Atlas of Groundwater Dependent Ecosystems (GDE Atlas), Phase 2

Task 5 Report: Identifying and mapping GDEs

Australian Government

National Water Commission

CSIRO

SINCLAIR KNIGHT MERZ

SKM

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TASK 5 REPORT: IDENTIFYING AND MAPPING GDES

- Final Report
- 17 July 2012

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Contents

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
1	15 May 2012	Stuart Richardson (Ch1 – 5, CH7)	-	-	Internal Draft #2
2	31 May 2012	Jon Fawcett (Ch8 – 13)	Jon Fawcett	31 May 2012	Internal Draft #3
3	6 June 2012	Stuart Richardson (Exec Summ, Ch1 – 5, Ch7)	Stuart Richardson	7 June 2012	External Draft for review
4	6 June 2012	Kate Dowsley (Ch6, Ch13)	Kate Dowsley	7 June 2012	External Draft for review
5	6 June 2012	Jon Fawcett (Exec Summ, Ch14, 15)	Jon Fawcett	7 June 2012	External Draft for review
6	4 July 2012	Shane Hogan, Ian Household, Angus Duguid, Moya Tomlinson, Mark Mitchell	Kate Dowsley	10 July 2012	Final Report for approval
7	11 July 2012	Stuart Richardson (check on revisions)	Greg Hoxley	13 July 2013	Final Report for issue

Distribution of copies

Revision	Copy no	Quantity	Issued to
pdf	External draft for review		Steering Committee, NWC, BOM
pdf	Final report for issue		Steering Committee, NSW, BOM

Printed:	17 July 2012
Last saved:	17 July 2012 12:10 PM
File name:	D:\Documents and Settings\kdowsley\My Documents\VW05230_task5_final_17072012.docx
Author:	Kate Dowsley, Jon Fawcett, Lauren Helm, Dougal Currie
Project manager:	Jude Teakle
Name of organisation:	National Water Commission
Name of project:	Atlas of Groundwater Dependent Ecosystems
Name of document:	Task 5 Report, Identifying and mapping GDEs
Document version:	Final Report
Project number:	VW05230.05

Acronyms

BOM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DERM	Department of Environment and Resource Management (Qld)
DIWA	Directory of Important Wetlands Australia
DTWT	Depth to Watertable
EHZ	Eco-Hydrogeological Zone
ET	Evapotranspiration
FLAG	Fuzzy Landscape Analysis GIS
GA	Geoscience Australia
GAB	Great Artesian Basin
GDE	Groundwater Dependent Ecosystem
GIS	Geographic Information Systems
ID	Inflow Dependent
IDE	Inflow Dependent Ecosystems
LandsatTM5	Landsat Thematic Mapper 5
LEB	Lake Eyre Basin
MDB	Murray-Darling Basin
MODIS	MODerate resolution Imaging Spectrometer
MSSR	Mean Seasonal Storage
NSW	New South Wales
NT	Northern Territory
NVIS	National Vegetation Information System
NWC	National Water Commission
P	Precipitation
SA	South Australia
SDM	Spatial Data Model
SKM	Sinclair Knight Merz
SWHC	Soil Water Holding Capacity
WA	Western Australia
WP	Work Package
WRP	Water Resource Plan

Acknowledgements

The information in this document, and the GDE maps which comprise the GDE Atlas, are the result of collaboration between many people across Australia. The authors wish to thank all who contributed to this work.

In particular, the efforts of the project team at CSIRO, led by Tanya Doody, are appreciated. The team developed the MODIS data for the entire continent, and advised on the Landsat analysis technique. The combined efforts of CSIRO and SKM have produced the remote sensing data included in the Atlas.

The GDE Atlas benefitted from the technical advice of reviewers with detailed knowledge of the Australian landscapes that were mapped. Specifically, these were:

Lindsay Hutley (*Charles Darwin University*), for advice on the nature of water use by tropical and savannah ecosystems, and review of preliminary rules, concepts and maps for northern Australia.

Peter Jolly (*Jolly Consulting*), for guidance on the processes that govern groundwater availability in northern Australia, review of preliminary rules, concepts and maps for northern Australia, and attendance at a workshop to discuss the mapping.

Ray Froend (*Edith Cowan University*), for advice on arid zone ecosystem water requirements and use patterns, and review of interim products for south western Australia.

Paul Boon (*Dodo Consulting*), for advice on the processes that describe where groundwater/ecosystem interaction is likely in south eastern mainland Australia, and for reviewing WP1 rule sets, interim products and attending workshops.

Derek Eamus (*University of Technology Sydney*), for advice on the processes that describe where groundwater/ecosystem interaction is likely in east coast Australia, review of preliminary rules, concepts and interim products for the east coast.

Tanya Doody (*CSIRO*), as reviewer of preliminary mapping for the Murray-Darling Basin and arid zone Australia, and for provision of advice on the use of input datasets and the concepts that describe groundwater use in these areas.

Chris Auricht (*Auricht Projects*), regarding the availablitity of national datasets, and achieving consistency with the ANAE framework.

Sib and Keith Corbett (*consultants: terrestrial ecology, hydrogeology, geomorphology*) for advice on the processes that describe where groundwater/ecosystem interaction is likely in Tasmania, and review of preliminary rules and concepts and interim products.

Maj Britt Di Falco (*UTAS, soil and vegetation specialist*) for attending a workshop and providing advice on the processes that describe where groundwater/ecosystem interaction is likely in Tasmania.

Sixteen workshops and video conferences were held over the duration of the GDE Atlas development, to discuss the concepts and data used to develop the GDE maps. Each workshop was attended by jurisdictional representatives, who contributed detailed local knowledge of the groundwater conditions and the ecosystems in each area, as well as information on previously recognised GDEs. The input and enthusiasm in these meetings was greatly appreciated.

The Steering Committee have contributed to every aspect of the project, including mapping concepts, data sources, terminology, and presentation of data. The commitment of the Steering Committee in promoting involvement within each jurisdiction for this project is also gratefully acknowledged.

Fiona Lynn, Mike Braimbridge	Department of Water (DOW), Western Australia
Michael Lawton, Angus Duguid, Athina Pascoe-Bell	Natural Resources, Environment, the Arts and Sport (NRETAS), Northern Territory
Claire Harding, David Deane, Nick Carboon	Department for Water (DFW), South Australia
Moya Tomlinson	Department of Environment and Resource Management (DERM), Queensland
Mark Mitchell	NSW Office of Water (NOW)
Jill McNamara	Department of Sustainability and Environment (DSE), Victoria
Ian Houshold, Rebecca Sheldon	Department of Primary Industries, Parks, Water and Environment (DPIPWE), Tasmania
Paul Marsh	Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC)
Carl Daamen, Dovey Dee, Alys Wall, Dave Poobalasingam	Bureau of Meteorology (BOM)
Peter Hyde, Adam Sincock, Michelle McCue, Shane Hogan	National Water Commission (NWC)

Executive Summary

The GDE Atlas

The National Atlas of groundwater dependent ecosystems (GDE Atlas) comprises maps that show the location of both known and potential GDEs across Australia, as well as ecological and hydrogeological information for each GDE. The database containing the GDE mapping is hosted by the Bureau of Meteorology (BOM) and is accessible through the BOM website (http:\\www.bom.gov.au).

The GDE Atlas is a management tool that enables the presence and the water needs of GDEs to be brought into the water planning and allocation process. It informs users where the groundwater requirements of ecosystems should be considered. It also enables this information to be viewed and used by a broad audience through the publicly accessible website.While the GDE Atlas makes information available to a broad range of end users, it is envisaged that the primary users of the Atlas will be water planners and environmental managers, and that the Atlas will be used in the early stages of planning and approvals processes to flag the location and characteristics of potential GDEs.

The primary mapping outputs developed for the GDE Atlas are[1]:

- Maps showing potential GDEs which are presented as three separate spatial layers[2]:
    - GDEs that rely on the subsurface presence of groundwater (vegetation)
    - GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs)
    - Subterranean GDEs (caves and aquifers)
- A spatial layer showing Inflow Dependent Ecosystems (IDEs[3])
- A spatial layer showing Inflow Dependence (IDs[4])
- Remote sensing data, showing results of the MODIS and Landsat analysis.

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[1] The terminology used here is defined in the glossary at the end of this report.

[2] The terminology describing GDE types was adopted from Eamus, et al 2006.

[3] IDE–Inflow Dependent Ecosystem. Ecosystems that are accessing a water source in addition to rainfall, such as water stored in the unsaturated zone, surface water or groundwater. These are the basic extents within which GDEs occur.

[4] ID–Inflow Dependence. Areas of the landscape where remote sensing indicates that a water source in addition to rainfall is being used. Information is displayed as pixels rather than as ecosystems as in the IDE layer.

