plateau bores (BP)	-	73	72	1	1	-	147

#Department of Water and Water Corporation monitoring bores

*These bore lines also have monitoring bores on the Blackwood Plateau.

**Only the HS line bores located within the area of Figure 2.

***EW bores not illustrated in Figure 6, but see Figures 8 and 9.

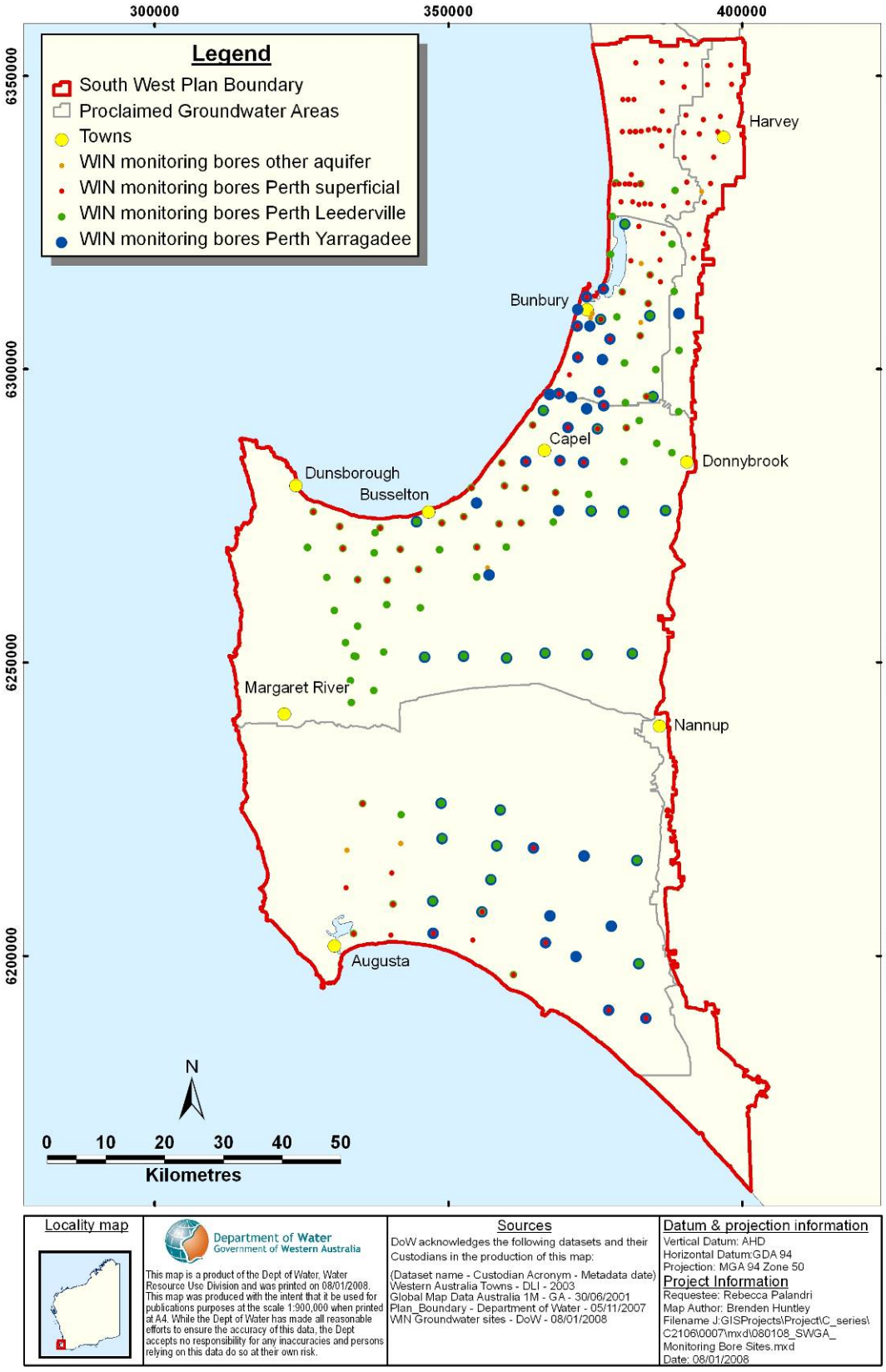

Figure 5 Department of Water groundwater monitoring bores in the South West groundwater areas

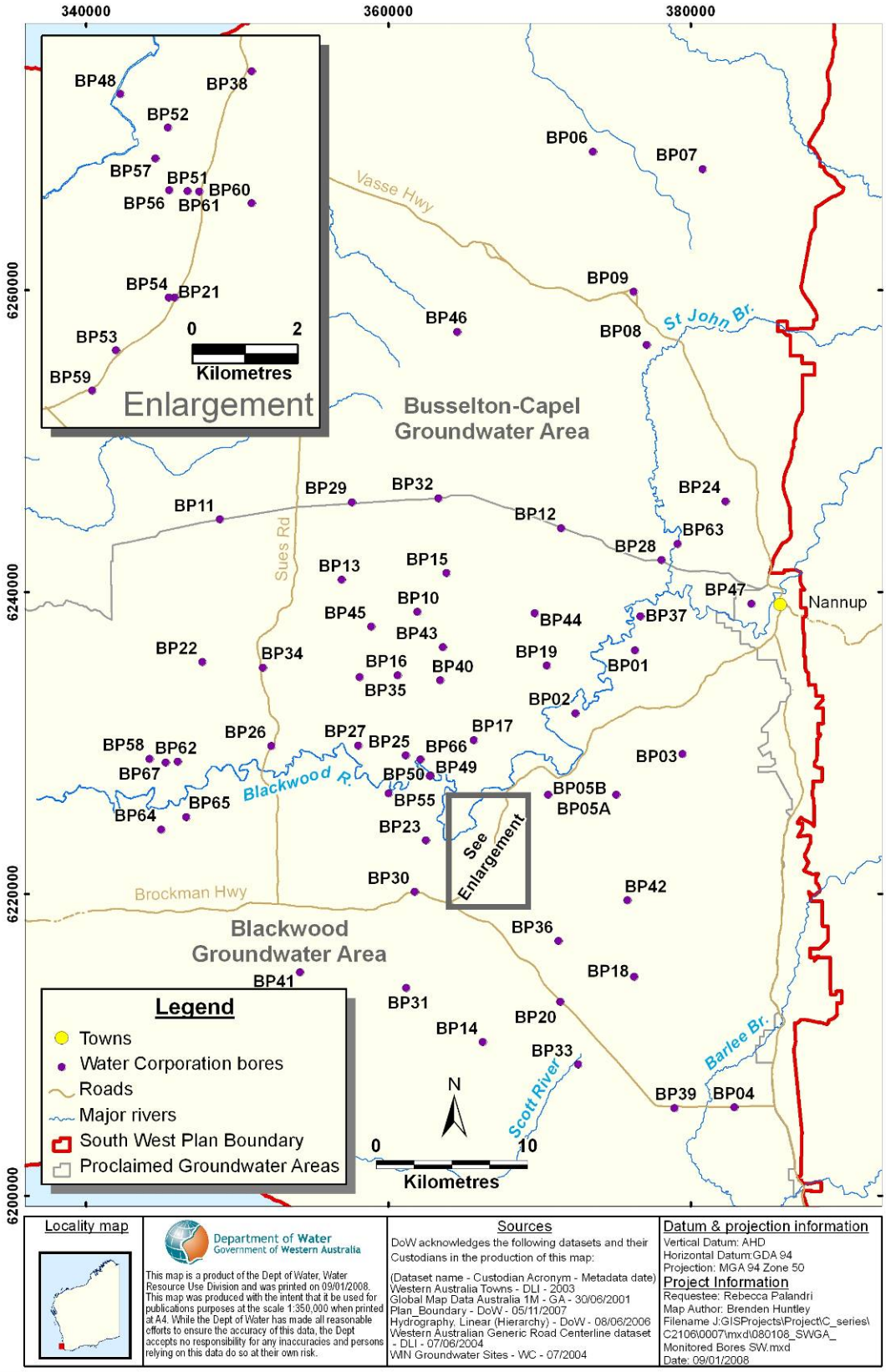

Figure 6 Blackwood Plateau (BP) groundwater monitoring bores installed by the Water Corporation in 2003

3 Groundwater quality monitoring sub-program

3.1 Background for the proposed sub-program

The groundwater quality sub-program is a longer term goal of the department and will detail the objectives and management framework for the groundwater quality monitoring network in the South West groundwater areas. Movement of the seawater interface, aquifer salinity, nutrients, and acid generation due to the oxidation of acid sulphate soils are some of the parameters to be measured and evaluated through this sub-program.

The seawater interface occurs where fresh groundwater meets and mixes with saline groundwater along the coast. Concentration of groundwater abstraction near the coast may result in localised movement of the seawater interface inland causing contamination of fresh aquifers. This is a potential problem around Bunbury and Busselton and is monitored through the licence conditions placed on large (>0.5 GL/a) groundwater licence holders in these areas. The department is also investigating the seawater water interface near Bunbury with the installation of a specific seawater interface monitoring bore.

An area of special interest to the department is the intensive horticultural belt in the Myalup and Lake Preston subareas. Groundwater salinity is increasing in this area and is thought to be the result of localised recycling of fertiliser salts and incursion of saline water (Kern 1998).

