Department of Environment

Hydrogeological Record Series

HG11 2005

The hydrogeology of groundwater dependent ecosystems in the Northern Perth Basin

THE HYDROGEOLOGY OF GROUNDWATER DEPENDENT ECOSYSTEMS IN THE NORTHERN PERTH BASIN

by

J.L. Rutherford, V.J Roy and S.L. Johnson

Water Resource Division

Department of Environment

DEPARTMENT OF ENVIRONMENT

HYDROGEOLOGICAL REPORT SERIES

REPORT HG 11

JUNE 2005

Acknowledgments

The report was prepared by Jasmine Rutherford, Valerie Roy and Seth Johnson in the Water Resources Division. The text was reviewed and edited by Philip Commander and Chris O'Boy.

For more information contact:

Department of Environment

Hyatt Centre, 2nd Floor
3 Plain Street
East Perth WA 6004

Telephone (08) 9278 0300

Facsimile (08) 9278 0586

Recommended Reference

The recommended reference for this publication is:
Rutherford, J., Roy, V. and Johnson, S.L., 2005, *The Hydrogeology of Groundwater Dependent Ecosystems in the Northern Perth Basin*, Department of Environment, Hydrogeological Record Series, HG11.

We welcome your feedback
A publication feedback form can be found at the back of this publication,
or online at www.wrc.wa.gov.au/public/feedback/

ISSN : 1329-542X

June 2005

Cover photograph:

Paperbark trees (Melaleuca Species) on the mud flats of Lake Logue, 12 km west of Eneabba. These trees are not groundwater dependent, as the regional watertable is more than 10 metres below the ground level.

Contents

Maps

Figures

Table

Appendices

Summary

Abstraction from regional aquifers has the potential to influence groundwater levels and impact on GDEs (Groundwater Dependent Ecosystems). This study covers the Northern Perth Basin, where recent increases in the allocation of groundwater resources, primarily for horticulture, have created the need to identify and characterise potential Groundwater Dependent Ecosystems (GDEs) to ensure their protection.

Critical to the identification of GDEs are reliable depth to groundwater data and current remnant vegetation maps. In this regional-scale study, potential GDE areas were delineated from remnant vegetation maps supplied by The Land Monitor Project, and groundwater level maps derived from an integrated interpretation of bore hole data, topography, geology and hydrogeology. The interrogation of these data sets in a GIS provided the platform to display and target known, and prospective, GDE areas. The field checking of approximately 100 potential GDE sites assisted in the validation of regional groundwater level and remnant vegetation data at a local scale. The methodology and results of this study will assist in the development of ecological water requirements (EWRs) and environmental water provisions (EWPs), and provide a framework for conducting finer scale investigations.

This report describes the development and use of the main outputs from this study, in particular the GIS database that identifies potential GDE areas with respect to regional aquifers, and includes a data sheet for each of the 98 potential GDE sites.

1 Introduction

1.1 Background

The Northern Perth Basin is located in the coastal Midwest of Western Australia and contains significant groundwater resources that are stored within a thick succession of sedimentary aquifers. Groundwater is present in the Cainozoic and Mesozoic aquifers; it is mainly fresh to brackish, and is used for a variety of horticultural and mining purposes.

The Department of Environment manages the groundwater resources in the Northern Perth Basin across three major groundwater areas (Arrowsmith, Jurien and Gingin) that are further divided into groundwater sub-areas. In some sub-areas, particularly around Gingin, groundwater resources are either fully allocated or approaching full allocation. Over the past decade, increasing groundwater demand has placed added pressure on these resources and may potentially impact on their long-term sustainability. At present, licensed groundwater allocation in the Northern Perth Basin is estimated at about 180 GL/year with most licences in the Gingin GWA.

A primary role of groundwater resource management is to ensure that there is minimal impact on the environment and its ecosystems from groundwater abstraction. Changes in the groundwater regime produced by rising water levels through land clearing, or falling water levels through abstraction for town water supplies, agriculture and industry may potentially impact on vegetation and faunal ecosystems. It is therefore important to identify groundwater dependent ecosystems (GDEs) that may be either partially or totally dependent on groundwater for their survival, and to understand their distribution and dependence on the regional aquifers.

The importance of improved methods of quantifying environmental groundwater requirements, for inclusion into aquifer management plans, has increased. From a national perspective, the spatial distribution of GDEs and a suggested approach to facilitate their identification, together with developing conservation priorities, is detailed in Hatton and Evans (1998). In Western Australia, the Department is undertaking EWR studies to understand the amount of groundwater resources required for maintaining the environment.

In the Northern Perth Basin, PPK Environment and Infrastructure undertook a study to identify and classify GDEs in the Arrowsmith and Jurien Groundwater Areas, which included a literature review, an inventory of cave systems, and a depth to groundwater map (PPK, 2001). This work also coincided with a vegetation study by V&C Semeniuk Research Group (2001). Stelfox (2001) provided a detailed understanding of aquifer contribution into the Moore River, which assists in developing EWRs for this riverine system. Storey and Davies (2002) determined the preliminary EWR for Gingin and Lennard Brooks, based on the hydrogeological framework by Johnson (2000). As part of a water supply proposal for Jurien, Welker Environment Consultancy (WEC) undertook an EWR study on behalf of the Water Corporation to assess potential impacts on GDEs in response to groundwater abstraction (WEC, 2003).

1.2 Scope and purpose

The objective of this study was to identify potential GDEs within the regional aquifer systems of the Northern Perth Basin. The study will provide important groundwater information to assist in the development and formulation of both ecological water requirements (EWRs) and environmental water provisions (EWPs). As such, the study has focused on the regional aquifers from which groundwater is allocated.

The study involved the development of a regional-scale GIS database comprising depth to groundwater and remnant vegetation data layers, in order to determine potential GDE areas. A number of field visits were undertaken to confirm the hydrogeology and potential GDE areas derived from the database. In addition, conceptual hydrogeological models for approximately 100 prospective GDE sites were developed (Appendix 1) for referencing during the EWR and EWP investigations. The main outputs of this study can be summarised as:

- Identification of potential GDE sites within regional aquifer systems;
- Compilation of regional-scale water level information into a GIS;
- Development of conceptual hydrogeological models of potential GDE sites; and
- Provision of a regional framework for decision making and planning future investigations.

2 The study area

2.1 Location

The study area covers the onshore portion of the Northern Perth Basin extending over an area of about 21 400 km^2 from Geraldton (in the north) to Gingin (in the south). The Darling Fault, north of Gingin, and the Urella Fault, northeast of Eneabba, marks the eastern boundary of the study area. The Arrowsmith, Jurien and Gingin Groundwater Areas have been the focus of the study (Fig. 1).

2.2 Climate

The Northern Perth Basin has a Mediterranean-type climate with hot dry summers and cool wet winters. The average annual rainfall increases southward from 480 mm per year in Geraldton to 600 mm per year in Gingin, and decreases progressively inland. Most rainfall occurs between April and October with little or no rain during the summer months. Annual evaporation is about 2 m per year and exceeds rainfall for all months except June and July.

2.3 Physiography

The landscape in the Northern Perth Basin mostly slopes westwards and is drained by westerly-flowing watercourses. There are four dominant physiographic units in the study area: Swan Coastal Plain, Arrowsmith Region, Dandaragan Plateau and Yarra Yarra Region (Fig. 2). These units are described in more detail in Playford et al. (1976) and have different landform features that relate to variations in the underlying geology, topography and drainage patterns.

2.3.1 Swan Coastal Plain

The Swan Coastal Plain forms a significant part of the western margin of the Northern Perth Basin and is characterised by low-lying coastal sediments consisting predominantly of limestone, dune sands and alluvium. The Gingin Scarp marks the eastern boundary of the plain and represents a remnant of the marine processes that eroded the area west of the scarp (Kern, 2001). The base of the scarp is often poorly drained and almost permanently inundated due to the presence of the Guildford Formation. The most common water-related landforms include lagoons, lakes, seasonal swamps and karstic features within the limestone. Coastal heath and scrubland are dominant vegetation types.