The GDE layers in the Atlas include GDEs identified in previous studies, and potential GDEs derived through new spatial analysis using existing feature layers and products developed from analysis of remotely sensed data. GDEs derived in the analysis are mapped according to the following classifications:

- High potential for groundwater interaction
- Moderate potential for groundwater interaction
- Low potential for groundwater interaction

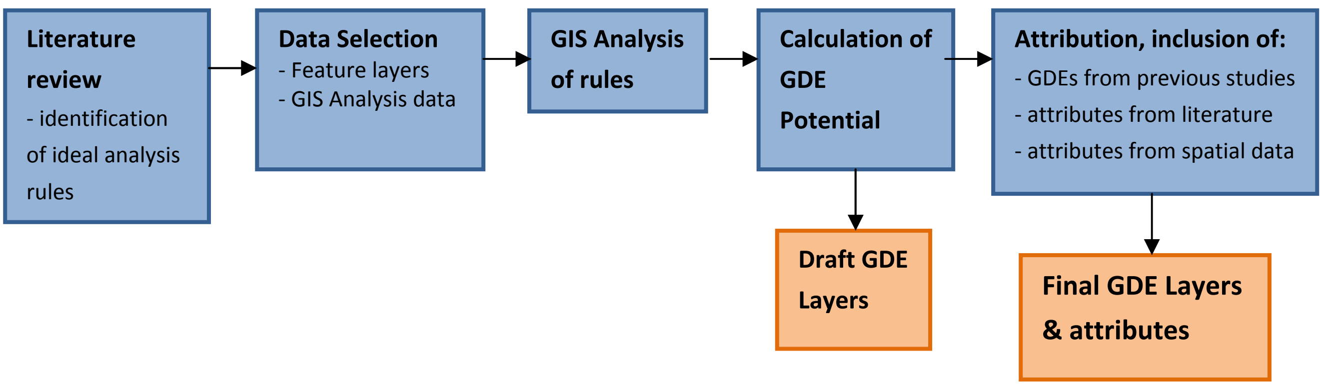
GDEs identified in previous studies were added to the GDE maps in the final stages of the methodology. The categories mapped in the Atlas for GDEs identified in previous studies are:

- Identified in previous study, fieldwork
- Identified in previous study, desktop

The GDE Atlas also contains contextual information that informs an understanding of the possible groundwater use for each potential GDE. This information describes the ecosystem's landscape setting, climate, geology, hydrology, ecology and hydrogeology.

Methodology used to identify and map GDEs

This report describes the methodology used to identify and map GDEs. The basic steps in the methodology are:



- **Basic steps to identify and map potential GDEs.**

This methodology was applied separately to eight GIS analysis regions (called work packages). Each work package represented an area of broadly similar hydrogeological, ecological and climatic

characteristics. It was assumed the interaction between groundwater and ecosystems was controlled by similar processes, and could be modelled by the same broad analysis rules within each work package.

The **literature review** enabled a conceptual understanding of the interaction between groundwater and ecosystems to be developed. From this, a set of rules describing the potential for groundwater/ecosystem interaction was developed for each work package.

In the **data selection** step, existing spatial data sets were compared against the rules to determine where analysis could be undertaken. The ability to implement the rules developed in the literature review was dependent on the availability of relevant spatial data.

Once the datasets available to implement the rules had been confirmed, **GIS analysis** combined the rules and data to provide an interim product that showed the outcomes of each rule for each ecosystem. The outcomes of each rule were then rated to indicate the potential for groundwater/ecosystem interaction to be occurring. The term ‘GDE potential’ has been used to indicate the potential for interaction between groundwater and ecosystems.

To **calculate an overall GDE potential** for each ecosystem, these ratings were combined using the following equation:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (for where normalised value was either 1, 2, or 3)}}$$

Weightings were applied to each rule to allow effective rules to have a greater influence on the overall GDE potential result. Results were validated using GDEs that had been identified in previous studies, which were assumed to reliably identify interaction between groundwater and ecosystems. Modelling in the Atlas therefore aimed to assign a high GDE potential to these ecosystems. The number of datasets used to derive the GDE potential result is indicated by the attribute ‘Lines of Evidence’, where a high value for ‘lines of evidence’indicates the result was based on several lines of evidence. A low value indicates the GDE potential result was based on limited data.

Attribution involved assigning characteristics to each ecosystem polygon, including attributes that identified whether previous studies had identified groundwater interaction (i.e. whether it should be classified and mapped as a ‘GDE identified in previous study’) and attributes describing the nature of groundwater/ecosystem interaction.

Application of the methodology

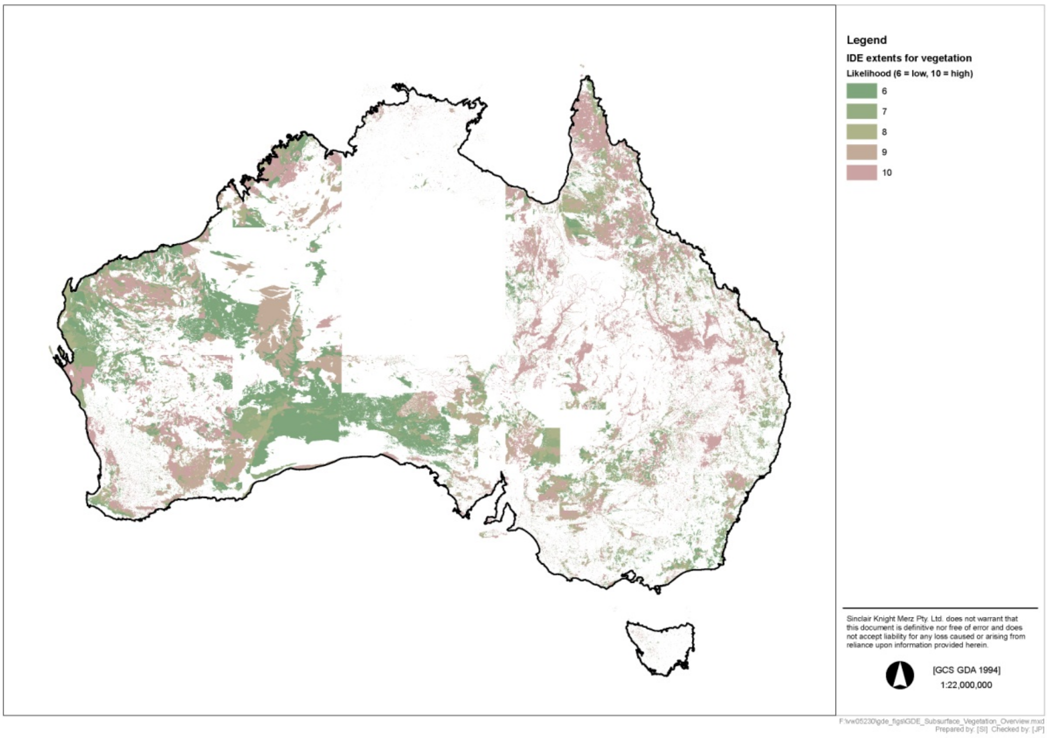
The methodology was applied to each work package area to identify potential groundwater interaction for mapped vegetation ecosystems (resulting in a map of ecosystems that rely on the subsurface presence of groundwater), and for mapped river, wetland and spring ecosystems (resulting in a map of GDEs that rely on the surface expression of groundwater). The rules and the datasets required to apply each rule are described for each work package in sections 6 to 13. This methodology was not used to map subterranean GDEs (caves and aquifers). Information on these GDEs was sourced from existing mapping only.

Appropriate input data was not available to model potential GDEs that rely on the subsurface expression of groundwater (vegetation) in some parts of Australia. Vegetation mapping was required as the basis for these GDE maps, and appropriate mapping was not available for the southern NT, and parts of NSW. Other options for mapping these areas were considered, but to maintain consistency in the method these options were not adopted. Mapping of rivers, wetlands and springs was available for all areas of Australia, which enabled complete nation-wide mapping of potential GDEs that rely on the surface expression of groundwater. The types and quality of input data varied across Australia which resulted in variations within the GDE mapping outputs. The quality of the input data was not specifically assessed as part of the project.