Some occurrence of acid sulphate soils has also been noted in this area. Further investigation of acid sulphate soils is planned for this area and is also currently occurring on other parts of the Swan coastal plain and parts of the Blackwood Plateau and Scott coastal plain.

To manage the salinity, nutrient and acid sulphate soils groundwater quality issues in the Myalup horticultural zone the department has implemented standardised monitoring procedures and commitments for local groundwater licence holders. The department will undertake regular review of the monitoring data that is submitted by licence holders to actively manage these groundwater quality issues.

Groundwater quality monitoring at selected sites with groundwater dependent ecosystems will also be conducted. This analysis plays an important role in assessing all the factors that may affect vegetation health at these sites.

4 Environmental water provisions monitoring sub-program

4.1 Background

As part of the water allocation planning process, the department has identified important groundwater-dependent ecological values in the study area and determined the water regimes required to maintain those values at a low level of risk. These water regimes are referred to as the ecological water requirement (EWR).

The EWR specifies the water needs of the ecosystem and is a primary factor in the determination of an environmental water provision (EWP) which considers environmental; social, cultural and economic factors. The outcome from this process is an allocation limit defined in the groundwater management plan.

The aerial and geographic extent of groundwater-dependent ecosystem (GDE) in the South West groundwater areas is very large. However, it is generally not practical to determine site-specific ecological water requirements for every high value, potential groundwater-dependent ecosystem identified within a large study area. Therefore, the department has selected sites as representative of a range of ecosystem types and landforms. The premise is that by limiting draw downs and constraining the impacts at these representative and most sensitive sites, other groundwater-dependent ecosystems within the vicinity are also protected from drawdown impacts.

For a summary of investigations into the ecological water requirements of GDE in the South West groundwater areas and the process adopted to choose the representative GDE refer to Hyde (2006).

Ecological water requirement work began in 2005/06 with the establishment of vegetation transects and shallow groundwater monitoring bores at 24 sites on the eastern Scott coastal plain and southern Blackwood Plateau. Baseline monitoring was conducted and using this limited data ecological water requirements were then determined for the 14 wetland and 10 terrestrial vegetation sites (Froend and Loomes 2006).

In 2007 vegetation transects were established and baseline monitoring was conducted at 15 sites on the Swan coastal plain between Bunbury and Dunsborough (Loomes *et al*. 2007). The department also installed shallow groundwater monitoring bores at the sites where no appropriate bores existed. Site specific EWR have not yet been determined for these GDE, but this will occur once sufficient monitoring data has been collected.

Other areas of interest where the department has recently established vegetation and eventually determine EWR are the western Scott coastal plain and the western

Blackwood Plateau. The Reedia wetlands, the Margaret River Swamps and Scott coastal plain threatened ecological communities have been specifically targeted.

4.2 Monitoring, assessment and reporting framework

We have developed a management framework for environmental water provisions that illustrates the process for monitoring, evaluation and reporting (Figure 7). The key components of the program are:

- groundwater level monitoring at representative GDE
- vegetation condition monitoring
- groundwater quality monitoring
- hydrological investigations where GDE are associated with connected surface water and groundwater systems.

In the following sections these components are described in more detail.

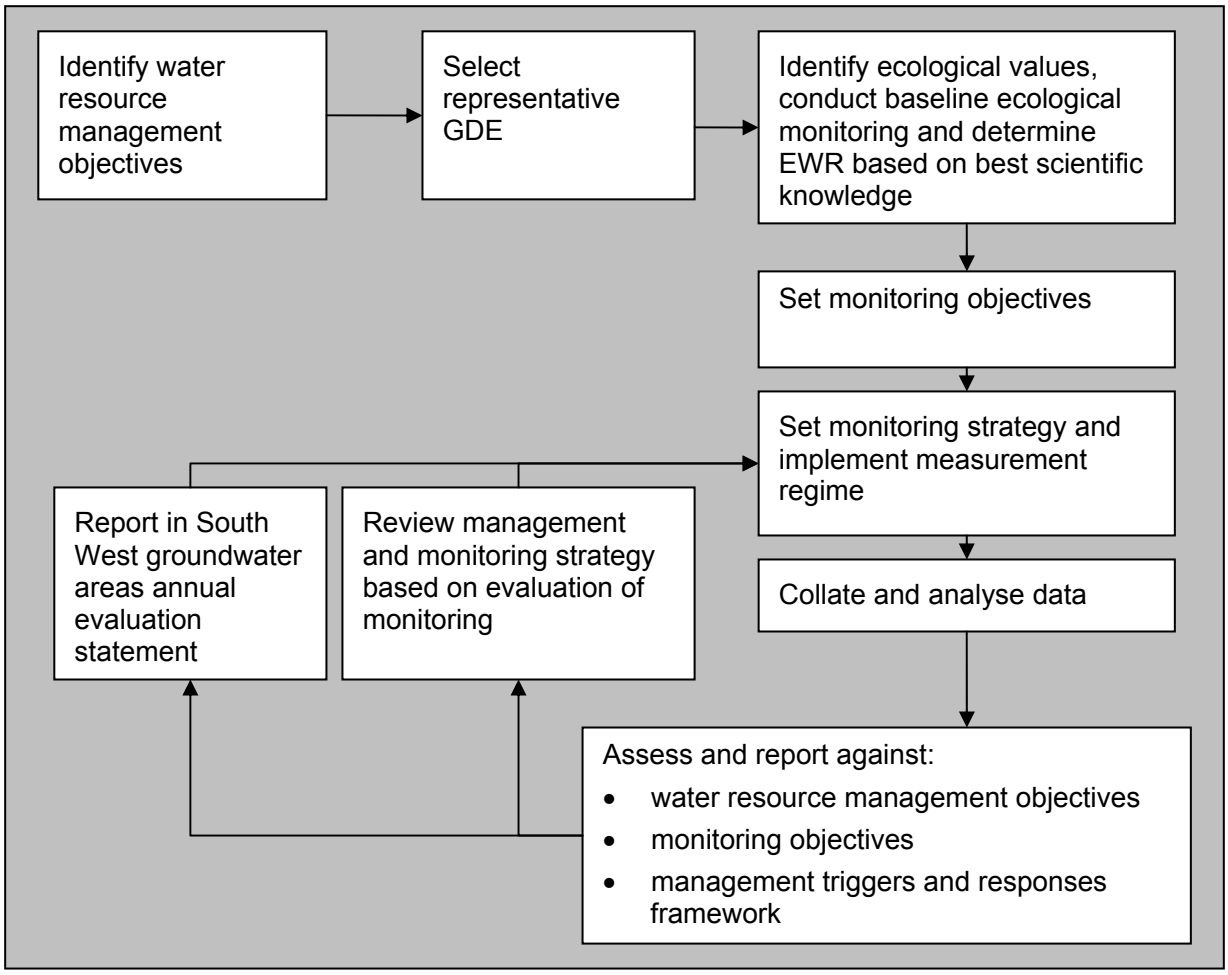

Figure 7 Environmental water provisions monitoring, evaluation and reporting framework for the South West groundwater areas

Vegetation condition monitoring

Vegetation condition measurement is conducted annually to assess the health of groundwater dependent vegetation. The annual frequency enables assessment of short term changes in the vegetation while the accumulated data allows us to track changes to the vegetation community that can occur over the longer term. The relationship between vegetation condition, groundwater level trends and EWR is a prime consideration.

Sites where we have determined EWR and are currently monitoring vegetation and groundwater levels are detailed in tables 3 and 4.

For a detailed explanation of the vegetation monitoring program refer to Froend and Loomes (2006) and Loomes *et al*. (2007). The annual vegetation condition monitoring reports are summarised in the South West groundwater areas annual evaluation statement.

Groundwater level monitoring

Groundwater level measurement at the representative GDE (see figures 8 and 9, and tables 3 and 4) is required to detect trends in the groundwater regime and monitor against the ecological water requirements that have been determined. Currently, water levels are measured every month.

The department is using statistical analysis of groundwater measurement data and control sites to help ascertain whether groundwater level trends at selected GDE are being influenced primarily by climatic factors or by other effects such as abstraction.

The department has established management triggers for groundwater levels at selected sites which instigate a management response to prevent ecological harm or unacceptable ecological impacts. For a detailed explanation of the triggers and responses refer to the Department of Water (2008) report.

Groundwater level data for all groundwater monitoring bores is available on request. Reporting of groundwater level trends against ecological water requirement criteria and the management actions undertaken in response to declines in ecosystem health or groundwater level trends will be documented in the web based South West groundwater areas annual evaluation statement.