2.3.2 Arrowsmith Region

The Arrowsmith Region comprises an undulating and dissected plateau that overlies the Jurassic and Cretaceous rocks. The Gingin and Dandaragan Scarps form the western and eastern boundary of the Arrowsmith Region, respectively. Most of the drainage lines are ephemeral. All of these watercourses terminate in swamps and lakes or sinkholes on the coastal plain, except for the Irwin, Hill and Moore Rivers, which reach the coast.

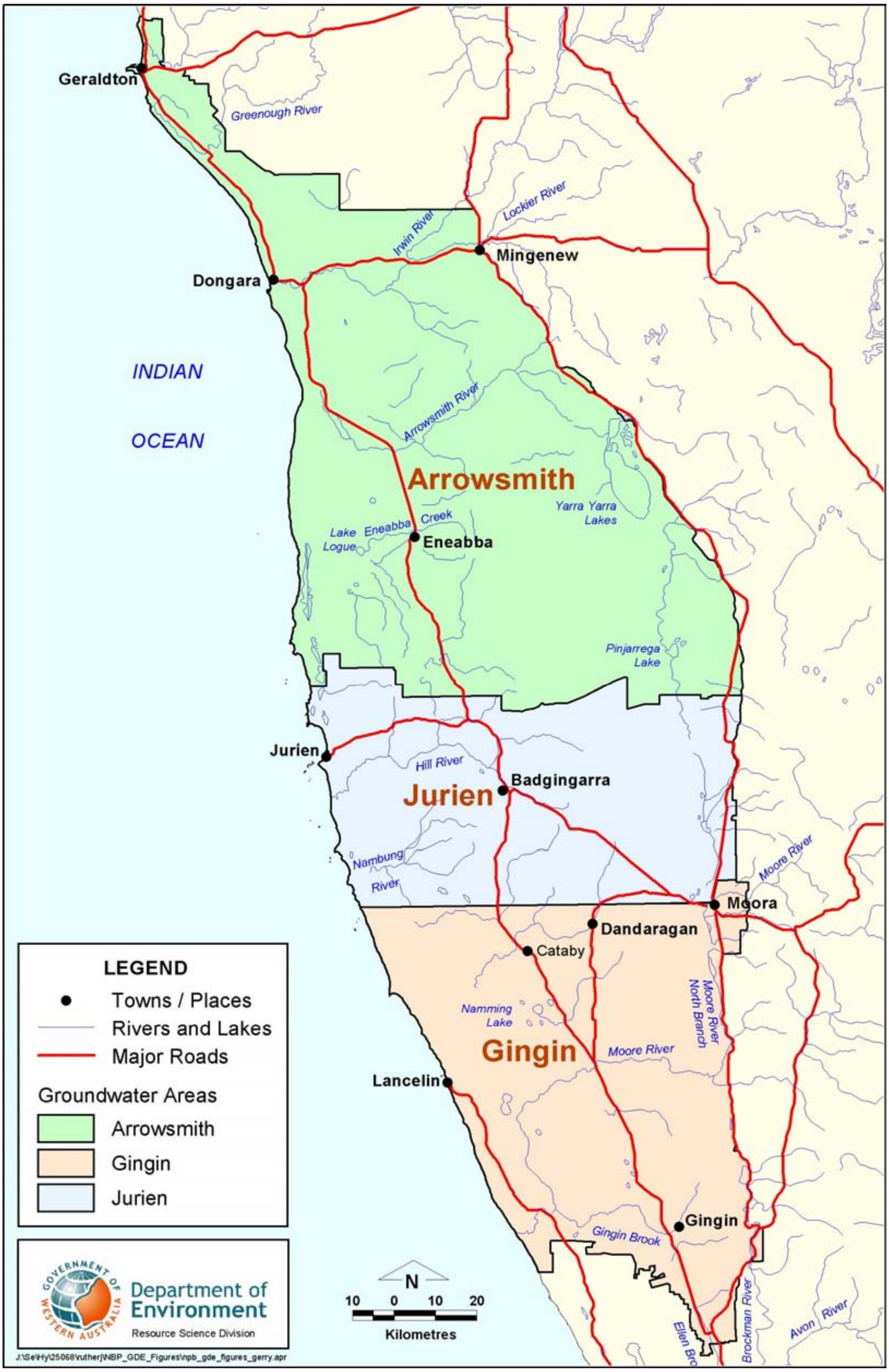

Figure 1: Study area; major groundwater management areas

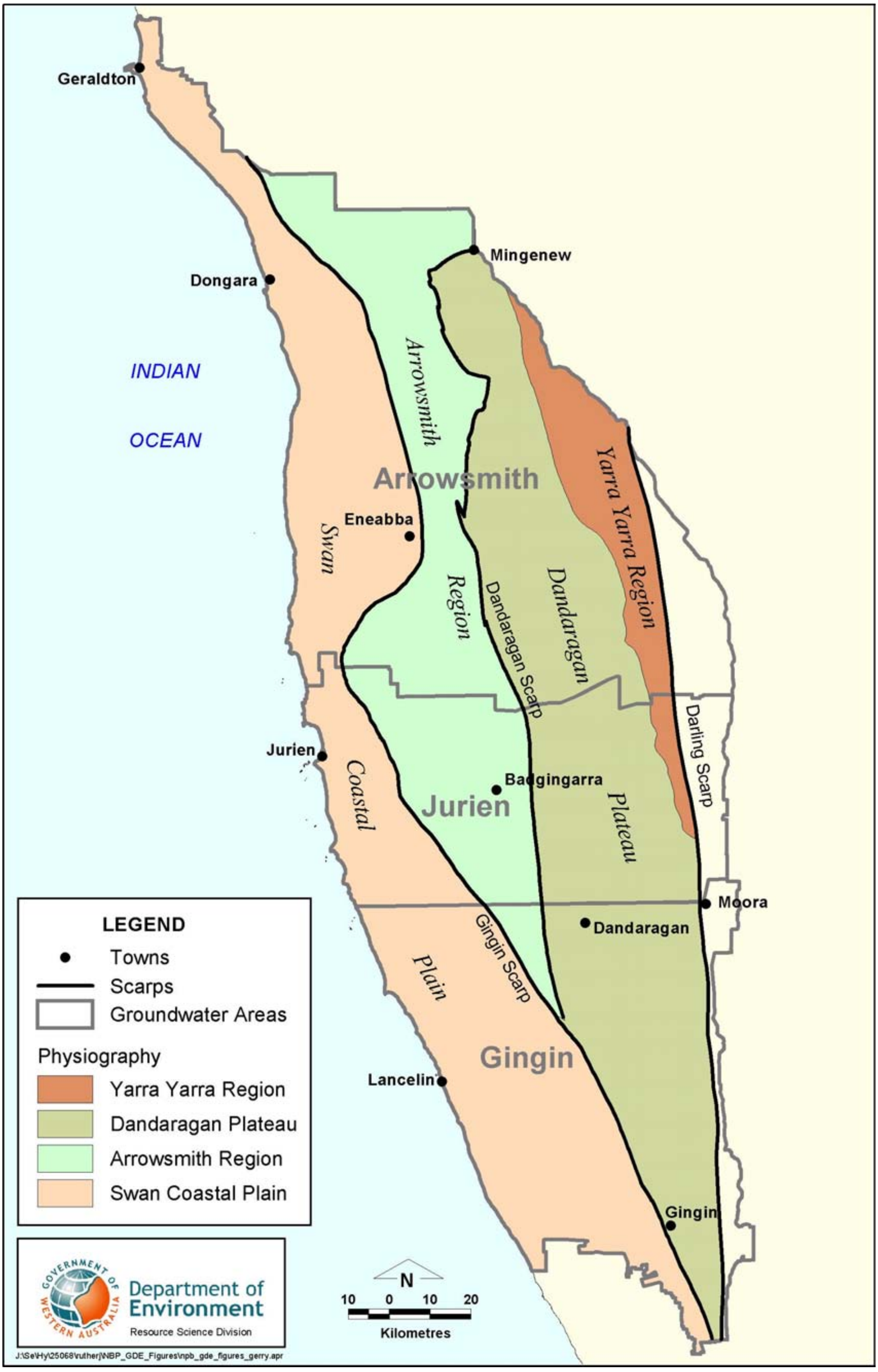

Figure 2: Physiography; major perennial and ephemeral watercourses

2.3.3 Dandaragan Plateau

The Dandaragan Plateau is very similar to the Arrowsmith Region but is less dissected by streams. Most watercourses are sporadic and ephemeral, except in the southern portion of the Dandaragan Plateau where there are a number of perennial groundwater-fed brooks (eg; Gingin and Lennard Brooks). The Dandaragan and Gingin Scarps form the western boundary and the Darling Scarp marks the eastern boundary of the plateau. The western edge of the Dandaragan Plateau is coincident with subcrop of the Otorowiri Member of the Parmelia Formation along the Dandaragan Scarp.