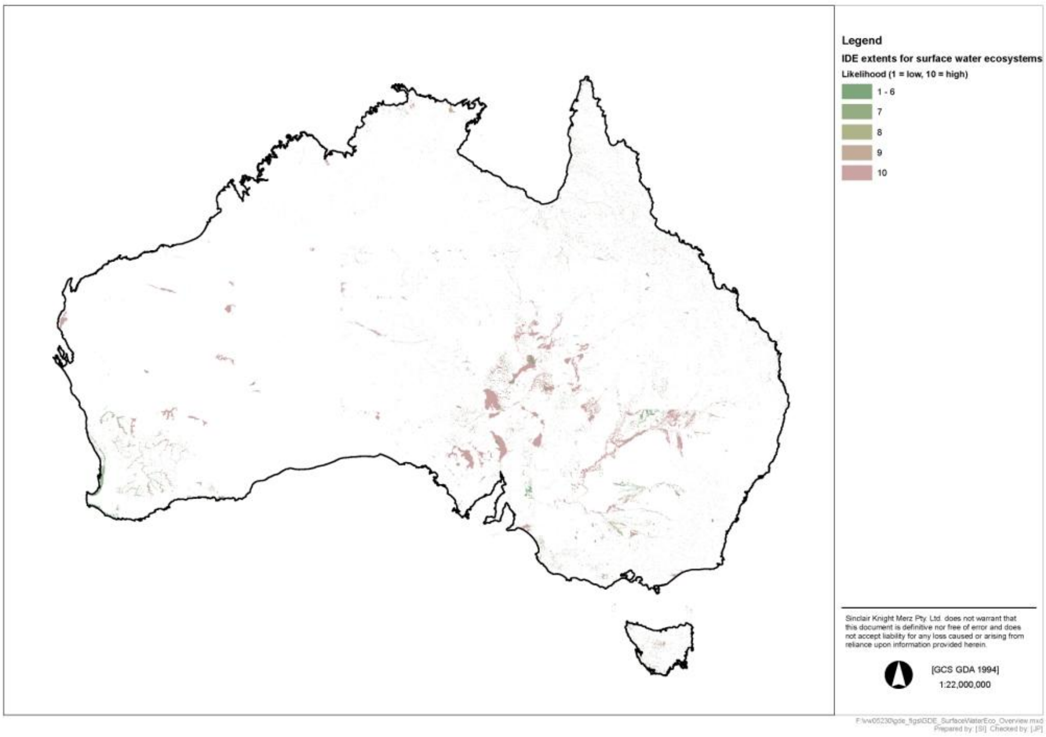
Ecosystem map layers created for the GDE Atlas

The IDE maps identify vegetation ecosystems that are likely to use a water source in addition to rainfall, such as water stored in the unsaturated zone, surface water or groundwater. These layers are the basis for further analysis in Task 5 to distinguish the ecosystems that potentially use groundwater, from those that rely on water stored in the unsaturated zone or surface water.

The benefit of including the IDE layers in the GDE Atlas is that all ecosystems that are using water in addition to rainfall (and could therefore possibly be GDEs) are included in the IDE layer. This enables users to view ecosystems that could not be identified as GDEs due to lack of data, but which may in reality be using groundwater. IDE layers allow a more complete understanding of the likely water use of ecosystems analysed during development of the GDE Atlas to be presented. The figures below show the IDE layers which are included in the GDE Atlas.



- **Map of vegetation IDEs**

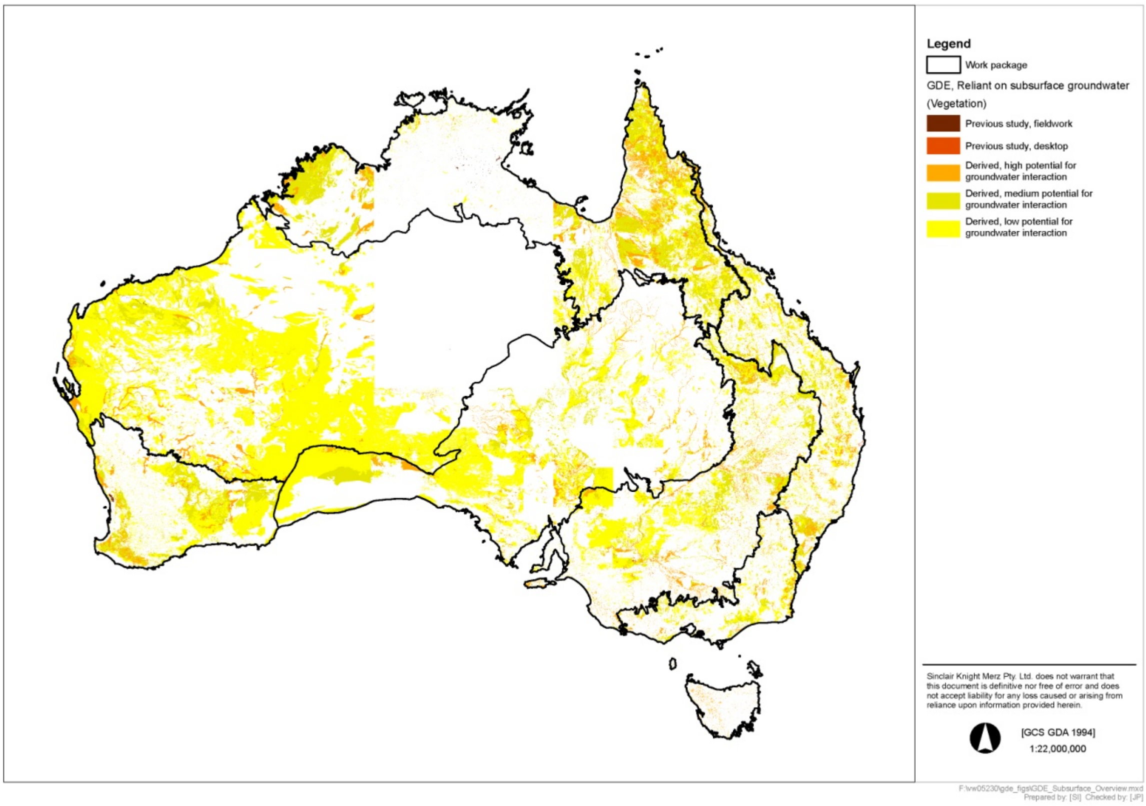


- **Map of surface water IDEs**

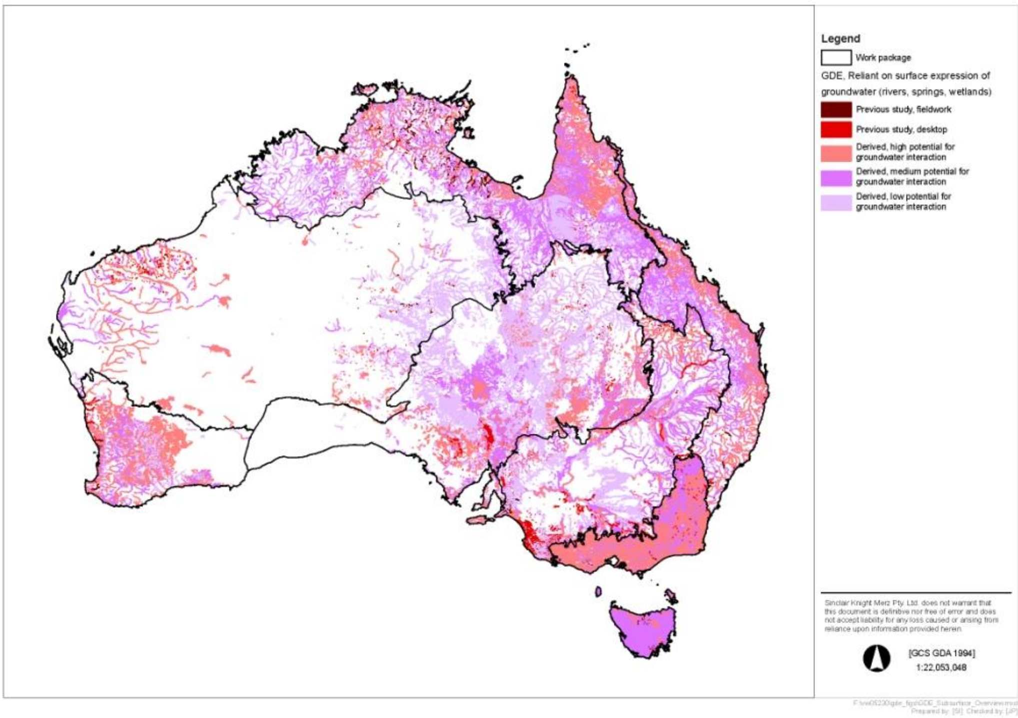
The map of GDEs that rely on the subsurface presence of groundwater (vegetation), and the map of GDEs that rely on the surface expression of groundwater (rivers, wetlands and springs) are the primary outputs of the GDE Atlas. A map of subterranean ecosystems was also created, however this involved a limited collation of existing data for cave systems and did not include any new mapping or analysis. Additional mapping or data for Subterranean GDEs exists, but was not collated for the GDE Atlas. The final maps are shown below.

The GDE maps include only the ecosystems where some assessment of the potential for groundwater interaction could be made. Where lack of data prevented potential groundwater interaction to be distinguished from water stored in the unsaturated zone or surface water use, the ecosystem was mapped in the IDE layers rather than the GDE maps. Ecosystem extents shown in the maps do not necessarily show the spatial extent of groundwater use. Rather, the ecosystem polygons should be interpreted as showing the area within which groundwater interaction may be occurring.