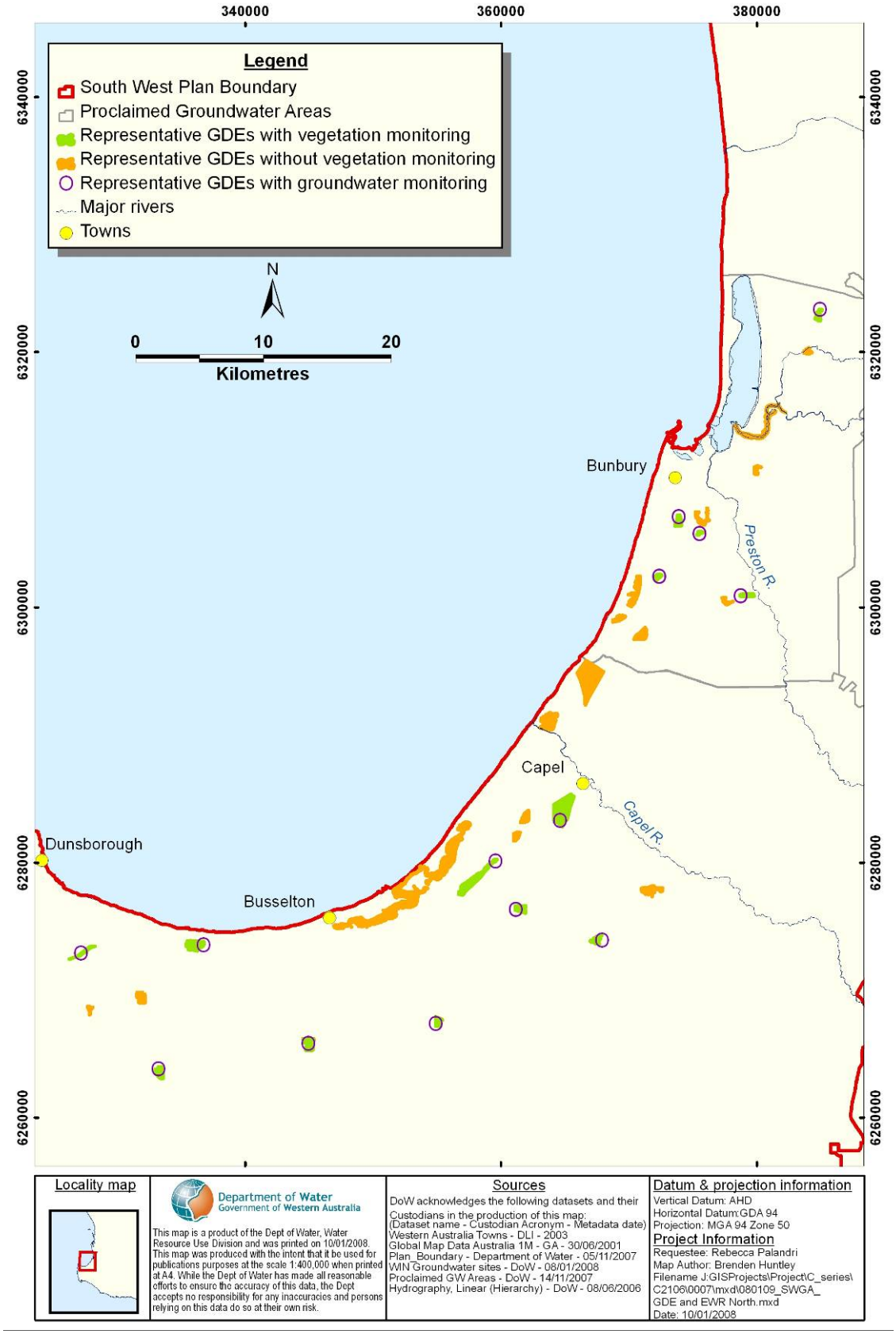

Figure 8 Representative GDE sites with groundwater and vegetation condition monitoring (northern area).

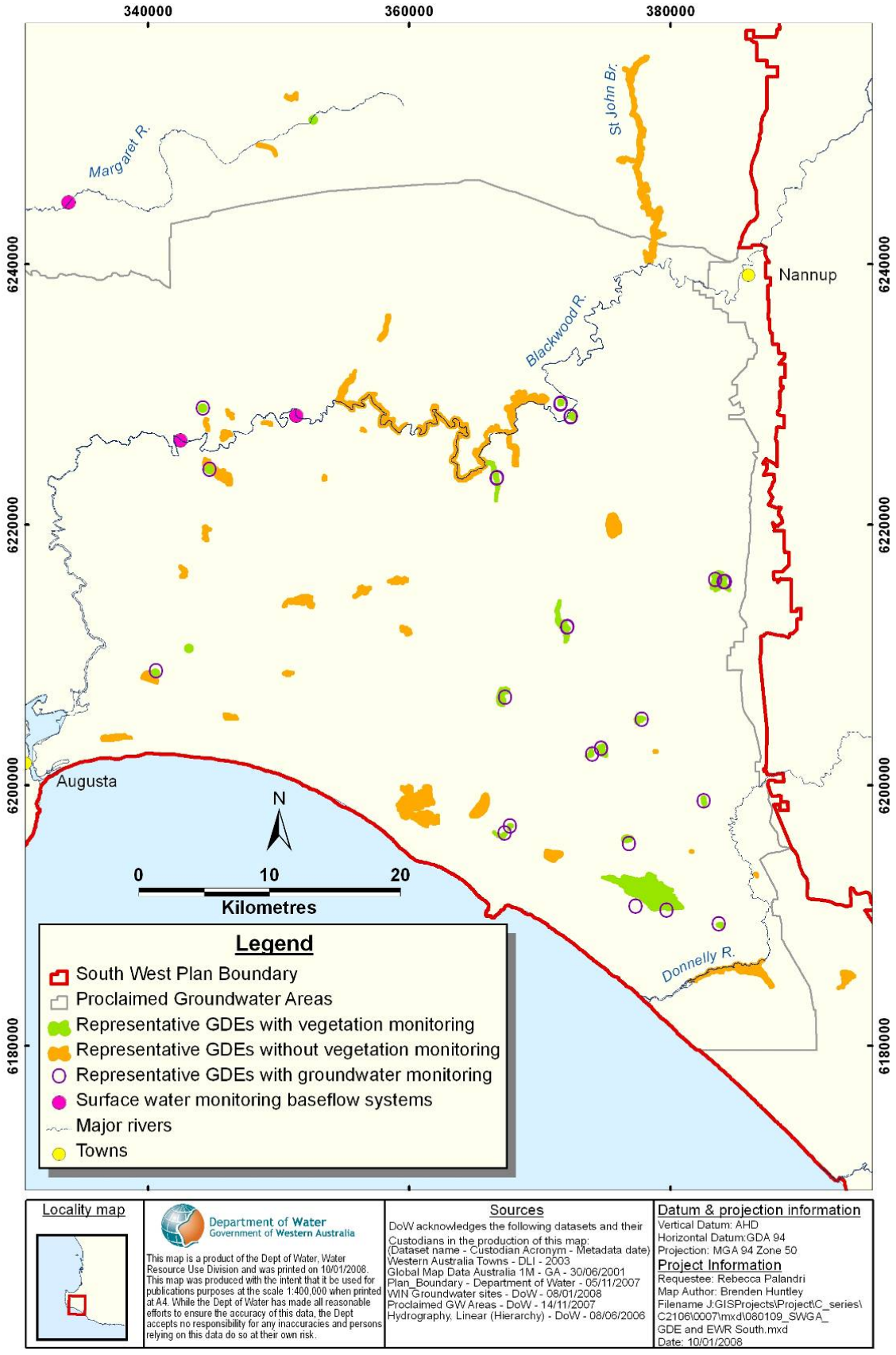

Figure 9 Representative GDE sites with groundwater and vegetation condition monitoring (southern area).

Table 2 Representative GDE monitoring sites for wetland vegetation in the South West groundwater areas

Site Name	Area	Location	EWR	Monthly ground-water level monitoring	Aquifer monitored	Annual vegetation monitoring
Jangardup Rd	Scott coastal plain	E: 0376796 N: 6195468	Yes	Yes	Superficial	Yes
Black point Rd	Scott coastal plain	E: 0374002 N: 6202371	Yes	Yes	Superficial	Yes
Pneumonia Rd	Scott coastal plain	E: 0382524 N: 6198769	Yes	Yes	Leederville	Yes
Black Point Rd-Fouracres Rd	Scott coastal plain	E: 0374674 N: 6202796	Yes	Yes	Leederville	Yes
Black Point Rd – base of dunes	Scott coastal plain	E: 0367690 N: 6196827	Yes	Yes	Superficial	Yes
Black Point Rd – dunes	Scott coastal plain	E: 0367 277 N: 6196134	Yes	Yes	Superficial	Yes
Lake Jasper – East	Scott coastal plain	E: 0379693 N: 6190381	Yes	Yes	Superficial	Yes
Lake Jasper – South	Scott coastal plain	E: 0377320 N: 6190681	Yes	Yes	Superficial	Yes
Scott River Rd	Scott coastal plain	E: 0340600 N: 6208650	Fieldwork commencing 2008			
Pagett Nature Reserve	Scott coastal plain	E: 0345500 N: 6214500	Fieldwork commencing 2008			
Darradup Rd – west	Blackwood Plateau	E: 0383 500 N: 6215 756	Yes	Yes	Leederville	Yes
Darradup Rd east – wetland	Blackwood Plateau	E: 0384052 N: 6215595	Yes	Yes	Leederville	Yes
Longbottom Rd – wetland	Blackwood Plateau	E: 0371576 N: 6229310	Yes	Yes	Leederville	Yes
Poison Gully	Blackwood Plateau	E:0366689 N: 6223558	Yes	Yes	Yarragadee	Yes
Brockman Hwy wetland	Blackwood Plateau	E: 0372353 N: 6228296	Yes	Yes	Leederville	Yes
Stewart Rd Causeway	Blackwood Plateau	E: 0372104 N: 6212136	Yes	Yes	Leederville	Yes
Reedia North	Blackwood Plateau	E:0344195 N: 6228920	Fieldwork commencing 2008			
Reedia South	Blackwood Plateau	E: 0344965 N: 6224240	Fieldwork commencing 2008			
Margaret River	Blackwood Plateau	E: 0352560 N: 6251150	Fieldwork commencing 2008			
Kemerton Buffer Zone	Swan coastal plain	E: 0384906 N: 6323330	Interim	Yes	Superficial	Yes