2.3.4 Yarra Yarra Region

The Yarra Yarra Region is an area of internal drainage between the Dandaragan Plateau and the Darling Scarp and is characterised by swamps and salt lakes. The Yarra Yarra Lakes are terminal salt lakes that receive runoff from the Darling Plateau to the east. In the south, the Coonderoo River flows southward along the line of the Darling Fault to join the Moore River at Moora.

2.4 Geology

The geology of the study area has been described in detail in earlier reports and published papers, with regional stratigraphic overviews presented by Playford et al. (1976), Backhouse (1984), and Mory and Iasky (1996).

2.5 Hydrogeology

There are a number of regional aquifers within the Northern Perth Basin (Fig. 3). The most significant of these aquifer systems are the superficial aquifer, Leederville–Parmelia Aquifer and Yarragadee Aquifer. The Lesueur, Eneabba, Cattamarra, Mirrabooka and Poison Hill represent minor aquifers, while the Kockatea Shale, Otorowiri Siltstone and Osborne Formation form aquicludes that influence aquifer interconnectivity. More detailed descriptions of individual aquifers are provided in Chapter 4.

Most knowledge on the hydrogeology in the Northern Perth Basin has been acquired through regional groundwater investigations by the Geological Survey of Western Australia. These bores now form the basis of the regional monitoring program and continue to provide valuable information on the behaviour of the aquifer systems. Further reading on the hydrogeology of specific areas is contained in publications, including Moncrieff and Tuckson (1989), Commander (1981; 1996), Davidson (1995), Nidagal (1995), Kay (1999), Kay and Diamond (2001), Kern, (1989 and 2001) and WRC (2002 a, b and c).

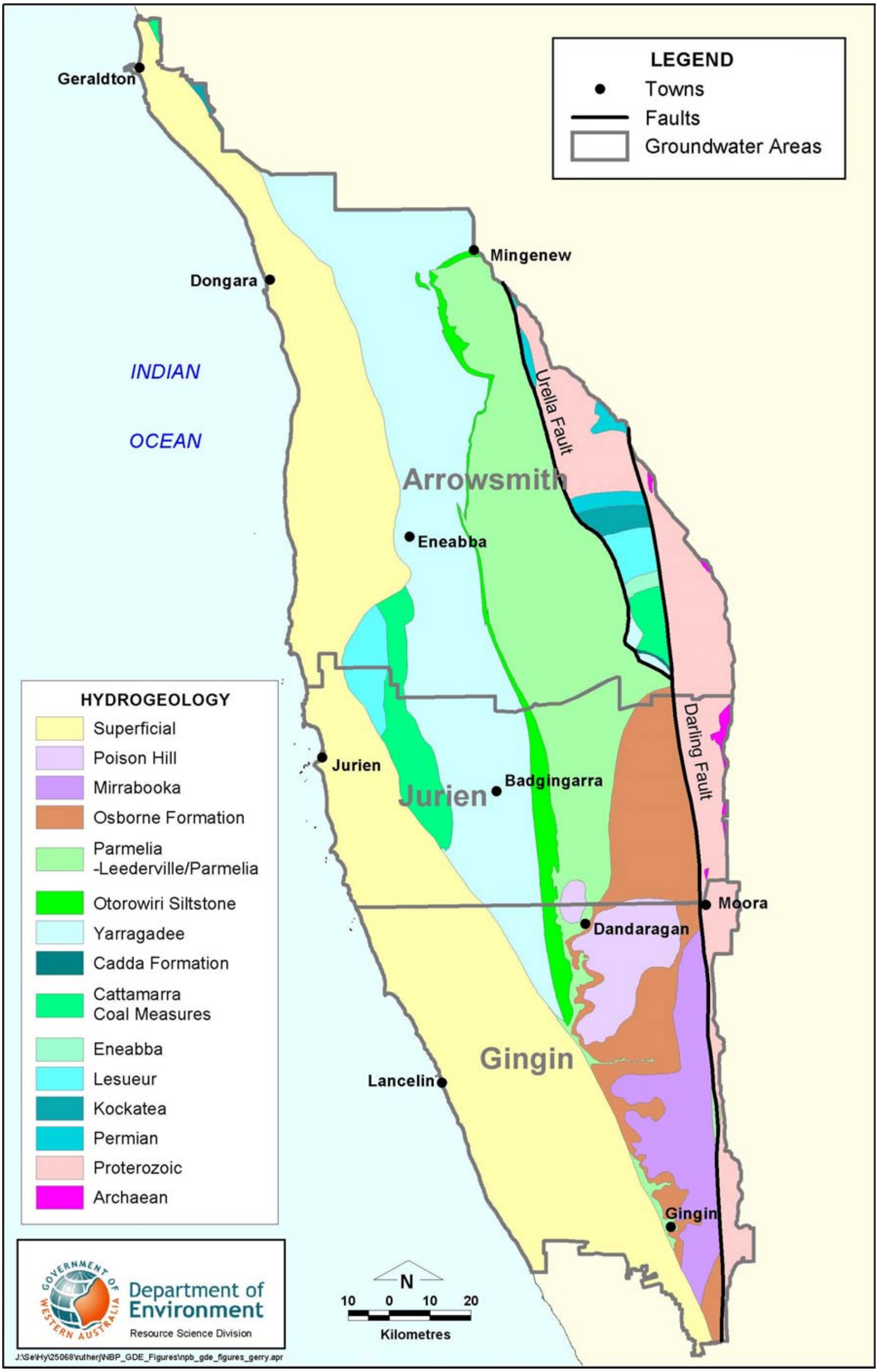

Figure 3: Hydrogeology of the Northern Perth Basin

2.6 Vegetation

Approximately 40% of the study area is covered by remnant native vegetation (Figure 4). There are large areas of native bushland that are well preserved along the Swan Coastal Plain within nature reserves and national parks, dominantly comprising low scrub heath (less than 2 m tall). The major national parks and reserves include the Moore River, Nambung, Alexander Morrison, Badgingarra, Mount Lesueur, Drovers Cave, and Watheroo National Parks.

2.7 Land use

Land use is highly diverse but largely dominated by agricultural activities such as grain cropping, grazing and other horticultural ventures. Most water for domestic and stock uses is sourced from groundwater, soaks and springs. Broad-acre irrigation occurs mainly in the southeast around Gingin for vegetables, fruit, grapes, olives and timber.

Large amounts of groundwater are used by the petroleum and mining industries for the processing of gas/condensate and industrial minerals. Several hydrocarbon fields occur throughout the Northern Perth Basin with the production of gas and condensate from the Dongara area and Woodada gasfield in the Eneabba area. There is also heavy-mineral sand mining around Eneabba and Cooljarloo (north of Cataby), and a proposed mine near Cataby.