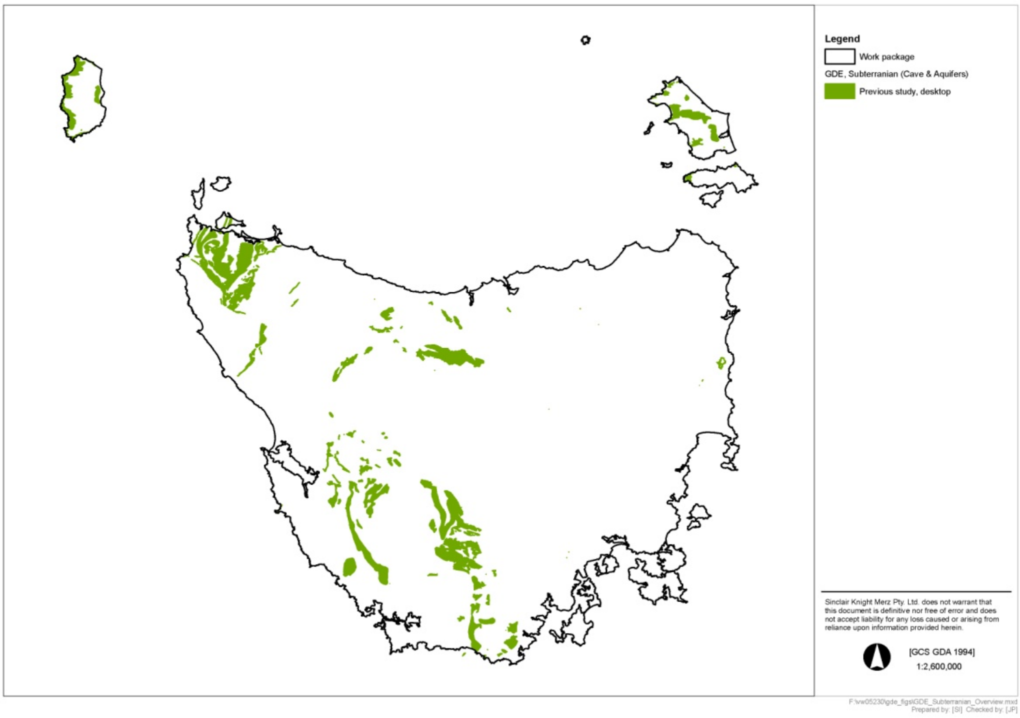
Each GDE within the final maps was attributed with data from existing national datasets that describe the broad climate, landscape setting and ecosystem characteristics. Where possible, attributes describing the nature of groundwater interaction were also populated.



- **Map of GDEs that rely on the subsurface presence of groundwater (vegetation)**



- **Map of GDEs that rely on the surface expression of groundwater (rivers, wetlands, waterholes, springs)**



- **Map of subterranean GDEs (caves and aquifers)**

1. Introduction

1.1. Overview of the GDE Atlas

The National Atlas of Groundwater Dependent Ecosystems (GDE Atlas) was developed to address a knowledge gap in the understanding and management of GDEs across Australia. It has been acknowledged that ‘the identification and assessment of the water needs of GDEs need to be brought into the planning and allocation process’[5]. The GDE Atlas is an important tool to help achieve this aim.

The GDE Atlas comprises maps that show the location of both known and potential GDEs across Australia, as well as ecological and hydrogeological information for each GDE. The database containing the GDE mapping is hosted by the Bureau of Meteorology (BOM) and is accessible through the BOM website (http:\\www.bom.gov.au). A screen shot of the website containing the final GDE mapping layers, as well as contextual information is shown in Figure 1.

The GDE Atlas is a tool to assist the consideration of ecosystem groundwater requirements in natural resource management, including water planning and environmental impact assessment. While the GDE Atlas makes information available to a broad range of end users, it is envisaged that the primary users of the Atlas will be water planners and environmental managers, and that the Atlas will be used in the early stages of planning and approvals processes to flag the location and characteristics of potential GDEs.

[5] NWC, 2009. *Australian water reform 2009: Second biennial assessment of progress in implementation of the National Water Initiative*, September 2009.

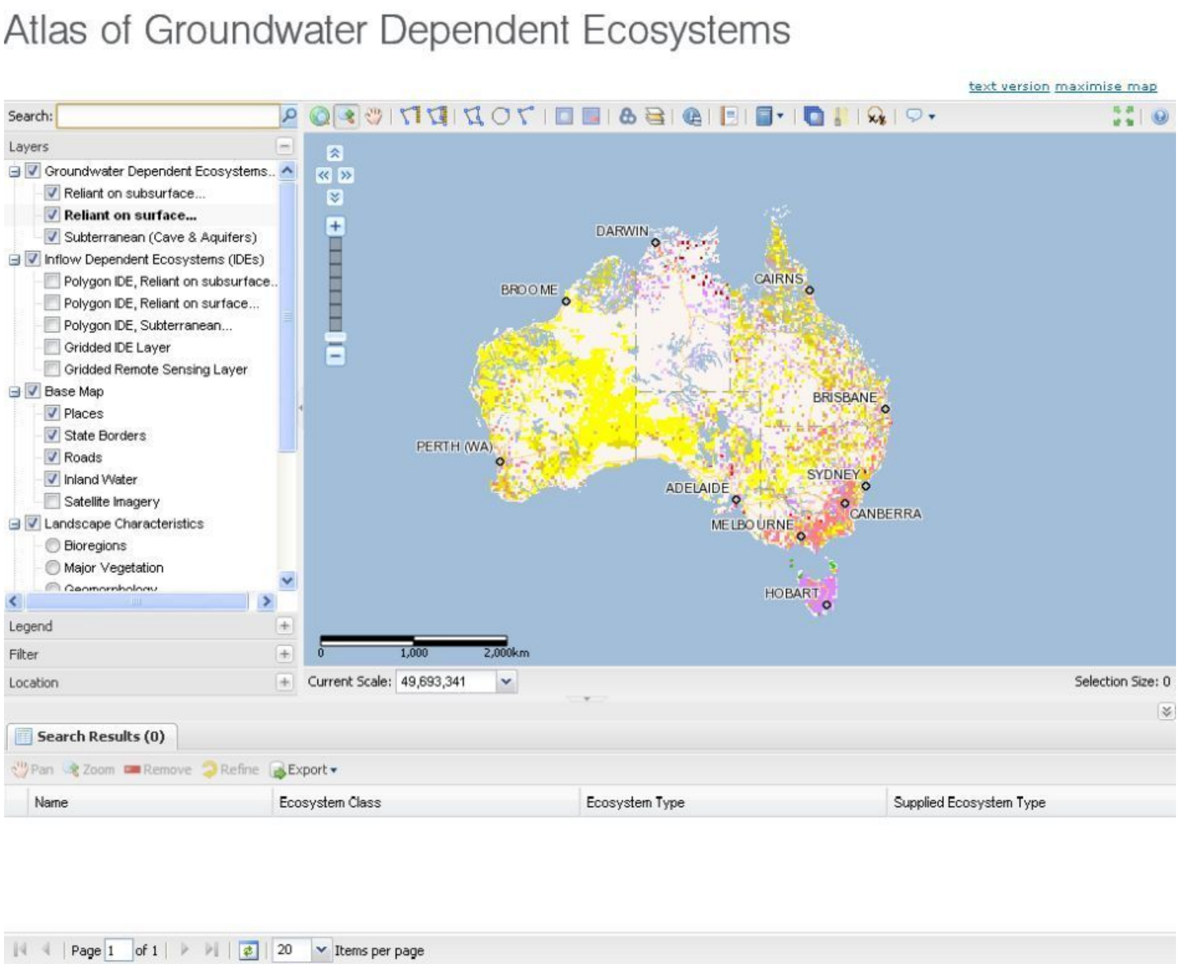


Figure 1 GDE Atlas website as presented on the BOM website

The primary mapping outputs developed for the GDE Atlas are[6]:

- Maps showing potential GDEs which are presented as three separate spatial layers:
  - GDEs that rely on the subsurface presence of groundwater (e.g. vegetation)[7], which includes both known (previously mapped) and derived (potential) GDEs
  - GDEs that rely on the surface expression of groundwater (e.g. rivers, wetlands, springs), which includes both known (previously mapped) and derived (potential) GDEs

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[6] the terminology used here is defined in the glossary at the end of this report.

[7] This terminology describing GDE types was adopted from Eamus, et al., 2006.

  - Subterranean GDEs (caves and aquifers), which includes known (previously mapped) GDEs only
- A spatial layer showing Inflow Dependent Ecosystems (IDEs[8])
- A spatial layer showing Inflow Dependence (IDs[9])
- Remote sensing data, showing results of the MODIS and Landsat analysis

The GDE Atlas is a national scale mapping product, and offers the most extensive broad scale inventory of potential GDEs currently available in Australia. More detailed information on the characteristics of individual GDEs may exist where detailed studies have been undertaken previously, however these studies were generally of limited spatial coverage. The GDE Atlas incorporates the results of these studies where possible, and extends the mapped coverage of potential GDEs across the country. The design of the GDE Atlas allows updates as more information becomes available.