Site Name	Area	Location	EWR	Monthly ground-water level monitoring	Aquifer monitored	Annual vegetation monitoring
Hay Park	Swan coastal plain	E: 0373905 N: 6307073	Interim	Yes	Superficial	Yes
Franklandia Nature Reserve	Swan coastal plain	E: 0378756 N: 6300900	Interim	Yes	Superficial	Yes
Manea Park	Swan coastal plain	E: 0375526 N: 6305770	Interim	Yes	Superficial	Yes
Harewoods Rd	Swan coastal plain	E: 0372390 N: 6302405	Interim	Yes	Superficial	Yes
Capel Nature Reserve	Swan coastal plain	E: 0364622 N: 6283269	Interim	Yes	Superficial	Yes
Spanish Settlers Reserve	Swan coastal plain	E: 0354893 N: 6267364	Interim	Yes	Superficial	Yes
Locke Nature Reserve	Swan coastal plain	E: 0336769 N: 6273503	Interim	Yes	Superficial	Yes
Ruabon Reserve	Swan coastal plain	E: 0361191 N: 6276284	Interim	Yes	Superficial	Yes
Vasse-Yallingup Siding	Swan coastal plain	E: 0327163 N: 6272900	Interim	Yes	Superficial	Yes
Taylors Nature Reserve wetland	Swan coastal plain	E: 0333217 N: 6263801	Interim	Yes	Superficial	Yes
Ludlow Rail Reserve	Swan coastal plain	E: 0359580 N: 6280090	Interim	Yes	Superficial	Yes
Tutunup	Swan coastal plain	E: 367915 N: 6273890	Interim	Yes	Leederville	Yes
Ambergate Reserve	Swan coastal plain	E: 0344960 N: 6265815	Interim	Yes	Superficial	Yes

Table 3 Representative GDE sites for terrestrial vegetation in the South West groundwater areas

Site Name	Area	Location	EWR	Monthly ground-water level monitoring	Aquifer monitored	Annual vegetation monitoring
Black point Rd	Scott coastal plain	E:0377818 N: 6205052	Yes	Yes	Superficial	Yes
Black Point Rd-Fouracres Rd	Scott coastal plain	E:0374672 N: 6202799	Yes	Yes	Leederville	Yes
Scott Rd	Scott coastal plain	E:0383669 N: 6189305	Yes	Yes	Superficial	Yes
Jack Track	Scott coastal plain	E:0367274 N: 6206784	Yes	Yes	Yarragadee	Yes
Darradup Rd east	Blackwood Plateau	E:0384148 N: 6215590	Yes	Yes	Leederville	Yes
Longbottom Rd	Blackwood Plateau	E:0371558 N: 6229250	Yes	Yes	Leederville	Yes
Brockman Hwy	Blackwood Plateau	E:0372341 N: 6228259	Yes	Yes	Leederville	Yes
Darradup Rd north	Blackwood Plateau	E:0375826 N: 6219540	Yes	Yes	Leederville	Yes
Stewart Rd	Blackwood Plateau	E:0371387 N: 6212820	Yes	Yes	Leederville	Yes
Poison Gully	Blackwood Plateau	E:0366689 N: 6223558	Yes	Yes	Yarragadee	Yes
Taylors Nature Reserve	Swan coastal plain	E: 0333600 N: 6263170	Interim	Yes	Superficial	Yes

Groundwater quality at GDE

Groundwater quality measurements at 11 of the representative GDE on the Swan coastal plain were conducted when bores were installed in early 2007. The analyses performed were to detect nutrients, metals, salinity, pH and other analytes that detect the formation of acid due to the oxidation of acid sulphate soils.

Ongoing and regular water quality measurement will be conducted at representative GDE and form part of the overall groundwater quality monitoring sub-program for the South West groundwater areas.

Hydrological investigations where GDE are associated with connected systems

In the South West groundwater areas there are surface water features such as lakes and rivers that are strongly connected to, and are dependent on, groundwater. These are known as connected systems. The department has recently conducted a review of connected systems in the South West groundwater areas, see Appendix 1.

The areas being investigated by the department to better understand inter-connectivity, and in some instances determine ecological water requirements are listed in Table 5. For example, on the perennial section of the Blackwood River down stream of Nannup the department is conducting a comprehensive eco-hydrological study of native fish and aquatic invertebrates.

The department also has a comprehensive surface water monitoring network which covers most river systems in the plan area.

Table 4 Investigations at GDE associated with connected systems

Connected system	Hydrological investigation	Hydrogeological investigation	EWR investigation
Blackwood River and tributaries (below Nannup) where in connection with the Yarragadee and Leederville Aquifers	Yes – current	Yes – current	Yes – current
Capel River	Yes – current	Proposed	Yes – current
Margaret River pools: Mid to upper reaches	Surface water monitoring only	Yes – completed	No
Margaret River below Ten Mile Brook	Yes – current	No	Yes – current
Donnelly River and Barlee Brook	Yes – current	No	No
Lake Jasper	Surface water monitoring	Groundwater monitoring	Proposed expert panel[1]

[1] Expert panel is where scientific knowledge across a range of appropriate disciplines, along with local and traditional understandings of the environment, can be brought together in a facilitated dialogue.

5 Connected systems investigations and monitoring sub-program

5.1 Introduction

Connected water resources are those where interaction occurs between water resources located above ground (surface water) and below ground (groundwater). In the South West groundwater areas groundwater is an important contributor to many surface water features (URS 2004a). These features include lakes, wetlands, river baseflow systems, estuarine and near-shore marine systems.

Surface water features such as wetlands and streams can have multiple sources of water. These include direct rainfall, runoff and groundwater. The interaction between surface water features and underlying aquifers can take place in different ways and in different settings. Stream reaches can interact with groundwater systems by:

1 gaining groundwater inflow

2 losing water to the underlying aquifer

or

3 both by variably gaining and losing depending on the time of year (Bureau of Rural Sciences 2006).

The Brunswick River is an example of a system that exhibits both gaining and losing attributes as it traverses the Superficial Aquifer of the Swan coastal plain (Annan 2006).

Lakes can also gain from or lose to the underlying aquifer. A throughflow situation can occur where parts of the lake receive groundwater and other parts lose water. Lake Jasper is an example of a throughflow lake that receives and loses groundwater through the Superficial Aquifer on the eastern Scott coastal plain (Turner *et al*. 1996).

Some wetlands can form where groundwater discharges to the land surface, and these tend to occur at breaks in slope or topographic depressions (Winter *et al*. 1998). Examples of such wetlands can be found on the Whicher Scarp in the South West groundwater areas.

Other wetlands are surface water dominated and arise where rapid drainage of water from the land surface is prevented. Many seasonal wetlands on the Blackwood Plateau are considered to function as a result of this process (URS 2004a, Strategen 2004), where surface water drainage is inhibited by topography and sub-surface impediments to vertical drainage such as impervious clays and indurated iron formations. Investigations and monitoring of seasonal wetlands and other GDE is documented in Section 3 and Hyde (2006).

A recent review by the department of river systems and larger permanent wetland systems identified around 10 clearly connected systems in the South West groundwater areas (Appendix 1).

5.2 Investigating, monitoring and managing connected surface water and groundwater resources

In the South West groundwater areas monitoring and management of connected systems has generally been separated between the two fields of groundwater and surface water resource assessment.

In recognition of the need to integrate the management of connected groundwater and surface water resources the department is undertaking investigations of selected systems that will improve our understanding of interconnectivity and tailor monitoring to the hydrogeological and geological processes occurring between the connected resources.

These types of investigations are currently occurring on the Capel, Blackwood and Margaret rivers. The work is largely driven by the water resource use pressures on these systems.

Ecological water requirement studies are also occurring on a number of connected river systems in the South West groundwater areas. While they are not specific investigations of interconnectivity, the consideration of connectivity is integral to assessing the hydrological dependencies of these ecosystems. Details of these studies are documented in Table 6.

5.3 Monitoring and investigations of connected systems in the South West groundwater areas

We have developed a framework for groundwater level measurement that illustrates the process for monitoring, assessment and reporting (Figure 10).

For most connected systems in the South West groundwater areas we are at the stage of assessing connectivity and setting monitoring objectives and strategy. This report now summarises our knowledge of the connectivity of these systems and describes where they sit in the management and monitoring framework.