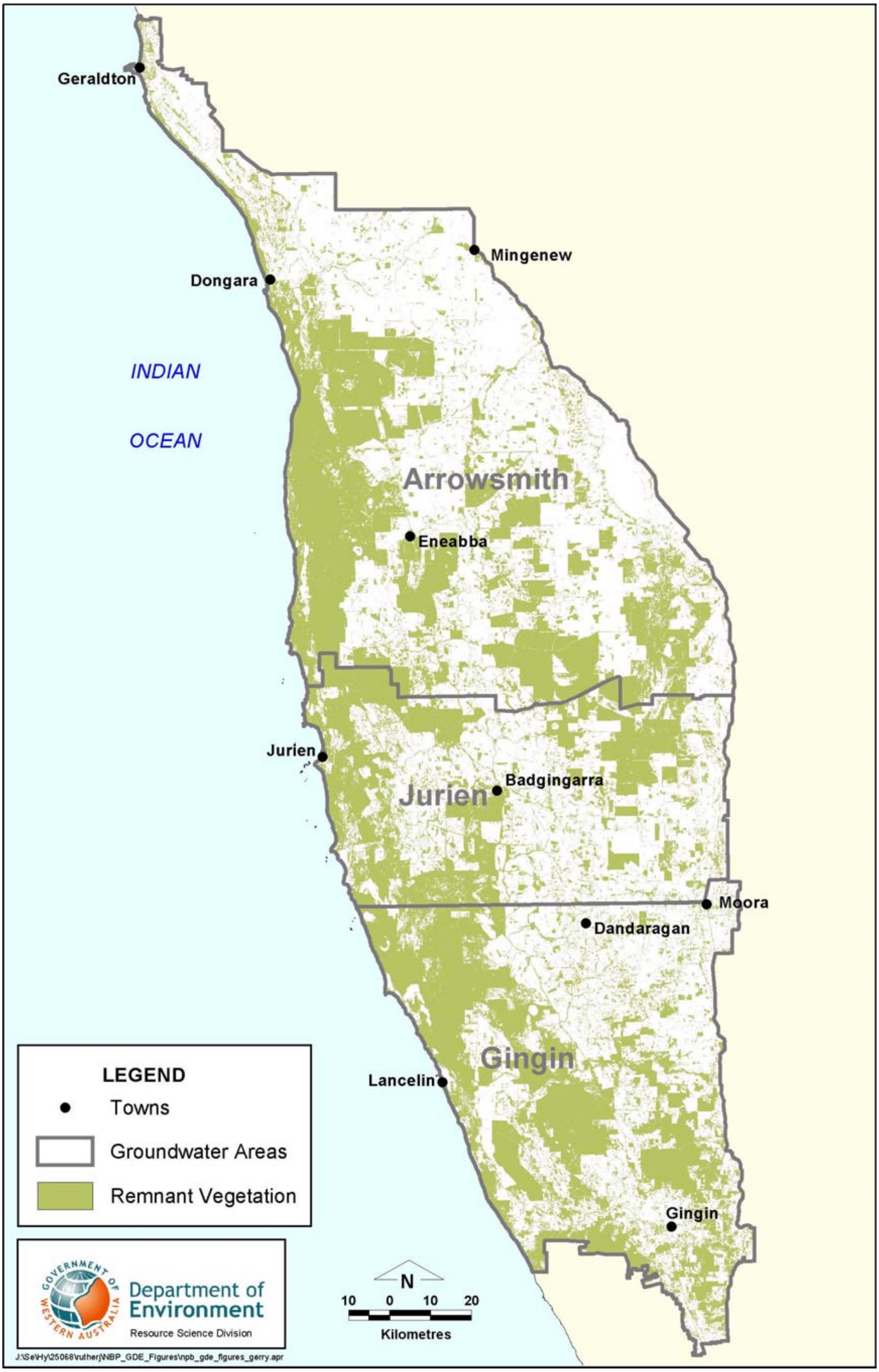

Figure 4: Remnant vegetation of the Northern Perth Basin

3 Methodology

3.1 A technical approach for identifying GDEs

The identification of groundwater dependent ecosystems (GDE) and their ecological water requirements (EWR) requires input and contribution from multi-discipline backgrounds. Figure 5 outlines a technical approach for identifying GDEs and the steps required to work towards determining EWR and EWP (environmental water provisions). This particular study has focused on the first three steps: (1) regional-scale understanding of the hydrogeology and relationship with different GDEs, (2) identification of perennial vegetation areas that may be groundwater dependent, and (3) more detailed studies of individual potential GDE sites at a localised scale.

In the early stages of evaluating GDEs, it is critical to develop the hydrogeological framework including an understanding of watertable configuration and depth to groundwater. This provides the context for understanding the interaction and relationship between groundwater resources and potential GDEs. In the early stages, there is little emphasis on vegetation or ecosystem types, with a focus on gaining a broad understanding of GDE distribution relative to water level, and determining the likely supporting hydrogeological regimes. The scale of the studies becomes more localised and focused with the continuation of additional investigations.

Step 4 requires the input of botanical expertise to identify and classify the different ecosystems, establish their groundwater dependency and their conservation or ecological value. This stage is vital as it draws on the best available hydrogeological understanding to determine how the ecosystems survive or have become dependent on the groundwater resources, and estimate how much water is used. During this stage, EWRs for the ecosystems are developed which provide the basis for determining the EWP.

The final two stages are focused on implementing and developing the EWP, and ensuring that GDEs of high conservation or ecological importance are adequately protected. Further hydrogeological studies or modelling may be required to determine ‘buffer zones’ and appropriate levels of monitoring.

3.2 The identification of potential GDEs

In order to identify potential GDEs, there needs to be an understanding of the hydrogeology, in particular depth to groundwater and the location of groundwater discharge areas. The complexity of hydrogeology in the Northern Perth Basin has required considerable interpretation to understand the depth to groundwater within the different regional aquifers.

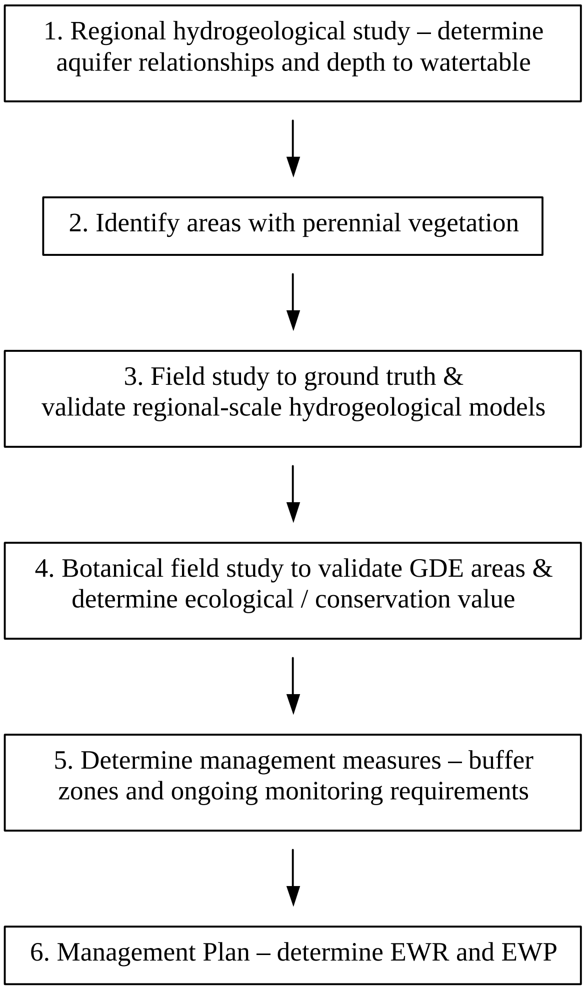

Figure 5: A technical approach for identifying GDEs

3.2.1 Depth to groundwater mapping

The groundwater elevation (or contour) map, shown in Figure 6, is a regional representation of watertable configuration within all aquifers. The groundwater contours (in AHD) were complied using data from the DoE monitoring bore network, as well as considering interpretations by PPK (2001) and Davidson et al. (2004). The water level contours were converted to a 3-D surface by interpolation between contours.