Information on the values, threats and conservation priority of ecosystems is not included. Marine and estuarine GDEs were not incorporated in this version of the Atlas. Subterranean GDEs were mapped only where existing mapping of caves was available, and only in Tasmania–as such, more information on subterranean GDEs exists but has not been collated for the GDE Atlas.

Where more detailed assessments of GDEs are required, the GDE Toolbox (Richardson et al., 2011) provides a framework and tools for identifying GDEs, assessing ecological water requirements and determining the impacts of changes in the groundwater environment on ecosystems. The GDE Toolbox contains information to help water managers obtain a more detailed understanding of GDEs and the nature of groundwater connection at a fine scale.

Development of the GDE Atlas involved a program of work which was completed over an 18 month period and consisted of seven major tasks. These tasks were:

- Task 1 – Proof of concept
- Task 2 – Data collation and review
- Task 3 – Development of basemap and EHZs[10]

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[8] IDE–Inflow Dependent Ecosystem. Ecosystems that are accessing a water source in addition to rainfall, such as water stored in the unsaturated zone, surface water or groundwater. These are the basic extents within which GDEs occur.

[9] ID–Inflow Dependence. Areas of the landscape where remote sensing indicates that a water source in addition to rainfall is being used. Information is displayed as pixels rather than as ecosystems as in the IDE layer.

- Task 4 – Remote sensing to identify inflow dependence
- Task 5 – Identification of GDEs
- Task 6 – Spatial Data Model (SDM)
- Task 7 – Development of web interface

Further detail on the scope and outputs of each of these tasks is contained in section 2.

1.2. The identification of GDEs (Task 5)

This report describes the methodology used to identify and map GDEs in Task 5 of the GDE Atlas project.

Analysis in Task 5 developed GDE maps for:

- Ecosystems that rely on the subsurface presence of groundwater (vegetation)
- Ecosystems that rely on the surface expression of groundwater (rivers, wetlands, springs)

The GDE maps created for the Atlas show GDEs that were identified in previous studies, as well as GDEs derived through analysis during the development of the GDE Atlas. The combination of these two data sources was one of the central concepts in the development of the GDE Atlas.

In the GDE Atlas, ecosystems were classified according to the potential for groundwater to be interacting with each ecosystem–that is, the potential that each ecosystem is a GDE. GDEs identified in previous studies were classified into categories based on the method of their identification–either through fieldwork or desktop studies. This combination of GDEs identified in previous studies, and the results of analysis to identify potential groundwater interaction in Task 5 resulted in the following mapping classifications.

GDEs derived in the analysis are mapped according to the following classifications:

- High potential for groundwater interaction
- Moderate potential for groundwater interaction
- Low potential for groundwater interaction

These terms are discussed in section 4.2 and defined in the glossary (section 1).

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[10] EHZs–Eco-Hydrogeological Zones. Regions where similar processes are likely to determine the interaction between groundwater and ecology, due to similar ecology, geology, climate, groundwater/surface water connections.

GDEs identified in previous studies were added to the GDE maps in the final stages of the methodology. The categories mapped in the Atlas for GDEs identified in previous studies are:

- Identified in previous study, fieldwork
- Identified in previous study, desktop

Subterranean GDEs (caves and aquifers) were included in the Atlas only where previous information which identified their potential locations and characteristics was provided for the project. The spatial coverage of mapped subterranean GDEs is therefore limited and shows only previously mapped caves.[11]

The GDE Atlas also contains specific information on the nature of groundwater use for each potential GDE. This information describes the ecosystem's landscape setting, climate, geology, hydrology, ecology and hydrogeology. The literature describing each GDE was included as a reference.

1.3. Structure of this report

This report focuses on Task 5 of the GDE Atlas, which describes the development of spatial layers that show known and potential GDEs. In Task 5 the knowledge and mapping products from previous tasks were drawn together to create the final GDE maps. This report describes the methodology, and how it was implemented in landscapes across Australia.

This report:

- Outlines the seven tasks required to complete the GDE Atlas
- Describes the methodology used to identify and map potential GDEs
- Details how the methodology was specifically applied across Australia
- Lists the data gaps and resulting limitations of the GDE mapping
- Describes the layout and interpretation of the maps/layers included on the GDE Atlas website
- Outlines the terminology used within the project to describe and map GDEs

The following sections are provided:

Section 1: Introduction. Provides broad context on the GDE Atlas overall, and then more specifically, on the identification and mapping of GDEs in Task 5.

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[11] Subterranean GDE mapping includes potential caves in Tasmania only. Notable omissions of Subterranean GDEs include all caves on mainland Australia, as well as aquifers and bore records of stygofauna.

Section 2: Summary of tasks undertaken in development of the GDE Atlas. Provides a brief summary of each task undertaken to develop the GDE Atlas and deliver a web-based tool to display the outcomes.

Section 3: Overview of remote sensing inputs to the GDE mapping (Task 4). Several spatial products were developed using remote sensing data and GIS analysis to identify potential GDEs. These products are presented and described in this section. The flow of products from remote sensing to the final GDE mapping is clarified.

Section 4: Methodology for identification and mapping of potential GDEs. Details the methodology used in Task 5 to identify GDEs, and the process by which knowledge from literature, existing spatial datasets, remote sensing data and reviewers were incorporated in the analysis.

Section 1: Limitations of the GDE mapping methodology. The limitations of the methodology described in section 4 are discussed, including issues with the data used in the analysis.

Section 6 - 13: Application of the methodology in each work package across Australia. This section describes the rules, data and analysis applied in each work package (analysis area) across Australia.

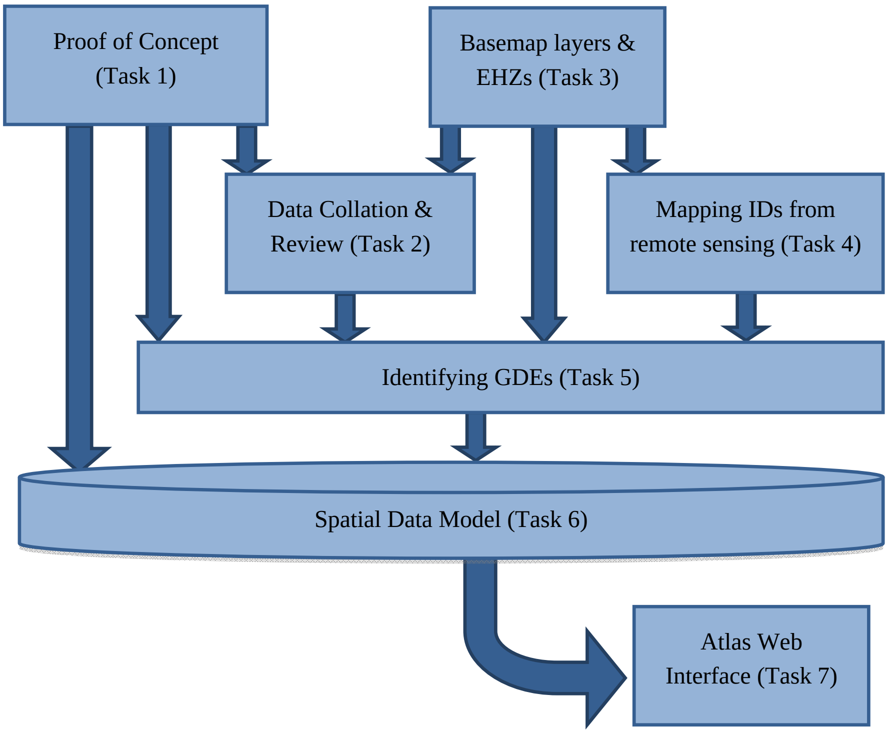
Section 14: Maps derived for the GDE Atlas. The maps developed using the methodology for identification of potential GDEs are described in this section. This includes the IDE layer, and the three GDE layers.

Section 15: Technical and data gaps. The data gaps encountered for each work package are summarised in this section. Technical gaps are also described, both in terms of conceptual understanding of interaction between groundwater and ecosystems in certain landscapes, and the technology used for the analysis.

Section 16: **Recommendations.** The recommendations for a future update of the Atlas are outlined, following on from the description of gaps in conceptual understanding and technical platforms.

2. Summary of tasks undertaken in the development of the GDE Atlas

Seven major tasks were completed during the development of the GDE Atlas. Each of these tasks is described in this section. The flow diagram in Figure 2 summarises how the seven tasks relate to each other.



- **Figure 2 Relationship between the seven project tasks. Flow chart indicates the flow of data from early tasks into subsequent tasks, and then finally into the spatial data model and website. (EHZ – ecohydrogeological zone)**

Task 1 – Proof of Concept

The Proof of Concept involved the development and testing of the methodology in two locations (Howard River area, NT and Namoi Catchment, NSW). The basic steps of the methodology were established in this task. The most important outcome of the Proof of Concept was confirmation of a set of attributes which were used throughout the project to describe each GDE. Agreement on the definitions and terminology used for the Atlas was reached in the Proof of Concept, and this allowed the GDE mapping layers to be confirmed.