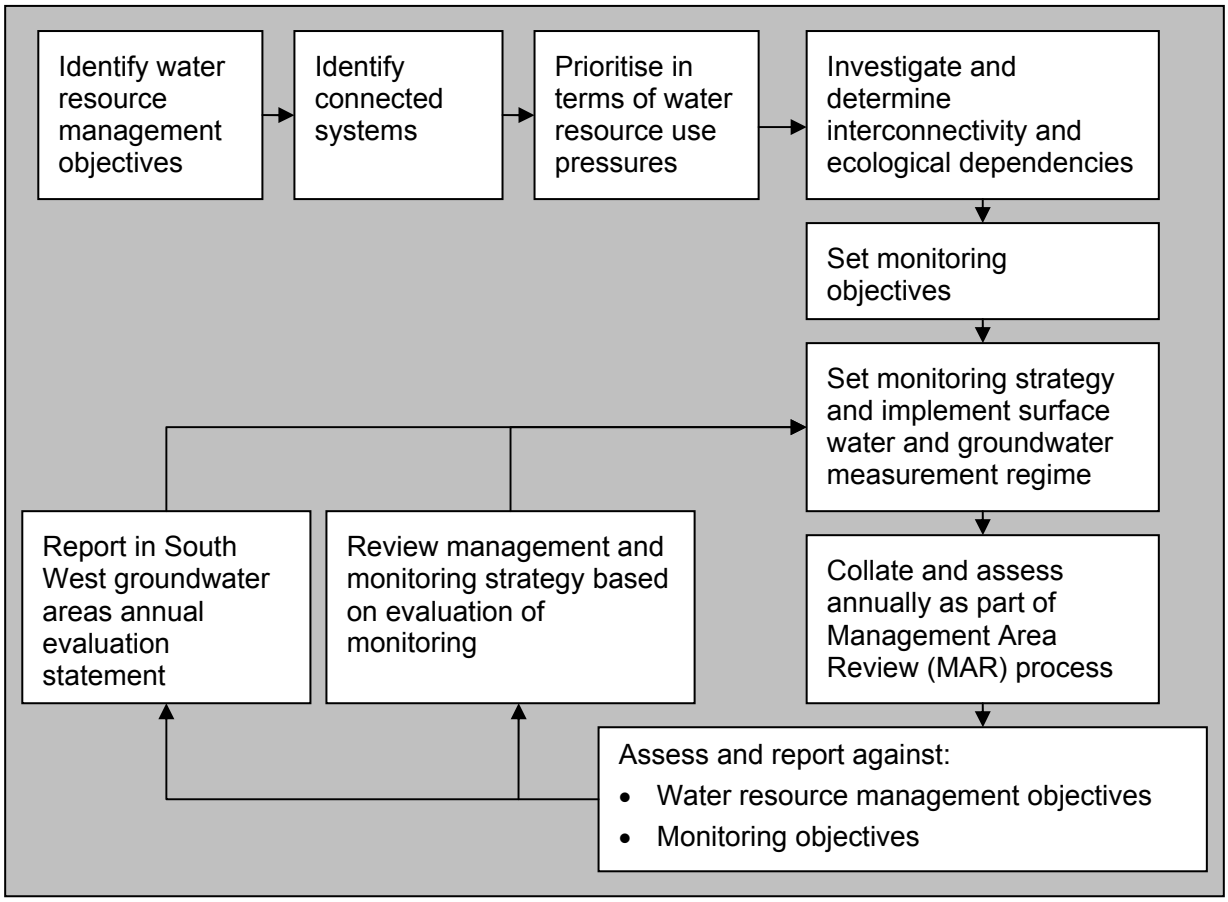

Figure 10 Management and monitoring framework for connected systems in the South West groundwater areas

The Blackwood River

The Blackwood River is strongly connected to groundwater where it dissects the Yarragadee and Leederville formations downstream of the Nannup town site. Summer flow is almost entirely dependent on groundwater discharge and the low salinity of this discharge is considered to be important for sustaining the high ecological and social values of the river (Goode 2006, Hyde 2006 and Goodreid 2007).

While the discharge volumes from each aquifer are believed to be similar, the Yarragadee Aquifer discharges into the river in a localised area over a few kilometres, while the Leederville Aquifer discharges at lower rates, but over a much longer stretch of the river.

The Blackwood River cuts through one of the few small areas where the Yarragadee Formation is exposed at the land surface. Otherwise the Yarragadee is present across most of the South West groundwater areas and is generally deep and overlain by other formations.

On the coastal plains the Yarragadee Aquifer is high yielding and is utilised by large resource development projects such as public water supply, irrigation and mining. The hydrological characteristics of the aquifer means that groundwater abstraction, particularly cumulative effects, from these distant areas has the potential to impact the summer flows in the Blackwood River and some of its tributaries.

Hydrological and hydrogeological data has been collected around the Yarragadee discharge zone of the Blackwood River over the past 5 years. The department is currently synthesising this information to:

- determine if relationships exist between groundwater base flows, groundwater levels, water chemistry and rainfall in the lower Blackwood River main channel, Milyeannup Brook and Poison Gully
- develop quantitative management triggers based on one or more of these relationships that alert the department to a variation in flow or groundwater level in these systems that is outside the range expected under the prevailing climatic conditions (and therefore may indicate an impact due to groundwater abstraction)
- develop management actions associated with these triggers
- provide recommendations for further investigation required to improve the management triggers.

Ongoing monitoring of the Blackwood River and perennial tributaries occurs through permanent gauging stations and snapshots of river flows and water quality during the low flow period. Consequently, the department is monitoring during these critical flow periods and is able to detect lower than usual flow events and investigate their cause.

The Capel River

Preliminary investigations have been undertaken on the inter-connectivity of Capel River with groundwater systems. The hydrology of the river was reviewed in 2007 (DoW 2007c, Durrant 2007). The latter study identified constant flow over summer periods (1998-2003) at the Yates Bridge gauging station (610219) as being primarily from summer flow releases from a large on-stream dam in the upper catchment. In summer 2007 the department coordinated discharge measurements and a surface water quality snapshot to avoid these dam releases to broadly identify the gaining reaches of the river. This work identified the main gaining reach as occurring about 10 km east from the base of the Whicher Scarp over the superficial formations of the Swan coastal plain (near Capel marron farm) (DoW 2007b).

The South West region's Catchment Science and Investigation Group is continuing this work in 2007/08 to further define the gaining reaches and establish discharge measurement sites. The group is also conducting baseline ecological monitoring and eco-hydrological investigations (R. Pickett pers. comm. 2007).

The department is also doing work on the Capel River to support the development of the Whicher surface water management plan. This work includes quantifying current water use and demand, mapping farm dams and conducting economic and social values studies. Permanent river cross-sections have been established at two reaches (one on the Whicher Scarp and one just up-stream of the Capel town site), to develop a hydraulic model and determine ecological water requirements (BEP 2006a, DoW 2007b).

The Margaret River

The mid to upper Margaret River contains a number of permanent pools that are dependent on groundwater discharge from the upper Mowen Member of the Leederville Aquifer (Schafer *et al*. 2007).

Some of the pools are utilised for consumptive use and some for recreation, for example Canebrake Pool is a popular recreational site managed by the Department of Environment and Conservation (BEP 2006b). The pools are also recognised as an important groundwater-dependent system, supporting the Hairy Marron (*Cherax tenuimanus*) which are found almost exclusively in the upper reaches of the Margaret River, and the more common smooth marron (*Cherax cainii*) (Beatty 2000, Beatty *et al*. 2003).

The permanent pools in the mid to upper Margaret River were assessed through a bathymetric survey and water level monitoring as part of the Cowaramup hydrogeological study. Initial monitoring results suggest that water levels in the pools have declined at a rate similar to that of the potentiometric head in the nearby observation bores (Schafer *et al*. 2007). There appear to be small daily oscillations in all pools that are related to evapotranspiration processes and surface water abstraction (Schafer *et al*. 2007).

Continuous water level measurement using data-loggers are being conducted at three of the permanent pools to detect impacts to pool water levels, and improve our hydrological understanding of the system. Field conductivity, dissolved oxygen, pH and temperature measurements are also being collected at monthly intervals (Schafer *et al*. 2007).

The department is also doing work on the Margaret River to support the development of the Whicher surface water management plan. The study area is below the confluence of Ten Mile Brook, which is approximately 5 km below the downstream extent of the permanent pools. This work includes quantifying current water use and demand, mapping farm dams and conducting economic and social values studies. Permanent river cross-sections have been established at two reaches (one just down stream of the Ten Mile Brook confluence and one around 3 km downstream of the Bussell Hwy crossing) to develop a hydraulic model and determine ecological water requirements (BEP 2006a, DoW 2007a). This work program is also being conducted on the Cowaramup, Wilyabrup and Chapman Brooks in the South West groundwater areas (DoW 2007a).

The Brunswick River

A detailed snap-shot of the inter-connectivity of the Brunswick River was conducted by Annan (2006). There are no further investigations planned for this type of work on the Brunswick River in the near future. However, the department is doing work on the Brunswick River to support the development of the Whicher surface water management plan. This work includes quantifying water use and demand, mapping farm dams and conducting economic and social values studies. Permanent river cross-sections have been established at two reaches (one just downstream of the Brunswick River town site and one at the Australind Bypass), to develop a hydraulic model and determine ecological water requirements (BEP 2006a, DoW 2007a).

The Donnelly River and Barlee Brook

The lower Donnelly River and Barlee Brook have been subject to recent investigations by the department because of recognition of strong interconnectivity with groundwater systems. While water resource use pressures on these systems is currently low and not likely to change in the foreseeable future investigations are likely to continue in these water ways due to the pristine nature (Barlee Brook sub-catchment), high ecological values and potential use as control or reference sites for monitoring against connected systems impacted by water resource use.

5.4 Investigation program

A summary of the investigative work for potential connected systems in the South West groundwater areas is documented below in Table 6.