Within a GIS environment, the water level surface was subtracted from the DEM (digital elevation model) for the topography to produce a depth to groundwater map. This methodology had been used previously by PPK (2001) and WEC (2003), and proved successful in the determination of depth to groundwater. The focus was to identify areas where the depth to groundwater is less than 20 m bgl (below ground level), which therefore have potential to support and sustain GDEs. It is possible to further subdivide into zones of 0 to 5 m bgl (GDEs with high groundwater dependency), 5 to 10 m bgl (GDEs with moderate dependency) and 10 to 20 m bgl (GDEs with low dependency). In summary, there is reducing likelihood of groundwater dependency with increasing groundwater depth.

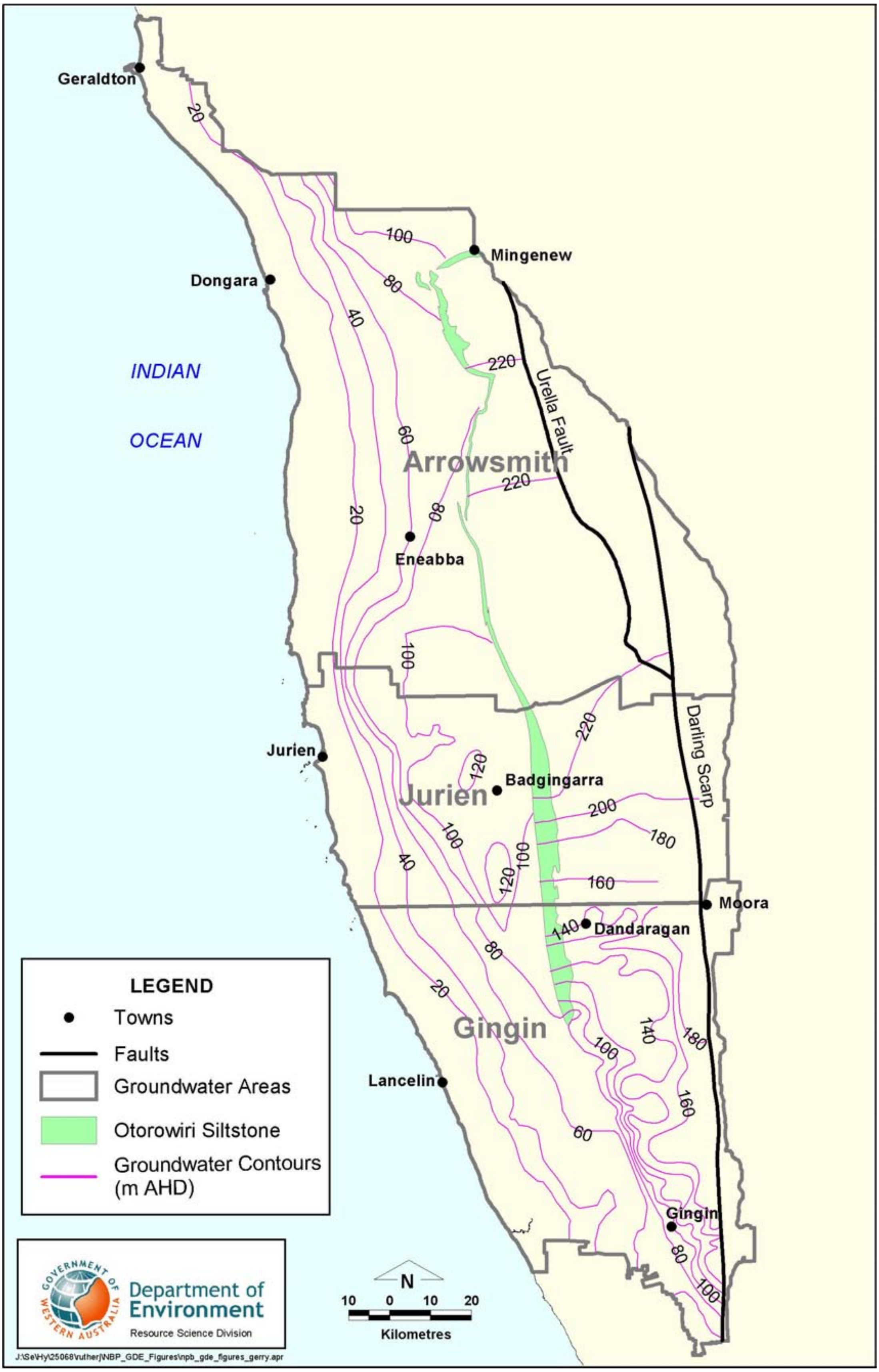

Figure 6: Watertable configuration in the Northern Perth Basin

The depth to groundwater data set is most reliable along the coastal plain due to aquifer uniformity and even data distribution. On the southern Dandaragan Plateau, there were difficulties in generating a groundwater contour map due to hydrogeological complexity and the presence of perched water above the Osborne Formation. It was decided to use a combination of water level data obtained by Kay (1999), Kay and Diamond (2001) and Davidson et al. (2004) to understand watertable configuration in the Mirrabooka and Poison Hill Aquifers. Although this data is appropriate for a regional-scale project, further investigations are required between Moora and Gingin to determine depth to groundwater in the Mirrabooka and Poison Hill aquifers. The depth to groundwater map is therefore a composite, including data from regional, local and perched aquifer systems.

3.2.2 Mapping extent of remnant vegetation

The remnant vegetation map produced by The Land Monitor Project (www.landmonitor.wa.gov.au) was used to determine potential GDE areas (Fig. 4). This map is the most comprehensive and current regional data available. The image distinguishes between perennial and non-perennial vegetation using variation in reflectance from Landsat TM data. The success of this method requires a contrast in signal between perennial vegetation and other cover types present in a survey area, such as annual crops, bare soil and rock outcrop.

The main limitations of the map are that a certain density of perennial vegetation is required to effectively classify an area as ‘perennial vegetation’. Omissions may occur at track and fire scar sites or recently revegetated areas where vegetation is scattered resulting in a high proportion of soil background. Conversely, the admission of cleared areas with persistent dark soil, in particular lake margins, may also occur (although in the case of lake margins, dark soils and vegetation may be coincident).

3.2.3 Areas of potential GDE

The potential GDE data set, shown on Map 1, is a major outcome of the study and will be invaluable in the identification and management of GDEs in the Northern Perth Basin. The data set has applications in the water allocation and licensing process, where proposals for abstracting groundwater can be positioned relative to areas of potential GDEs. In this situation, it may require the proponents to undertake further studies to demonstrate groundwater dependency or that abstraction will have no impact. Another use is assisting the Department to move toward determining accurate EWPs for each aquifer system, rather than using the conservative, preliminary EWRs set at 30% of rainfall recharge in superfical aquifers and 10% in confined aquifers (WRC, 2002a, b and c).

The potential GDE areas were delineated in the GIS by combining the vegetation and depth to groundwater classes. The resultant data set portrays the spatial distribution of both non-perennial and perennial vegetation classified according to the four classes of depth to groundwater (0 to 5 m; 5 to 10 m; 10 to 20 m; and non-GDE). Figure 7 illustrates how the depth to groundwater and vegetation data sets were merged to produce the potential GDE data set.