The design of the attribute table and confirmation of the spatial products to be mapped for the Atlas were used to: provide a framework for reviewing and recording information required from literature (Task 2); design the spatial data model (Task 6); and to develop a prototype version of the web interface (Task 7).

Primary Outputs of Task 1	Documentation
- Attribute table (see Appendix A) - Agreed terminology (see Section 3) - Confirmation of mapping layers (subsurface/surface/C&A GDEs)	- Proof of Concept Report: SKM & CSIRO, 2011. *Atlas of Groundwater Dependent Ecosystems (GDE Atlas), Proof of Concept Report*, May 2011.

Task 2 – Data Collection and Review

Task 2 involved the collection of existing jurisdictional and commonwealth literature and spatial data, on the location and characteristics of GDEs, groundwater setting and processes, and ecology. The literature was used to provide an understanding of the processes which control the presence of likely GDEs at the scale of Eco-Hydrogeological zones (EHZs). A preliminary set of rules for GIS analysis (GIS analysis rules) was then developed based on this initial conceptualisation. The GIS analysis rules defined where interaction between ecosystems and groundwater was likely to occur.

The literature was also used to identify ecosystems that had been assessed as GDEs in previous work. The location of GDEs identified in previous work was included in the spatial database and any appropriate descriptions of the GDE setting were included in the Atlas attribute table.

Primary Outputs of Task 2	Documentation
- Spatial record of GDEs that were identified in previous studies (see Appendix B) - Tier 3 attributes populated for these GDEs where appropriate - Conceptual understanding of indicators of groundwater interaction/use developed in previous work. - Preliminary rules for GIS analysis developed.	- Data Collation & Review Report: SKM, 2011. *Atlas of Groundwater Dependent Ecosystems (GDE Atlas), Data Collation & Review report*, August 2011.

Task 3 – Creating the Basemap

The Basemap is a collection of national spatial datasets that were collated and used to provide context for the GIS analysis. The most important outcome of Task 3 was the development of EHZs, which defined areas where the processes that control interaction between groundwater and ecology are broadly similar. These zones were developed by integrating climate, bioregion and groundwater province spatial datasets.

The EHZs were used in subsequent tasks as the basis for extrapolating the rules which enabled the regional identification and attribution of GDEs. The EHZs also provide details for Tier 1 (broad, high level) attributes. Fifty-seven EHZs across Australia were delineated.

Primary Outputs of Task 3	Documentation
- Basemap - Collated national datasets - EHZs (see Appendix C.1)	- Basemap Technical Paper: SKM 2011. *Atlas of Groundwater Dependent Ecosystems, Basemap Explanatory Paper*, January 2011. - Available: See Appendix C.2

Task 4 – Using remote sensing to map Inflow Dependence (IDs)

Analysis of satellite imagery (MODIS and Landsat) was used to identify landscapes which potentially use water in addition to rainfall. These are the preliminary spatial extents within which groundwater interaction and use may be occurring. MODIS data was used to assess changes in the rate of evapotranspiration (ET) over time, and Landsat data was analysed to map the vegetation greenness using spectral response.

The combination of these layers allowed the creation of a single Inflow Dependence (ID) layer which inferred where landscapes may access water in addition to rainfall. This additional water source could be either water stored in the unsaturated zone, groundwater, or surface water; the subsequent analysis in Task 5 determined the likelihood of this additional source of water being groundwater.

Primary Outputs of Task 4	Documentation
- Nation-wide layer of analysed MODIS data (see Appendix D.1) - Nation-wide layer of analysed Landsat data (see Appendix D.2) - Combined MODIS and Landsat into an ID layer (see Appendix D.3) - Open water extents (see Appendix D.4)	- SKM & CSIRO, 2012. *Task 4 report: Mapping Inflow Dependency from remote sensing*, April 2012

Task 5 – Identifying potential groundwater dependence

Task 5 involved the analysis of datasets (using the conceptual models of GDEs developed during the Task 2 literature review, and GIS analysis rules) to identify potential groundwater dependence for each ecosystem. After several iterations, this resulted in the final mapped extents of potential GDEs, with completed attribute tables. The Task 5 methodology and outputs are described in detail in section 4 to section 13.

Primary Outputs of Task 5	Documentation
- Nation-wide mapping of GDEs that rely on the surface expression of groundwater (river, spring, waterhole, and wetland GDEs). - Nation-wide mapping of GDEs that rely on the subsurface presence of groundwater (vegetation GDEs). - Mapping of Subterranean GDEs where previous information was available. - Mapping of GDEs that had been identified in previous studies - Attributes tables populated to the extent possible for each GDE.	- SKM, 2012. *Task 5 report: Identifying GDEs*, June 2012 - Available: on the GDE Atlas website (http:\\www.bom.gov.au)

Task 6 – Data Management

The spatial data model (SDM) was developed at the beginning of the GDE Atlas development to support the data collation (Task 2). The Proof of Concept (Task 1) informed the design of the SDM. The Spatial Database housed all data for the GDE Atlas.

Primary Outputs of Task 6	Documentation
- Spatial Database containing all GDE and contextual information to be displayed on the GDE Atlas	- SKM, 2011. *National Atlas of Groundwater Dependent Ecosystems, Spatial Data Model*, August 2011

Task 7 – Web development

The completed GDE Atlas is publicly available via a web interface, hosted by the Bureau of Meteorology (BOM). Task 7 involved designing the functionality, format and style of the web interface.

Primary Outputs of Task 7	Documentation
- Website displaying GDE Atlas functioning on the BOM system	- SKM, 2011. *Product Requirement Specification*, Rev. B, June 2011. - SKM, 2011. *Business Requirements Solution Overview*, Rev. B, August 2011. - SKM, 2011. *Product Technical Specification*, Rev. B, December 2011. - SKM, 2012. *Web Atlas Development Management Plan,* Rev. C, January 2012.

3. Overview of remote sensing inputs to the GDE mapping (Task 4)

Remote sensing analysis in Task 4 produced some of the key data sources used to identify GDEs in Task 5. While not specifically part of the Task 5 methodology, the development of the remote sensing products requires explanation in order to understand how they were used in Task 5, and what information they convey in the GDE Atlas.

In developing the GDE Atlas, both MODIS and LandsatTM satellite remote sensing data was used as they each addressed different project needs. MODIS data is collected at a high frequency (8-day intervals) which allows detailed analysis of temporal variability. It is a suitable data source for broad coverage but has a low spatial resolution (250m), which limits the ability to detect ecosystems with relatively small spatial dimension (e.g. wetland or river channels). Landsat imagery is a medium resolution satellite image sensor (30m optical resolution) and offers sufficient spatial detail for use in 1:25,000 scale mapping. It is obtained twice monthly which gives rise to opportunities for examining seasonal patterns in vegetation surface cover, however availability of cloud-free images can be limited in some areas.

The following remote sensing products are spatial layers in the GDE Atlas:

- Gridded remote sensing layer[12]
- Gridded Inflow Dependence (ID) layer

This section provides a brief overview of what these layers convey, and demonstrates how the remote sensing products fed into the development of the GDE layers. More detail on the development of the remote sensing data is in the report: ‘SKM & CSIRO, 2012. *Task 4 Report: Mapping Inflow Dependency from remote sensing*, April 2012’.