Table 5 Status of the investigations on potential connected systems in the South West groundwater areas

Connected system	Hydrological investigation	Hydrogeological investigation	EWR investigation
Brunswick River	Yes – current	No	Yes – current
Capel River	Yes – current	Proposed	Yes – current
Cowaramup and Willyabrup Brooks	Yes – current	No	Yes – current
Margaret River pools: Mid to upper reaches	Surface water monitoring only	Yes – completed	No
Margaret River below Ten Mile Brook	Yes – current	No	Yes – current
Chapman Brook	Yes – current	No	Yes – current
Blackwood River and tributaries (below Nannup) where in connection with the Yarragadee and Leederville Aquifers.	Yes – current	Review of existing data	Yes – current
The Donnelly River and Barlee Brook	Yes – current	No	No
Lake Jasper	Surface water monitoring	Groundwater monitoring	Proposed expert panel

6 Conclusions

This report details the measurement and monitoring of groundwater resources in the South West groundwater areas to support the South West groundwater areas allocation plan. Table 7 summarises the monitoring, assessment and reporting that will occur for each of the monitoring sub-programs.

Table 6 Monitoring sub-programs and the monitoring, assessment and reporting that will occur for each

Monitoring sub-program	Monitoring	Assessment	Reporting
Groundwater levels	Measure and monitor groundwater levels	• Annual assessment of groundwater level data • Comprehensive statistical analysis of measurement data every four years	• Annual assessment is summarised in the annual evaluation statement for the South West groundwater areas management plan • Report produced for statistical analysis of data that occurs every four years
Groundwater quality	Focus is on groundwater quality monitoring in the Myalup horticultural zone	• Annual assessment of groundwater quality trends in the Myalup horticultural zone	• Annual assessment of Myalup horticultural zone summarised in the annual evaluation statement for the South West groundwater areas management plan
Environmental water provisions	• Monthly groundwater level measurement at representative GDE • Annual vegetation condition monitoring at representative GDE	• Annual assessment of environmental water provisions • Vegetation condition is assessed against key indicators	• Assessment of environmental water provisions is summarised in the annual evaluation statement for the South West groundwater areas management plan • Vegetation condition report is produced annually

Monitoring sub-program	Monitoring	Assessment	Reporting
Connected systems	• Measurement and monitoring of surface water levels and flow • Groundwater monitoring bores have been installed specifically to measure and monitor water levels at selected connected systems • The groundwater level monitoring network is utilised to measure and monitor groundwater levels near connected systems	Groundwater levels are assessed as part of the annual assessment process and the four yearly statistical analysis. Blackwood River – Yarragadee discharge zone summer base flows are assessed every year.	• Investigation reports produced as work is completed. • Blackwood River – Yarragadee discharge zone summer base flows are reported in the annual evaluation statement for the South West groundwater areas management plan.

All of this information will be used in reviewing the South West groundwater areas allocation plan and in licence assessments to ensure that the impacts from groundwater abstraction are minimised on current use and the environment. All monitoring conducted through the monitoring programs feed back into the management framework to meet the water resource management objectives in the plan.

Appendices

Appendix A — Review of connected systems – South West groundwater areas

To support the release of the South West groundwater areas allocation plan the department has conducted a review of the connectivity of river and iconic freshwater lakes in the South West groundwater areas and the surface water and groundwater resource use pressures on them.

This review is a key component of the management and monitoring framework developed for connected systems in the South West groundwater areas (Figure 10).

Identifying connected systems in the South West groundwater areas

The identification of connected systems in the South West groundwater areas was done by identifying all the major river systems and permanent lakes and then reviewing the hydrological and hydrogeological literature relevant to these systems. Given the general paucity of such studies it was also important to draw on the intellectual property of the department to assess the connectivity of these systems. The results of this review are detailed in Table 8.

It is important to note that seasonal wetlands are prevalent over much of the study area, including the Scott and Swan coastal plains and the Blackwood Plateau. However, these were not considered in this report and only larger permanent wetland systems, such as Lake Jasper were reviewed. Investigations and monitoring of seasonal wetlands and other GDE is documented in Hyde (2006).

Table A1 Studies undertaken on connected systems in the South West groundwater areas

System	Study or understanding of inter-connectivity
Swan coastal plain	
Brunswick River	Honours thesis by Annan (2006), revealed a strong groundwater contribution to summer flows and identified gaining and losing stretches of the river. Seven methods were compared for investigating groundwater-surface water interactions including hydrogeological mapping, hydrograph analysis, temperature studies, seepage measurements, a salinity survey, field observations and water budgeting. Brunswick River hydrology summary (Crossley 2007): observed monthly flows and daily flow duration analysis indicated groundwater contribution to summer baseflow.
Capel River	Capel River hydrology summary (Durrant 2007) – flow duration curves (Capel Railway Bridge) indicate the contribution of groundwater discharge to summer flows on the Swan coastal plain. During summer 2007, the Catchment Science and Investigation team of DoW (2007b) identified that the main gaining reach of the Capel River was approximately 15 km long and located between Scott Rd on the Whicher Scarp and the Capel Marron Farm on the Swan coastal plain.

System	Study or understanding of inter-connectivity
Collie River	Flows are regulated from the Wellington dam in the upper catchment. This makes it difficult to determine the volume and importance of groundwater discharge to the river. No specific investigations of inter-connectivity have been undertaken, but expect that there are reaches gaining from the Superficial aquifer on the Swan coastal plain.
Preston River	Flows are regulated from the Glen Mervyn dam in the upper catchment. The river is also used as a conduit to deliver irrigation water. These factors make it difficult to determine the volume and importance of groundwater discharge to the river.
Ferguson River	The river is used as the conduit to deliver irrigation water therefore the summer flows are highly variable and it is difficult to determine the volume and importance of groundwater discharge to the river
Ludlow River	Flow data analysis and field verification show that the Ludlow River is ephemeral on the Swan coastal plain (J. Hall pers. comm. 2008).
Abba River	Flow data analysis and field verification show that the Abba River is ephemeral on the Swan coastal plain (J. Hall pers. comm. 2008).
Sabina River	The downstream area of the catchment is artificially drained. The lower section of the river has been altered and is called the Sabina diversion drain (DoW 2007c). Flow data analysis and field verification show that the Sabina River is ephemeral on the Swan coastal plain (J. Hall pers. comm. 2008).
Vasse River	The downstream area of the catchment is artificially drained. The lower section of the river has been altered and is called the Vasse diversion drain (DoW 2007c). Flow data analysis and field verification show that the Vasse River is ephemeral on the Swan coastal plain (DoW 2007c, J. Hall pers. comm. 2008).
Buayanup River	The downstream section of the catchment is artificially drained and the river has been modified to facilitate this drainage. Where not influenced by artificial drainage flow data analysis and field verification shows that the Buayanup River is ephemeral on the Swan coastal plain (J. Hall pers. comm. 2008).
Carbanup River	Flow data analysis and field verification show that the Carbanup River is ephemeral on the Swan coastal plain (DoW 2007c, J. Hall pers. comm. 2008). Some expressions of groundwater may occur where the river bed has been excavated for water storage (R. Pickett pers. comm. 2007).
Blackwood Plateau	
Blackwood River and tributaries (Leederville and Yarragadee Aquifer discharge zone)	Hydrogeological studies (URS 2004a and 2006, Water Corporation 2005) and groundwater modelling confirm hydraulic connection between underlying aquifers and the Blackwood River and its tributaries. Quantification of groundwater contribution to baseflow in the Blackwood River has been estimated using the SWAMSv2 groundwater model (Varma 2007). Unpublished data from the DoW. Summer discharge measurements have been taken 2003–2007 to estimate baseflow. Data confirms strong groundwater contribution to St John Brook, McAtee Brook, Milyeannup Brook, Poison Gully and Blackwood River main channel from Darradup.
St John Brook	Baseflow into St John Brook is maintained by groundwater outflow from the Leederville Formation. The brook maintains a small perennial flow. (URS 2004b).
Spearwood Creek, Adelaide Brook and Reedia wetlands	Hydrogeological assessment of these areas (URS 2004c) suggests that groundwater discharge from the Vasse Member of the Leederville formation maintains perennial baseflow in these tributaries and supports the wetlands.