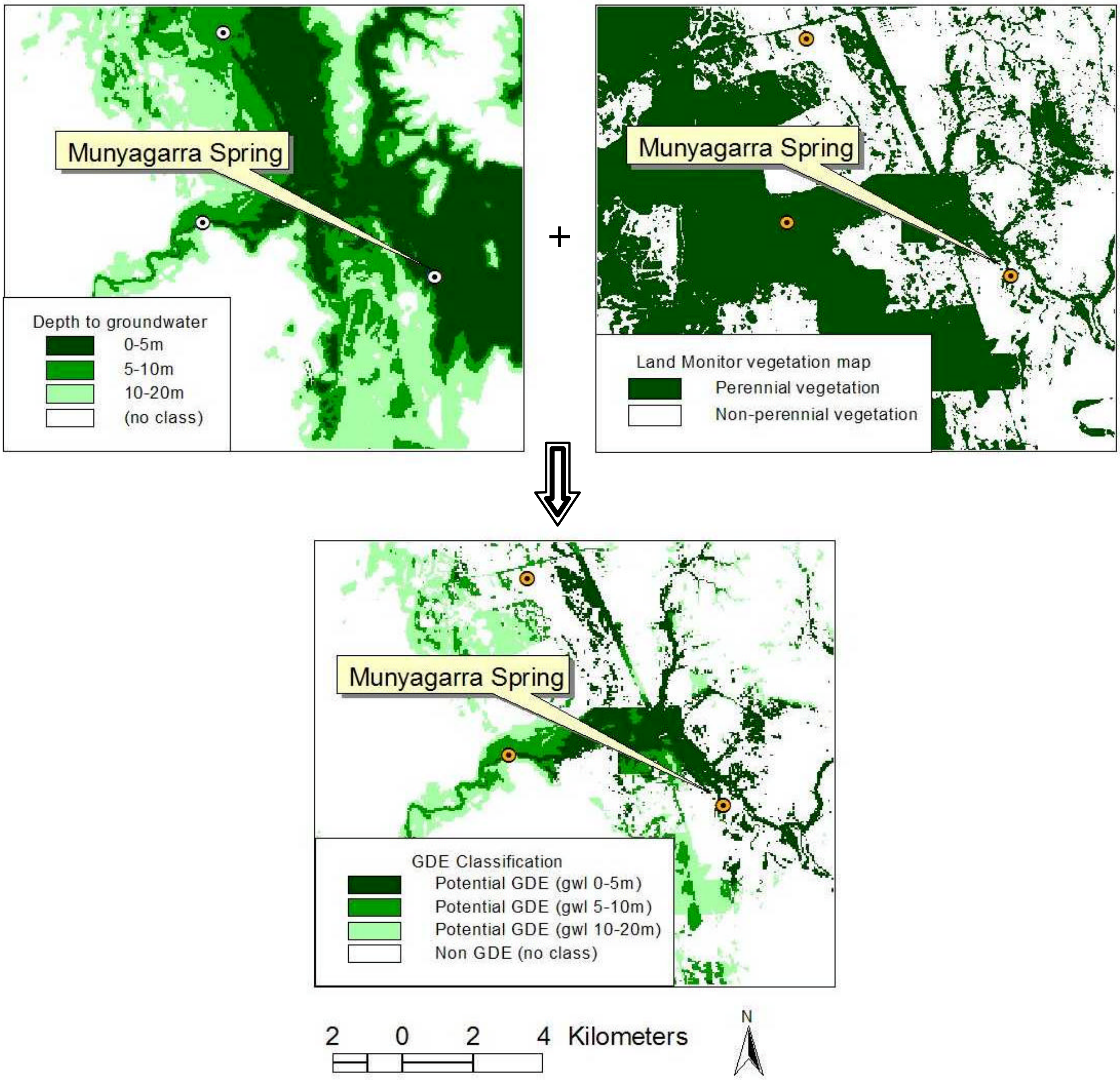

Figure 7: Methodology to determine potential GDE at Cantabilling Spring near Hill River (Note: 7a is the depth to groundwater data set; 7b is the vegetation data set; and 7c is the resultant data set formed through combining the depth to groundwater and vegetation maps.

3.3 Potential GDE sites

In order to validate the regional data set on the potential GDE area, it was decided to undertake a more detailed and localised review. Nearly 100 potential GDE sites were reviewed across the Northern Perth Basin with a data sheet generated for each site (Appendix 1). The data sheets were developed using groundwater information from WIN database and field observations. At each site, a conceptual hydrogeological schematic was created to illustrate the groundwater processes and interaction between the GDE and groundwater resources.

The data sheets are considered a useful field tool that provides a summary of existing groundwater knowledge and shows how groundwater may interact with the potential GDE. Each data sheet contains the following information: GDE site name and classification; map reference and site coordinates; a locality map (including bore locations and cadastre), physiography, hydrogeology, depth to watertable, groundwater quality, GDE considerations and a schematic diagram highlighting dominant groundwater processes.

4 Relationship of potential GDEs to the major aquifers

4.1 Aquifer descriptions and relationship to GDEs

The hydrogeology provides a framework to identify groundwater regimes that sustain GDEs and may often control their spatial distribution. An understanding of the hydrogeology is therefore important in determining the groundwater dependency of any ecosystem. This section of the report discusses each of the regional aquifers in the Northern Perth Basin, in respect to the likely groundwater environments or regimes that GDEs may require for their survival, and the key findings of a statistical analysis on the potential GDE data set. It is recommended that readers refer to Map 1 and Appendix 1 when reading this section for clarification and for gaining a spatial understanding of potential GDE distribution.

4.1.1 Superficial Aquifer

Quaternary and Tertiary superficial formations on the Swan Coastal Plain host the major unconfined aquifer system in the Northern Perth Basin. The superficial aquifer extends from the coast up to 40 km inland, and consists of predominantly alluvial, shallow marine and aeolian sequences that have been deposited in bands that parallel the coastline (Moncrieff and Tuckson, 1989). The sediments which constitute the superficial aquifer range from predominantly clayey (Guildford Clay) in the east adjacent to the Gingin Scarp through a sandy succession (Bassendean Sand) in the central coastal plain area, to sand and limestone (Tamala Limestone) within the coastal belt. The aquifer has an average thickness of about 30 m in the study area.

4.1.1.1 Tamala Limestone

The Tamala Limestone (Playford et al., 1976) is dominated by sand dunes and limestone ridges along the coastal belt. The depth to watertable is variable being at or near surface in topographic depressions and coastal lakes through to greater than 50 m beneath large sand dunes and limestone ridges. The most dominant water-related features in the Tamala Limestone that may support potential GDEs are the coastal lake systems and the extensive network of caves.

Most discharge from the Tamala Limestone takes place to coastal lake systems, often as marginal springs, and to the ocean. The coastal lakes are large salt pans, such as Leeman Lagoon (GDE site #42), positioned in interdunal swales that have fringing salt-tolerant vegetation. The water level is at or near the lake surface and may be subjected to tidal influences. A number of marginal springs, such as Eatha Spring (GDE site #47) and Lower Three Springs (GDE site #43), are located on the eastern fringe of these coastal lakes and discharge fresh to brackish groundwater with potential for supporting GDEs.

The presence of karst structures in the form of sub-surface cave systems that receive water from surface runoff entering conduits within the limestone may provide an ideal habitat for GDEs, such as stygofauna. Little is known about water levels in the cave systems; however, many caves are believed to be dry or intermittently wet. The study by PPK (2001) is the most comprehensive account of cave systems.

4.1.1.2 Bassendean Sand and Guildford Formation

In central and eastern parts of the coastal plain, Bassendean Sand and the underlying Guildford Formation contain numerous springs, swamps, and interdunal lakes that represent areas of groundwater discharge. The Bassendean Sand (Playford et al., 1976) dominates the central portion of the coastal plain and as the name suggests is sandy with minor clay. The Guildford Formation is often present at the base of the Gingin Scarp and is largely clayey. The water levels are generally less than 10 metres, although shallow water levels occur mainly at the base of the Gingin Scarp due the low permeability of the Guildford Formation.

The Bassendean Sand and Guildford Formation are likely to support several types of GDEs associated with riverine baseflow, shallow watertable and wetlands. Groundwater is known to discharge from the Bassendean Sand into the Lower Gingin Brook, Moore River (downstream of Regans Ford) and Nambung River. The shallow watertable supports a large part of the remnant vegetation in the western portion of the Gingin GWA, as well as supplementing a number of swamps and wetlands. Wetlands occur in topographic and interdunal depressions on the coastal plain and along the base of the Gingin Scarp.