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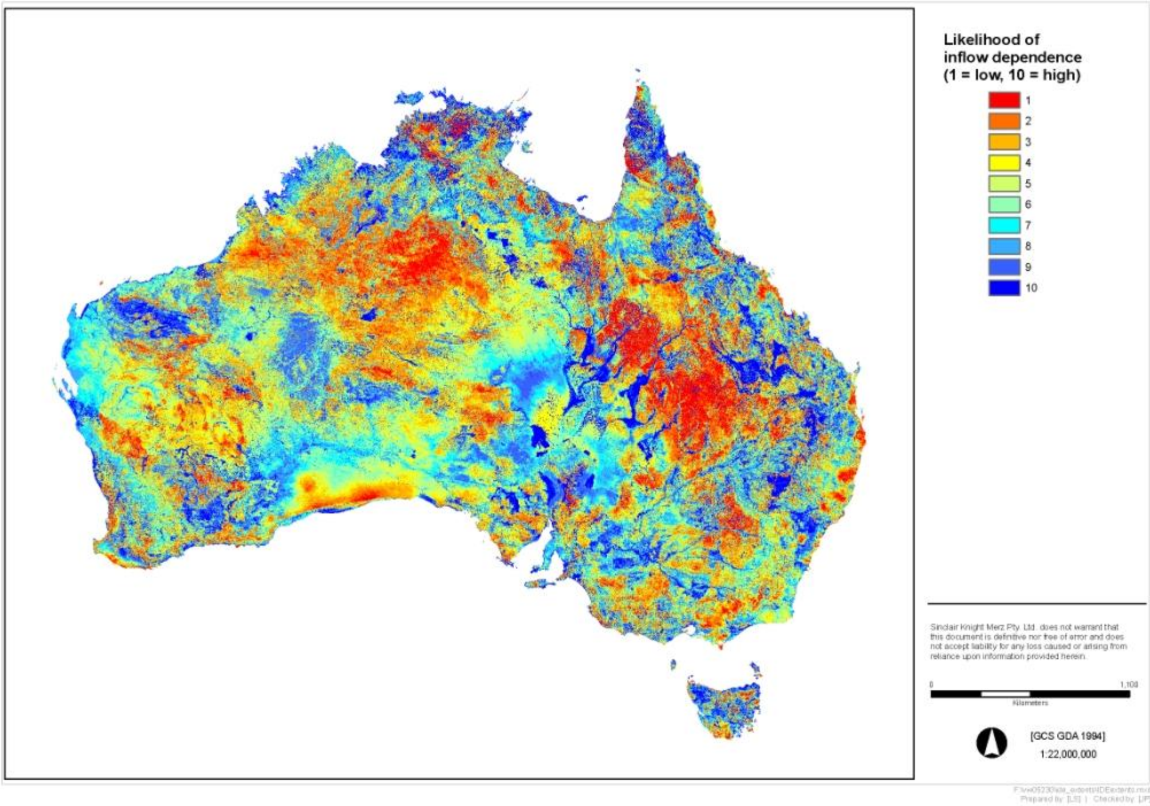
[12] The input data to this layer are the Landsat data, MODIS data (pIDE and MSSR). Albedo and Optical Water Likelihood (OWL) layers were also used to limit the influence of reflectance from bare surfaces in the pIDE data. The development of each of these datasets and how they were combined to create a single national layer is described in the Task 4 report (SKM & CSIRO, 2012. Task 4 Report: Mapping Inflow Dependency from remote sensing, April 2012.)

3.1. Gridded Remote Sensing Layer

This layer (shown in Figure 3) provides complete coverage of Australia and is the result of integrating the MODIS and Landsat data and then resampling to derive pixels of 25m × 25m resolution. Each pixel has a likelihood rating of between 1 and 10, whichindicates whether the landscape is likely to be accessing a source of water in addition to rainfall. The likelihood rating is based on the following criteria:

- The volume of evapotranspiration relative to rainfall (MODIS)
- The relative volume of dry season water use (MSSR)
- The presence of surface water (Landsat and MODIS)
- Whether vegetation is active during dry periods (Landsat)
- Whether the spectral response is similar to alpine GDEs (Landsat)

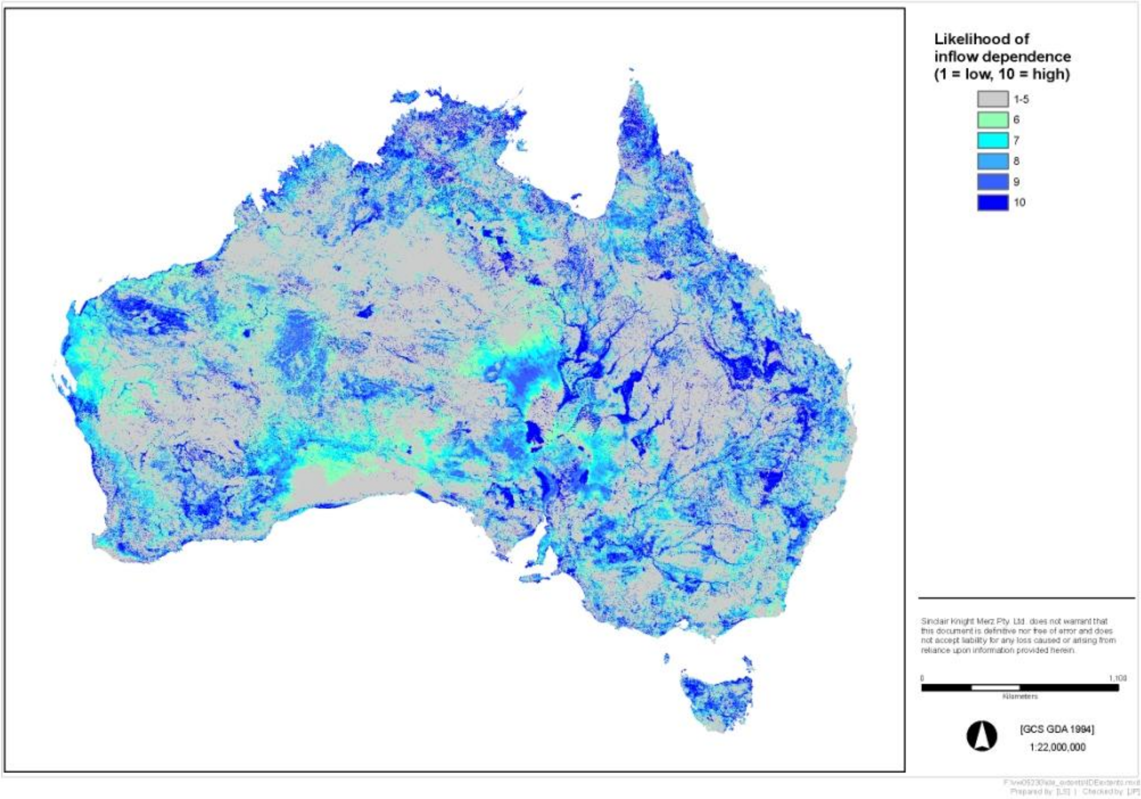
Higher likelihood ratings (6 to 10) suggest that the landscape is more likely than not to be using an additional source of water, such as groundwater. The ratings form a spectrum: ratings of 6 indicate landscapes that are slightly more likely to be using an additional source of water, and ratings of 10 indicate landscapes that are highly likely to be accessing an additional source of water. Low likelihood ratings (1 to 5) suggest that the landscape is less likely to be accessing an additional water source–these landscapes are more likely to rely solely on rainfall.



- **Figure 3 Gridded remote sensing layer, showing likelihood of inflow dependence at 25m resolution.**

3.2. Gridded ID (Inflow Dependence) Layer

This layer (shown in Figure 4) is the selection of pixels from the nation-wide gridded remote sensing layer (described in section 3.1) that have a likelihood of greater than 5. The purpose of creating this layer (which is a subset of the Gridded Remote Sensing layer) was to identify all areas across Australia where ecosystem use of a water source in addition to rainfall is likely–these are Inflow Dependent (ID) landscapes. Like the nation-wide layer, this layer also consists of 25m × 25m pixels with likelihood ratings assigned, however in this case, only likelihoods of 6 to 10 are displayed.