System	Study or understanding of inter-connectivity
Chapman Brook	Chapman Brook hydrology summary (Rodgers 2007) – insufficient data available to determine the interaction between groundwater and surface water with any certainty. Flows in Feb, March and April have only been observed in 2, 3 and 4 years respectively, out of the 10 years of observations.
Margaret River	Hydrogeological study of the Cowaramup area confirmed connection between more than 20 large permanent pools in the mid to upper Margaret River and the Leederville Aquifer. (Schafer *et al*. 2007).
Carbanup River	No indication of perennial flow in the Carbanup River on the Blackwood Plateau. Groundwater contribution may occur as the river traverses the seepage face that exists on the Yelverton Shelf and Whicher Scarp (Schafer *et al*. 2007).
Scott coastal plain	
Barlee Brook	Recent fieldwork between Vasse Hwy and Stewart Road indicates strong contribution to the Barlee Brook from the Leederville and/or Yarragadee Aquifers (R. Pickett pers. comm. 2007).
Lake Jasper	In a study of the groundwater–lake water interactions at Lake Jasper Turner *et al*. (1996) found there to be strong interactions between the lake and the Superficial Aquifer. There is hydraulic connection between the Superficial aquifer and the Yarragadee Aquifer.
Lake Quitjup	Lake Quitjup hydrology study (URS 2005) indicates that the lake is in hydraulic connection with groundwater in the superficial formations. A conceptual water balance indicates that about half the inflow to the lake is derived from groundwater and half from direct rainfall. No surface water inflow or outflow is apparent.
Lake Smith	No studies to date. Similar to Lake Jasper and Lake Quitjup it is most likely that there is a strong in hydraulic connection with groundwater in the superficial formations.
Lake Wilson	No studies to date. Similar to Lake Jasper and Lake Quitjup it is most likely that there is a strong in hydraulic connection with groundwater in the superficial formations.
Donnelly River	Perennial flow downstream of Scott Road crossing (R. Pickett pers. comm. 2007). L. Baddock pers. comm. 2004 in Rockwater (2004) the low piezometric head of bore SC22B may indicate that there is discharge from the top of the Yarragadee Aquifer to Donnelly River in that area.
Scott River and tributaries	Some perennial pools exist downstream of Brennan's Bridge on the Scott River Road (R. Pickett pers. comm. 2007). Upstream of the Brennan's Bridge the river is ephemeral (J. Hall pers. comm. 2008).
Leeuwin-Naturaliste Ridge	
Wilyabrup & Cowaramup Brooks	Wilyabrup & Cowaramup brook's hydrology summary (Coppolina 2007) – permanent pools indicate some connection with groundwater.

Water resource pressures on connected systems in the South West groundwater areas

Assessment of the water resource pressures on some of these systems (Table 1) was conducted by the department using llicensing databases and water use studies to define a low, moderate or high rating for the pressures on surface water and groundwater resource use in these systems. An explanation of the assessment criteria used as guide to facilitate this process is detailed in Table 9 and the results of the assessment are presented in Table 10.

Table A2 Assessment criteria used to define surface water and groundwater resource use pressures for connected systems in the South West groundwater areas

Assessment Rating	Surface water resource use pressures	Groundwater resource use pressures
Low	Small number of licensed or unlicensed users drawing directly from the streamline. Small number of on-stream and off-stream farm dams within the catchment area. Summer flows are regulated by environmental water provision releases from large upstream dams. Low future demand for consumptive use of surface water.	Small number of groundwater abstraction points within 500m of the stream line. No large licenses (>1 GL/a) exist in close proximity (<2 km) to the surface water feature. Results of regional groundwater modelling indicate that at full use of current groundwater entitlements GDE along the streamline are at Low level of risk.
Moderate	Medium number of licensed or unlicensed users drawing directly from the streamline. Moderate number of on-stream and off-stream farm dams within the catchment area. Moderate future demand for consumptive use of surface water.	Medium number of groundwater abstraction points within 500m of the stream line. No large licenses (>1 GL/a) exist in close proximity (<2 km) to the surface water feature. Results of regional groundwater modelling indicate that at full use of current groundwater entitlements GDE along the streamline are at Moderate level of risk.
High	Large number of licensed or unlicensed users drawing directly from the streamline. Large number of on-stream and off-stream farm dams within the catchment area. High future demand for consumptive use of surface water.	Large number of groundwater abstraction points within 500m of the stream line. Large licenses (>1 GL/a) exist in close proximity (<2 km) to the surface water feature. Results of regional groundwater modelling indicate that at full use of current groundwater entitlements GDE along the streamline are at High to Severe level of risk.

Table A3 The results of an assessment of surface water and groundwater use resource pressures in and around connected systems in the South West groundwater areas

System	Assessment	
	Surface water resource use pressures	Groundwater resource use pressures
Swan coastal plain		
Brunswick River	Moderate	Low
Lower Collie River	Regulated flow	Low
Preston River	Regulated flow	High
Ferguson River	Regulated flow	High
Capel River	High and some regulated flow	High

Carbanup River	Moderate	High
Vasse River	Low	Moderate
Abba River	Low	Low
Sabina River	Low	Moderate
Ludlow River	Low	High
Blackwood Plateau		
Carbanup River	Low	Low
Blackwood River and tributaries in Yarragadee discharge zone	Low	Distant Yarragadee abstraction can impact-moderate
St John Brook	Low	Low
Spearwood and Adelaide Creeks	Low	Low
Chapman Brook	High	Moderate
Margaret River	Moderate-high	Moderate-high
Scott coastal plain		
Barlee Brook	Low	Low
Lake Jasper	Low	Moderate
Lake Quitjup	Low	Moderate
Lake Smith	Low	Moderate
Lake Wilson	Low	Moderate
Donnelly River	Low-Moderate	Low
Scott River and tributaries	Moderate	High
Leeuwin Block		
Wilyabrup & Cowaramup Brooks	Moderate-High	Low

Further details of the surface water and groundwater use around selected rivers are detailed below.

The Capel River

Strong demand exists for surface water through private on-stream and off-stream dams and direct pumping from the River (BEP 2006a). There are around 65 landowners that either pump water directly from the river or have on-stream dams for irrigation (BEP 2006a). Initial estimates of surface water use in the catchment are 5.24 GL/a (K. Bennett, pers. comm. 2007).

Groundwater abstraction in close vicinity to the river includes many small allocations for domestic and stock purposes and a moderate number of allocations around 0.5 GL/a for irrigation. Large licences are predominantly related to mining activities, such as a current licence for 2.6 GL/a from a combination of surface water and groundwater sources (BEP 2006a).

The impact of groundwater abstraction on the Capel River catchment was indirectly assessed through an analysis of groundwater trends in the South West groundwater areas (Commander and Palandri 2007) and groundwater modelling (Varma 2007). Both of these studies showed that both local groundwater use and the cumulative effect of regional groundwater abstraction was impacting piezometric heads in the confined Yarragadee and Leederville Aquifers and that this had possible consequences for the groundwater table in connection with the Capel River.

The Blackwood River

Within the Yarragadee Aquifer discharge zone of the Blackwood River there are approximately 15 licensed groundwater allocations and no licensed surface water allocations. All of the 15 groundwater draw points are small domestic allocations which together total less than 0.03 GL/a, and are licensed to take water either from the Yarragadee or from the Leederville Aquifer.

In terms of current groundwater abstraction it is distant pumping from the Yarragadee Aquifer on the coastal plains that has the potential to impact summer base flows in the Yarragadee discharge zone of the Blackwood River.

The Margaret River

The mid to upper Margaret River contains a number of permanent pools that are dependent on groundwater discharge from the upper Mowen Member of the Leederville Aquifer (Schafer *et al*. 2007).

Some of the pools are utilised for consumptive use and some for recreation, for example Canebrake Pool is a popular recreational site managed by the Department of Environment and Conservation (BEP 2006b). The pools are also recognised as an important groundwater-dependent system, supporting the Hairy marron (*Cherax tenuimanus*) which are found almost exclusively in the upper reaches of the Margaret River, and the more common smooth marron (*Cherax cainii*) (Beatty 2000, Beatty *et al*. 2003).

There are 49 licensed surface water users in the Margaret River catchment, including the Water Corporation (BEP 2006b). Collectively, they can take just over 3.0 GL/a of surface water from the Margaret River and its tributaries. The Water Corporation is licensed to take 1.0 GL/a to provide drinking water to the Margaret River Town Water Supply Scheme. This water is sourced from the Ten Mile Brook Dam (BEP 2006b).

Twenty private water users pump directly from the Margaret River and are licensed to take a total of 0.5 GL/a. This direct pumping also occurs from the permanent pools during summer when many parts of the upper Margaret River have dried out (BEP 2006b).

The majority of groundwater abstraction occurs in a 10 km radius around the river in the mid-reaches (334567E, 6245470N). There are around 24 licensed groundwater users taking about 0.4 GL/a. The majority of this water is taken from the shallow and unconfined Leederville Aquifer. There is some potential for combined abstraction from the shallow and deeper Leederville Aquifer to impact water levels in the permanent pools (Schafer *et al*. 2007).

The Brunswick River

A recent water use survey along the river found there are eight licensed surface water users and ten unlicensed groundwater users extracting water from the

Brunswick River system (DoW 2006). The majority of land owners in the lower catchment receive water for stock and irrigation purposes from the Wellington reservoir on the Collie River. Therefore, surface water and groundwater resources from the Brunswick River catchment are under relatively low water resource use pressure.

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.
Allocation limits	The amount of water set aside for annual licensed use. Each water resource (aquifer) within a subarea has AL set and will be amended over time to reflect significant monitoring outcomes and sustainability determinations.
Aquifer	A geological formation or group of formations that is able to receive, store and transmit significant quantities of groundwater.
Base flow	The component of stream flow supplied by groundwater discharge
Bore	A narrow, normally vertical hole drilled in soil or rock to monitor or withdraw groundwater from an aquifer.
Confined aquifer	An aquifer lying between confining layers of low permeability strata (such as clay, coal or rock) so that the water in the aquifer cannot easily flow vertically.
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 (evapotranspiration) or engineering works (groundwater pumping).
Draw down	The lowering of a watertable resulting from the removal of water from an aquifer or reduction in hydraulic pressure
Ecological water requirements	The water regime needed to maintain ecological values of water-dependent ecosystems at a low level of risk.
Environmental water provisions	The water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social, cultural and economic impacts. They may meet in part or in full the ecological water requirements
Groundwater	Water which occupies the pores and crevices of rock or soil beneath the land surface
Groundwater area	Are the boundaries that are proclaimed under the *Rights in Water and Irrigation Act 1914* and used for water allocation planning and management
Groundwater subarea	Areas defined by the Department of Water within a groundwater area, used for water allocation planning and management
Groundwater-dependent ecosystem	An ecosystem that is dependent on groundwater for its existence and health.
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
m AHD	Australian Height Datum – height in metres above mean sea level + 0.026m at Fremantle.