Throughout the coastal plain, a number of springs have been previously named; however, these systems are essentially small wetlands with a watertable at the surface, such as Nhargo Spring (GDE site #5); and Mungenooka Spring (GDE site #19). There are also a number of perched wetlands that are not connected with the regional aquifer, which highlight the need for a detailed understanding of the hydrogeology. The best example is Lake Logue (GDE site #36), where the regional watertable is more than 10 m below the lake surface.

4.1.2 Mirrabooka and Poison Hill Aquifers

The distribution and hydrogeology of the Mirrabooka and Poison Hill aquifers is complex and poorly understood. These aquifers occur predominantly on the Dandaragan Plateau and comprise four Late Cretaceous geological units, including Poison Hill Greensand, Gingin Chalk, Molecap Greensand and Mirrabooka Member of the Osborne Formation.

Watertables within these aquifers appear to be discontinuous making it difficult to determine a regional watertable configuration. The depth to watertable is generally less than 10 m in the eastern areas and increases westward (Kay and Diamond, 2001). The aquifers are highly prone to waterlogging problems due to poorly developed external drainage and the near-surface presence of impermeable Kardinya Shale Member of the Osborne Formation.

The Poison Hill and Mirrabooka aquifers are likely to support several types of GDEs associated with riverine baseflow and shallow watertable. Groundwater is known to discharge from these aquifers into Gingin and Lennard Brooks, Red Gully Creek and parts of the Moore River. The shallow watertable may support GDEs related to the Wannamal Lake system. Many potential GDEs in the Poison Hill and Mirrabooka aquifers may be dependent on perched water, such as Bunyanocca Spring (GDE site #80) and Dandaragan Spring (GDE site #81).

4.1.3 Leederville–Parmelia Aquifer

The Leederville–Parmelia Aquifer is a significant multi-layered aquifer system in the Northern Perth Basin, where the Parmelia Formation is unconfined and outcrops on the northern portion of the Dandaragan Plateau. In the southern section of the study area, the Leederville Formation overlies the Parmelia forming a gradational contact near Dandaragan. The Kardinya Shale Member of the Osborne Formation locally confines the Leederville–Parmelia Aquifer. The depth to watertable is often great, more than 20 m, which limits the distribution of GDEs to areas of groundwater discharge.

The Leederville–Parmelia Aquifer is likely to support several types of GDEs associated with riverine base flow and springs. Riverine baseflow related to groundwater discharge from the aquifer occurs in the Arrowsmith River at Otorowiri Spring (GDE site #20) and Danthatarra Spring (GDE site #21), Moore River near Mogumber, as well as Gingin and Lennard Brooks (as described in Johnson, 2000).

There is a line of springs along the Dandaragan Scarp that potentially support GDEs, which are associated with the contact between the Otorowiri Siltstone and western boundary of the Leederville-Parmelia Aquifer. In the most part, the springs are formed where the outcrop of the Otorowiri Siltstone (a major aquiclude) is just below the height of the watertable in the Leederville-Parmelia aquifer, and as such represent aquifer overflow (Commander, 1981). Examples of potential GDEs related to spring discharge are Woonaroo Spring (GDE site #22); Nebroo Spring (GDE site #28) and Eneabba Spring (GDE site #34).

Another groundwater feature with potential GDEs are the lakes within the Yallalie Depression (inferred to be a meteorite crater). The lakes are positioned close to the potentiometric surface in the Parmelia Aquifer, but there is a possibility that the lakes may be perched on Pliocene lacustrine sediments.

4.1.4 Yarragadee Aquifer

The Yarragadee Aquifer is a major multi-layered aquifer system in the Perth Basin. It is largely comprises sandstone and minor shale horizons. The aquifer is confined for the most part beneath the Otorowiri Siltstone, and is unconfined where the Yarragadee Formation outcrops between the Gingin and Dandaragan Scarps. The depth to watertable, where unconfined, is generally greater than 20 m except in discharge areas along the Irwin and Hill Rivers.

The Yarragadee Aquifer may support several types of GDEs where associated with riverine baseflow. There is local discharge into the Hill River, where the river has incised below the regional potentiometric surface in the aquifer, such as at Bitter and Coomallo Pools (GDE site #53-54) and Hill River Spring (GDE site #55). The fact that the river flow at these sites is not perennial suggests that most discharge is used by vegetation (Commander, 1981). There is also potential for GDEs to be dependent on baseflow in the downstream portion of the Irwin River near Mendara Spring (GDE site #9). In places, there is minor perching of water that may potentially support localised GDE sites, where related to near-surface ferricrete and silcrete, such as at Warradarge Spring (GDE site #46).

4.1.5 Cattamarra Aquifer

The Cattamarra Formation (Mory and Iasky, 1996) comprises an interbedded siltstone, shale and sandstone aquifer. The aquifer is associated with the sandstone beds comprising only 25% of the formation. The formation outcrops in a narrow faulted block that is bound by the Warradarge Fault and Lesueur-Peron Faults. The groundwater in the aquifer is brackish to saline, which may impact on GDE distribution, and is a factor in land salinisation.

The Cattamarra aquifer may support GDEs where associated with riverine baseflow and isolated springs. There are a number of groundwater discharge areas in the Hill River area associated with the aquifer, such as Cantabilling Spring (GDE site #59) and Yeramulla Spring (GDE site #57). The aquifer also discharges to the overlying superficial aquifer and to gaining streams on the Eneabba Plain, such as Erindoon and Bindoon Creeks (GDE site #38). As these creeks contribute to the water balance in Lake Indoon (GDE site #37), it can be suggested that discharge from the Cattamarra aquifer may support potential GDEs related to this lake system.

4.1.6 Eneabba and Lesueur Aquifers

The Eneabba Formation forms an interbedded confined aquifer that is undifferentiated from the Lesueur Sandstone. For the purpose of this study, groundwater within the Eneabba Formation and Lesueur Sandstone have been grouped into a single aquifer. The aquifer is bounded to the east by the Lesueur Fault and Beagle Fault in the west. The thick shale and siltstone beds of the Eneabba Formation may confine groundwater in the Lesueur Sandstone; however, where the Eneabba Formation comprises sandstone it is indistinguishable from the Lesueur Sandstone.

The Eneabba-Lesueur aquifer may support GDEs where associated with spring flows and riverine baseflow. A number of springs occur along the Beagle Fault representing upward discharge from the aquifer, such as at Woolmulla Pool in Cockleshell Gully (GDE site #50) and Diamond of the Desert Spring (GDE site #48). At Three Springs (GDE site #44), groundwater discharging from the Eneabba-Lesueur aquifers emerges from the Tamala Limestone before soaking back into the limestone (Commander, 1981). In places, it is also possible that GDEs in the Hill River are dependent on seasonal baseflow derived from the Eneabba-Lesueur aquifers (Commander, 1981).

4.2 Key findings on potential GDE distribution

Perennial vegetation, inferred to be largely remnant vegetation, covers about 42% of the study area implying that the remaining 60% of the landscape is modified by diverse land uses. Potential GDE areas (where depth to groundwater is less than 20 m) cover about 17% of the landscape, while vegetated, non-GDE areas (where depth to groundwater is greater than 20 m) cover about 25%.

Potential GDEs in the Northern Perth Basin are most common in the superficial aquifer (Table 1). This finding is not surprising as the superficial aquifer is regionally extensive, has large areas of shallow watertable and is overlain by numerous national parks. Potential GDEs associated with the Mirrabooka and Poison Hill aquifers appear to cover about 6% of the study area; however, this figure may be an over-estimation as there are problems with separating GDEs dependent on the aquifer and those reliant on perched systems.

An important finding is that potential GDEs in the Leederville-Parmelia and Yarragadee Aquifers have a limited distribution. At present, the amount of water allocated for the environment from these aquifers is set at 10% of sustainable yield (WRC, 2002a, b and c). These limits can be considered conservative based results of this study, but further EWR studies are required prior to recommending changes to the allocation limits.

Table 1. Proportion of potential GDEs in each regional aquifer

Regional aquifers	Potential GDE	
	GDE area (km^2)	% GDE of total GDE area*
Superficial Aquifer	2707	82
Mirrabooka and Poison Hill Aquifers	210	6
Leederville-Parmelia Aquifer	112	4
Yarragadee Aquifer	115	4
Cattamarra Aquifer	109	3
Lesueur and Eneabba Aquifers	42	1
Total Potential GDE Area	**3294***	**100**

In respect to the superficial aquifer, potential GDEs occur across nearly 40% of the aquifer with the remaining parts of the aquifer (60%) either cleared or with a watertable greater than 20 m bgl (Table 2). As mentioned previously, it is likely that areas of potential GDE are over-estimated for the Mirrabooka-Poison Hill aquifer due to the issue of perched systems. Also, the distribution of potential GDE in the Leederville-Parmelia and Yarragadee Aquifers is considered small and localised.

Table 2. Percentage breakdown of cleared land, potential GDE and non-GDE areas in the major aquifers

Regional aquifers	Cleared (non-perennial vegetation)	Potential GDE	Non GDE
Superfical Aquifer	38	38	24
Mirrabooka and Poison Hill Aquifers	65	14	21
Leederville-Parmelia Aquifer	66	3	31
Yarragadee Aquifer	70	2	28

5 Conclusions

This study has defined the distribution of potential GDEs (where depth to watertable is less than 20 m bgl) within the regional aquifer systems of the Northern Perth Basin. The study provides the hydrogeological framework that will assist in the development and formulation of both ecological water requirements (EWRs) and environmental water provisions (EWPs).

The methodology involved the development of a regional-scale GIS database that merged depth to groundwater and remnant vegetation data layers to determine potential GDE areas. The main output is a digital layer showing the distribution and extent of potential GDEs (Map 1) that will be invaluable in the identification and management of GDEs in the Northern Perth Basin. In addition, conceptual hydrogeological models for approximately 100 prospective GDE sites were developed (Appendix 1) and it is recommended that these be referenced during future EWR investigations.

There is a large amount of variability in the hydrogeological setting of potential GDEs. The superficial aquifer supports potential GDEs related to coastal lakes, marginal springs and caves in the Tamala Limestone, as well as shallow watertables and wetlands in the Bassendean Sand and Guildford Formation. The Mirrabooka and Poison Hill aquifers are likely to support potential GDEs associated with shallow watertable; however, there is some confusion between high water levels in the aquifer and those of perched systems on the Kardinya Shale. In the Leederville-Parmelia, Yarragadee, Cattamarra, Eneabba and Lesueur aquifers, there is a variety of potential GDEs associated with riverine baseflow in discharge areas, and around springs related to the presence of aquicludes (such as Otorowiri Siltstone) and faults.

The superficial aquifer contains more than 80% of all potential GDEs in the Northern Perth Basin. In comparison, there are very small areas of potential GDEs in the major confined aquifers (Leederville-Parmelia and Yarragadee Aquifer). This spatial understanding of potential GDE distribution is important for prioritising EWR investigations and for future determination of EWPs.

6 References

BACKHOUSE, J., 1984, *Revised Late Jurassic and Early Cretaceous Stratigraphy in the Perth Basin*, Geological Survey of Western Australia, Report 12, Professional Papers for 1982, pp. 1-6.

COMMANDER, D. P., 1981, *The Hydrogeology of the Eneabba Area, Western Australia*, MSc Thesis, University of Western Australia, 254 pp.

COMMANDER, D. P., 1996, *Groundwater Prospects for Irrigation in the Irwin River Valley*, Water and Rivers Commission, Hydrogeology Report 10.

DAVIDSON, W. A., YU, X. and MILLIGAN, N. H., 2004, *Perth Region Aquifer Modelling System (PRAMS)*, Water and Rivers Commission Hydrogeology Report 202 (in prep).

DAVIDSON, W. A., 1995, *Hydrogeology and Groundwater Resources of the Perth Region Western Australia*, Geological Survey of Western Australia, Department of Minerals and Energy, 257 pp.

HATTON, T. and EVANS, R., 1998, *Dependence of Ecosystems on Groundwater and its Significance to Australia*, Occasional Paper No. 12/98, Land and Water Resources Research and Development Corporation, 77 pp.

JOHNSON, S., 2000, *Hydrogeological Assessment of the Perennial Brooks on the Dandaragan Plateau*, Water and Rivers Commission, Hydrogeology Report 180, 22 pp.

KAY, T., 1999, *A Hydrogeological Assessment of the West Koojan – Gillingarra Land Conservation District, Western Australia*, MSc Thesis in Environmental Geology, University of Wales, Cardiff, 147 pp.

KAY, T. and DIAMOND, R., 2001, *A Hydrogeological Assessment of the Victoria Plains, Red Gully, Gingin Townsite and Eclipse Hill Subareas of the Gingin Groundwater Area*, Water and Rivers Commission, Hydrogeology Report HR 156.

KERN, A. M., 1989, *The Geology and Hydrogeology of the Superficial Formations between Cervantes and Lancelin, Western Australia*, Geological Survey of Western Australia, Hydrogeology Report 1988/22, p.11-36.

KERN, A. M., 2001, *Hydrogeology of the Coastal Plain between Cervantes and Leeman, Perth Basin*, Water and Rivers Commission, Hydrogeology Report HG 3, 31 pp.

MONCRIEFF, J. S. and TUCKSON, M., 1989, *The Hydrogeology of the Superficial Formations between Lancelin and Guilderton, Perth Basin*, Geological Survey of Western Australia, Report 25, Professional Papers, pp.39-57.

MORY, A. J. and IASKY, R. P., 1996, *Stratigraphy and Structure of the onshore Northern Perth Basin*, Geological Survey of Western Australia, Report 46.

NIDAGAL, V., 1995, *Hydrogeology of the Coastal Plain between Leeman and Dongara, Perth Basin*, Geological Survey of Western Australia, Record 1994/10, 37pp.

PLAYFORD, P. E., COCKBAIN, A. E. and LOW, G. H., 1976, *The Geology of the Perth Basin, Western Australia*, Geological Survey of Western Australia, Bulletin 124.

PPK ENVIRONMENT & INFRASTRUCTURE PTY LTD, 2001, *Identification of Groundwater Dependent Ecosystems and the Level of Dependency in the Jurien and Arrowsmith Groundwater Areas,* Report written for Water and Rivers Commission.

STELFOX, L., 2001, *Assessment of Potential Groundwater Contamination from the Moore River,* Water and Rivers Commission, Hydrogeology Report No.189.

STOREY, A. W. and DAVIES, P. M., 2002, *Preliminary Ecological Water Requirements for Gingin and Lennard Brooks*, Report written for Water and Rivers Commission, 65 pp.

V & C SEMENIUK RESEARCH GROUP, 2001, *Identification of Groundwater Ecosystem Components in the Gingin Groundwater Area – Stage 1*.

WATER AND RIVERS COMMISSION, 2002a, *Managing the Water Resources of the Gingin Groundwater Area, WA*, Resource Allocation Branch of Resource Management Division and Swan Goldfields Agricultural Region, 29 pp.

WATER AND RIVERS COMMISSION, 2002b, *Managing the Water Resources of the Arrowsmith Groundwater Area, WA*, Resource Allocation Branch of Resource Management Division and Midwest Gascoyne Region, 26 pp.

WATER AND RIVERS COMMISSION, 2002c, *Managing the Water Resources of the Jurien Groundwater Area, WA*, Resource Allocation Branch of Resource Management Division and Midwest Gascoyne Region, 24 pp.

WELKER ENVIRONMENTAL CONSULTANCY (WEC), 2003, *Jurien Region, Ecological Water Requirements Study*, Report written for Water Corporation, 65 pp.