Nested bores	A group of bores drilled next to each other where each bore intercepts a different aquifer or intercepts various levels within the same aquifer.
Non-artesian well	A well, including all associated works, from which water does not flow, or has not flowed, naturally to the surface but has to be raised, or has been raised, by pumping or other artificial means
Observation bore	A narrow, normally vertical hole drilled in soil or rock to monitor water levels and potentiometric head in an aquifer.
Potentiometric head	A measure of an aquifer's water pressure, as reflected by the height to which its water will climb when tapped by a well.
Recharge	Water that infiltrates into the soil to replenish an aquifer
Salinity	The measure of total soluble salt or mineral constituents in water. Water resources are classified based on salinity in terms of total dissolved salts (TDS) or total soluble salts (TSS). Measurements are usually in milligrams per litre (mg/L) or parts per thousand (ppt).
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Through flow	The flow of water within an aquifer.
Unconfined aquifer	Is the aquifer nearest the surface, having no overlying confining layer. The upper surface of the groundwater within the aquifer is called the watertable. An aquifer containing water with no upper non-porous material to limit its volume or to exert pressure.
Water entitlement	The quantity of water that a person is entitled to take on an annual basis in accordance with the *Rights in Water and Irrigation Act, 1914* or a licence.
Water table	The saturated level of the unconfined groundwater. Wetlands in low-lying areas are often seasonal or permanent surface expressions of the watertable.
Wetland	Wetlands are areas that are permanently, seasonally or intermittently waterlogged or inundated with water that may be fresh, saline, flowing or static, including areas of marine water of which the depth at low tide does not exceed 6 metres.

Volumes of water

One litre	1 litre	1 litre	(L)
One thousand litres	1,000 litres	1 kilolitre	(kL)
One million litres	1,000,000 litres	1 Megalitre	(ML)
One thousand million litres	1,000,000,000 litres	1 Gigalitre	(GL)

References

Annan K 2006, *A comparison of techniques for investigating groundwater-surface water interactions along the Brunswick River, Western Australia,* honours thesis, University of Western Australia, Crawley.

Beatty SJ 2000, *The reproductive biology and ecological role, using stable carbon isotope analysis, of marron,* Cherax tenuimanus *(Smith 1912), in Lake Navarino, south-western Australia,* Unpublished honours thesis, Murdoch University, Perth.

Beatty SJ, Morgan DL and Gill HS 2003, 'Reproductive biology of the large freshwater crayfish Cherax cainii in south-western Australia,' *Marine and Freshwater Research,* vol. 54, pp. 597–608.

BEP—*see* Beckwith Environmental Planning.

Beckwith Environmental Planning Pty Ltd 2006a, *Capel River – Surface Water Management, Issue Scoping Report,* prepared for Department of Water, Government of Western Australia, Perth.

—— 2006b, *Margaret River, Wilyabrup Brook, Cowaramup Brook and Chapman Brook – Surface Water Management, Issue Scoping Report,* prepared for Department of Water, Government of Western Australia, Perth.

Bureau of Rural Sciences 2006, *Connected Water: Managing the linkages between surface water and ground water*, Australian Government, Department of Agriculture, Fisheries and Forestry, Canberra, viewed 16 July 2008, <www.connectedwater.gov.au>.

Commander DP & Palandri RE 2007, *South West groundwater areas: Groundwater level trends review. Assessment of groundwater level monitoring results in the Bunbury, Busselton-Capel and Blackwood groundwater areas,* Hydrogeology Report HR259, Department of Water, Government of Western Australia, Perth.

Coppolina M 2007, 'Wilyabrup Brook Hydrology Summary,' unpublished report, in possession of the Department of Water, Government of Western Australia, Perth.

Crossley K 2007, 'Brunswick River Hydrology Summary,' unpublished report, in possession of the Department of Water, Government of Western Australia, Perth.

DoW—*see* Department of Water.

Department of Water 2005, *Investigating Western Australia's groundwater resources: A 15 year plan of action (2005 –2020),* HG 10, Department of Water, Government of Western Australia, Perth.

—— 2006, 'Brunswick River water use survey,' unpublished report, in possession of the Department of Water, Government of Western Australia, Perth.

—— 2007a, 'South West environmental water provisions Project: Final Report,' unpublished report to South West Catchment Council, Project W1-02 in possession of the Department of Water, Government of Western Australia, Perth.

—— 2007b, 'South West Inflo – Capel River Gaining Reaches,' unpublished report, in possession of the Department of Water, Government of Western Australia, Perth.

—— 2007c, 'Surface hydrology of the Cape-to-Cape Region of Western Australia,' unpublished report, in possession of the Department of Water, Government of Western Australia, Perth.

—— 2008, *Management triggers and responses for groundwater-dependent ecosystems in the South West groundwater areas allocation plan,* Department of Water, Government of Western Australia, Perth.

Durrant J 2007, 'Capel River Hydrology Summary,' unpublished report, in possession of the Department of Water, Government of Western Australia, Perth.

Froend R & Loomes R 2006, *Determination of ecological water requirements for wetland and terrestrial vegetation – southern Blackwood and eastern Scott coastal plain*, prepared for the Department of Environment, report no. 2005-07, Centre for Ecosystem Management, Edith Cowan University, Joondalup.

Goode B 2006, *A survey of Aboriginal social water requirements for the southern Blackwood Plateau and the Scott coastal plain, South West, Western Australia*, report for the Department of Environment, Brad Goode and Associates Consulting Anthropologists and Archaeologists, Dunsborough.

Goodreid AB 2007, *Social Water Requirements for the Blackwood groundwater area,* Environmental Water Report 2, Department of Water, Government of Western Australia, Perth.

Hyde NL 2006, *A summary of investigations into ecological water requirements of groundwater-dependent ecosystems in the South West groundwater areas,* Environmental Water Report 3, Department of Water, Government of Western Australia, Perth.

Johnson SL 2005, *The Management Area Review Process – A Groundwater Perspective*, Hydrogeology report no HR237, Department of Water, Government of Western Australia, Perth.

Kern AM 1998, 'Results of a study for the re-evaluation of groundwater allocation policy – Myalup subarea,' unpublished report, in possession of the Department of Water, Government of Western Australia, Perth.

Loomes R, Ogden, G & Froend R, 2007, *Selection and establishment of vegetation transects at groundwater dependent ecosystem criteria sites in Bunbury, Busselton–Capel groundwater areas*, prepared for the Department of Environment, Centre for Ecosystem Management, Edith Cowan University, Joondalup.

Rockwater Pty Ltd 2004, *Assessment of hydrogeology, drainage and potential effect on the water table of drawdown in the Yarragadee Aquifer*, report prepared for the Water Corporation, Western Australia, Perth.

Rodgers S 2007, 'Chapman Brook Hydrology Summary,' unpublished report, in possession of the Department of Water, Government of Western Australia, Perth.

Schafer D, Kern A & Johnson S 2007, *Cowaramup groundwater investigation,* Hydrogeology report no. HR262, Department of Water, Government of Western Australia, Perth.

Strategen 2004, *South West Yarragadee – Blackwood Groundwater Area, water study report*, prepared for the Water and Rivers Commission, Strategen, Perth.

Taylor CJ & Alley WM 2001, *Groundwater-level monitoring and the importance of long-term water-level data,* United States Geological Survey Circular 1217, United States of American, Denver, Colorado.

Turner JV, Townley LR, Barr AD, Linderfelt WR, Woodbury RJ, Gailitis V, Bartle GA & Watson GD1996, *Groundwater–lake water interaction near Lake Jasper, D'Entrecasteaux National Park, Western Australia*, CSIRO Division of Water Resources Consultancy Report 96/15, in possession of Cable Sands (WA) Pty Ltd.

URS 2004a, *Establishment of interim ecological water requirements for the Blackwood Groundwater Area, WA – Stages 1 and 2,* prepared for the Department of Environmental Protection and Water and Rivers Commission, URS, Perth.

—— 2004b, *Hydrogeological assessment of groundwater dependent ecosystems at St John Brook*, prepared for the Water Corporation, URS, Perth.

—— 2004c, *Hydrogeological assessment of groundwater dependent ecosystems of the Reedia wetlands*, prepared for the Water Corporation, URS, Perth.

—— 2005, *Lake Quitjup hydrology study,* prepared for the Water Corporation, URS, Perth.

—— 2006, *Blackwood River Valley Model*, prepared for the Water Corporation, URS, Perth.

Varma S 2007, *Southern Perth Basin groundwater resource assessment using SWAMS and ESCP models*, Hydrogeological report no. 251, Department of Water, Government of Western Australia, Perth.

Water Corporation 2005, *South West Yarragadee hydrogeological investigations and evaluation, southern Perth Basin,* IPB Project No. R302, Infrastructure Planning Branch, Planning and Development Division, Water Corporation, Perth.

Winter TC, Harvey JW, Franke OL & Alley WM 1998, *Groundwater and surface water a single resource*, United States Geological Survey Circular 1139, United States of American, Denver, Colorado.