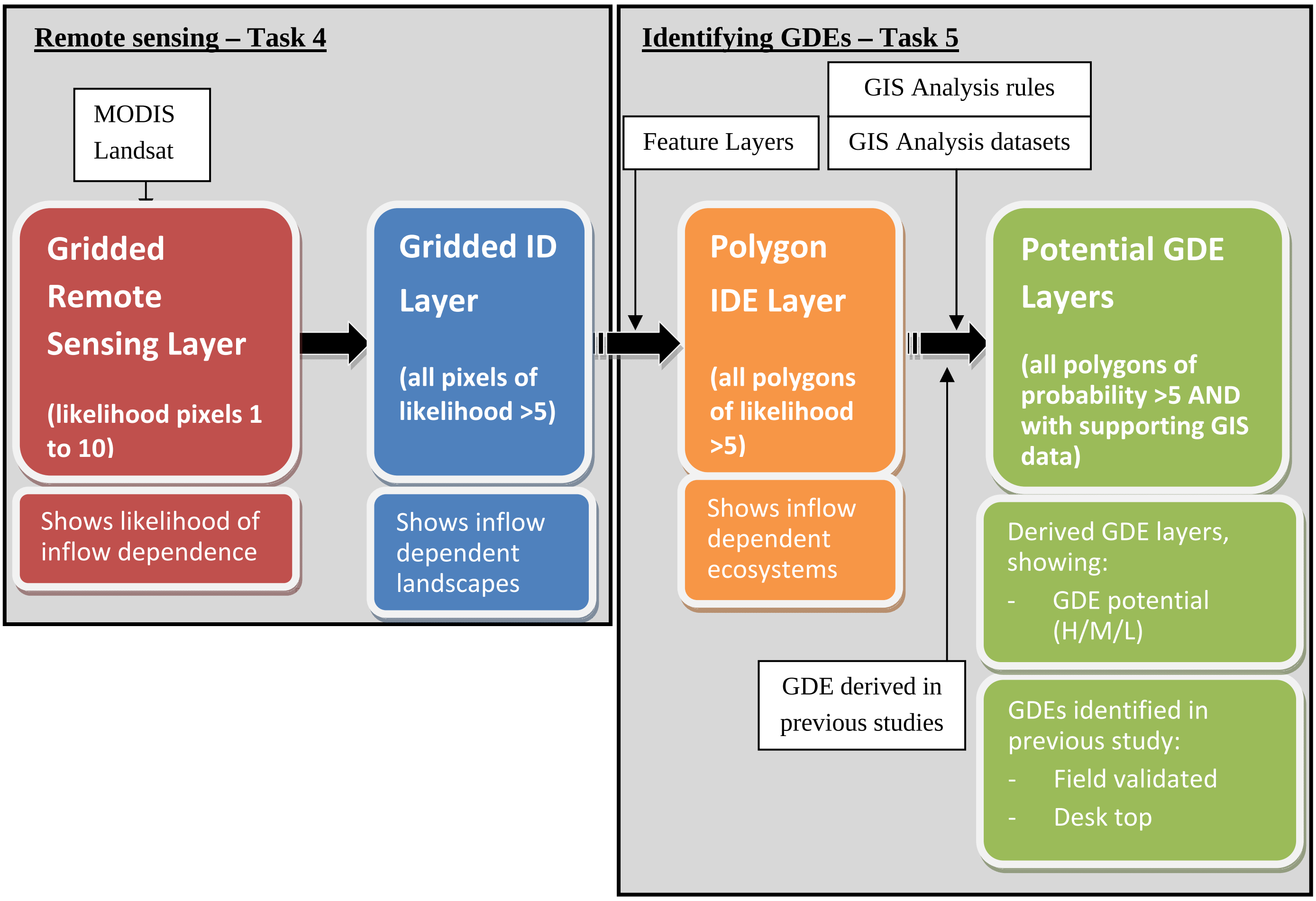


- **Figure 4 Gridded ID layer, showing inflow dependent landscapes at 25m resolution**

3.3. Use of remote sensing to identify groundwater dependence

To identify GDEs, the remote sensing likelihood rating was initially assigned to each ecosystem polygon. This created the Inflow Dependent Ecosystem (IDE) layer, showing ecosystems with likelihoods of 6 or more, which are likely to be accessing water in addition to rainfall. The polygons within this layer were analysed further in Task 5 to determine whether the additional source of water they were accessing was groundwater. If data indicated the potential of these polygons to be accessing groundwater (as opposed to water stored in the unsaturated zone or surface water), they were included in the potential GDE layers. The process of distinguishing groundwater use from surface water use or use of water stored in the unsaturated zone is described in detail in section 4 ‘Methodology for identifying and mapping potential GDEs’.

The flow of data from the remote sensing to the IDE layer, and then to the GDE layers, is summarised in Figure 5. Each of the layers shown is included in the Atlas to support the final GDE layers.



- **Figure 5 The spatial layers progressively developed for the GDE Atlas, with each layer derived from the previous one. The creation of the Potential GDE Layers is described in section 1.**

The IDE layer shows all ecosystems that are likely to be accessing a water source in addition to rainfall. Of these ecosystems, the only ones included in the GDE layers were those where additional information (GIS analysis datasets, described in section 4) was available to determine the potential for groundwater use. This means that some IDEs are likely to be using groundwater but the information was not available to make this conclusion. Rather than excluding these ecosystems from the GDE Atlas entirely, the IDE layer allows them to be included, but not labelled as potential GDEs. It also means that the GDE layers only contain ecosystems where the additional information has allowed the potential for groundwater interaction to be meaningfully determined.

The benefit of including the remote sensing layers in the Atlas is that the remote sensing can be significantly more detailed than the IDE or GDE mapping. By transferring the 25m × 25m remote

sensing data onto the larger ecosystem polygons, much of this detail in the remote sensing was lost. In most cases, ecosystem polygons contained a range of likelihood values when overlain by the gridded pixel data. The likelihood value that occurred most often within the ecosystem polygon was chosen to represent the whole polygon. With the gridded remote sensing and the gridded ID layer visible in the Atlas, users can gain an insight to the level of variation of ID likelihood within a single ecosystem polygon.

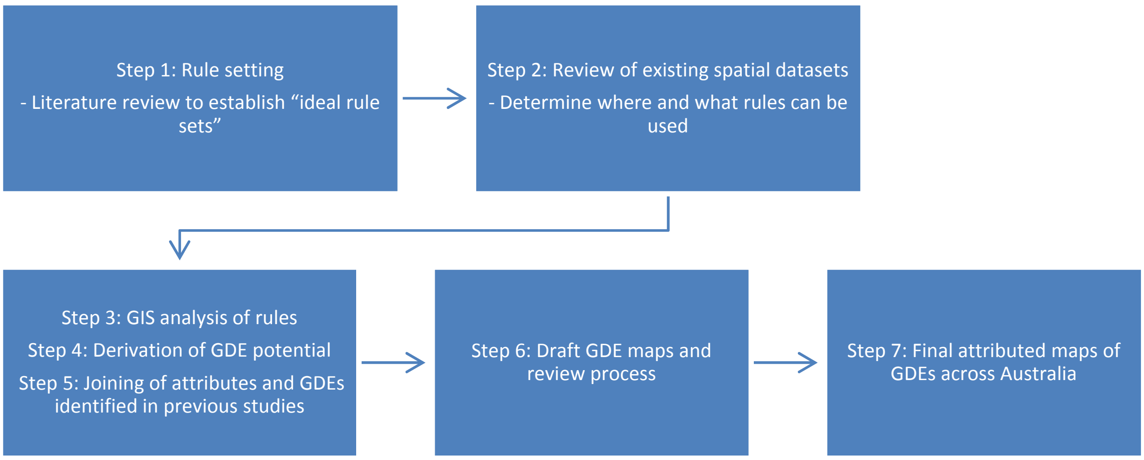
Another benefit of having the gridded remote sensing and ID layers underpinning the IDE and GDE mapping in the Atlas, is that the ecosystem mapping used to create the GDE maps was not always complete. There were several cases identified where an ecosystem was known, or could be seen in satellite imagery, but was not mapped as a polygon in the existing ecosystem mapping. With the remote sensing and ID layers underpinning the IDE and GDE layers, users of the Atlas are still able to identify landscapes that transpire more than rainfall, and that therefore could potentially be using groundwater, even though they are not mapped as ecosystems.

4. Methodology for identifying and mapping potential GDEs (Task 5)

4.1. Introduction

This section describes the methodology used to identify potential GDEs in Task 5. Potential GDE layers were developed by integrating information from literature on GDEs with existing spatial data sets within a GIS environment. Essentially, Task 5 of the GDE Atlas used combinations of existing data to develop new knowledge regarding the potential of ecosystems to be interacting with groundwater across Australia. The methodology (Figure 6) consisted of five components (more detailed description of the method is supplied in section 4.2). These were:

1) A review of literature which led to the development of a series of ideal rule sets on how GDEs may be mapped
2) Existing spatial data sets were compared against the rules to determine where analysis could actually be undertaken (including the remote sensing outputs as discussed in Section 3)
3) Draft maps of potential GDEs were then developed through GIS analyses and a series of reviews were undertaken
4) A series of attributes, including GDE potential, landscape setting and ecosystem type (amongst others) were then joined to polygons. This included tagging the GDEs that had already been identified in previous studies
5) Completion of the final attributed GDE potential layers



▪ **Figure 6 Basic steps in developing the GDE layers**

4.2. Methodology Overview

The methodology described in this section details the development of rules which describe groundwater interaction with ecosystems, the use of data (including remote sensing) to implement these rules, and the calibration of the data to derive GDE mapping that logically represented groundwater interaction across Australia.

Two final GDE layers were developed for the GDE Atlas using the methodology described in this section. These showed:

- Ecosystems that rely on the subsurface presence of groundwater (vegetation)
- Ecosystems that rely on the surface expression of groundwater (rivers, wetlands, springs)

Three categories of GDE potential were mapped within each of the GDE layers:

- High potential for groundwater interaction
- Moderate potential for groundwater interaction
- Low potential for groundwater interaction

These GDE potential categories indicate the potential for each ecosystem to be interacting with groundwater, based on the physical landscape and ecosystem characteristics. For example, a shallow watertable, constant ET in dry periods, or known groundwater-using vegetation are physical characteristics of an ecosystem that suggest the potential for groundwater interaction is high. Conversely, vegetation growing over deeper watertables, with seasonal ET suggests that the potential for groundwater interaction is lower. A low potential for groundwater interaction means that ecosystems are relatively unlikely to be interacting with groundwater. This will include ecosystems that are not interacting with groundwater. High potential for groundwater interaction means that there is a strong possibility that ecosystems are interacting with groundwater.

The GDE potential does not convey the confidence of the prediction, or the reliability of the GDE potential result. This is convyed using the ‘Lines of Evidence’ attribute (explained in section 4.6.7).

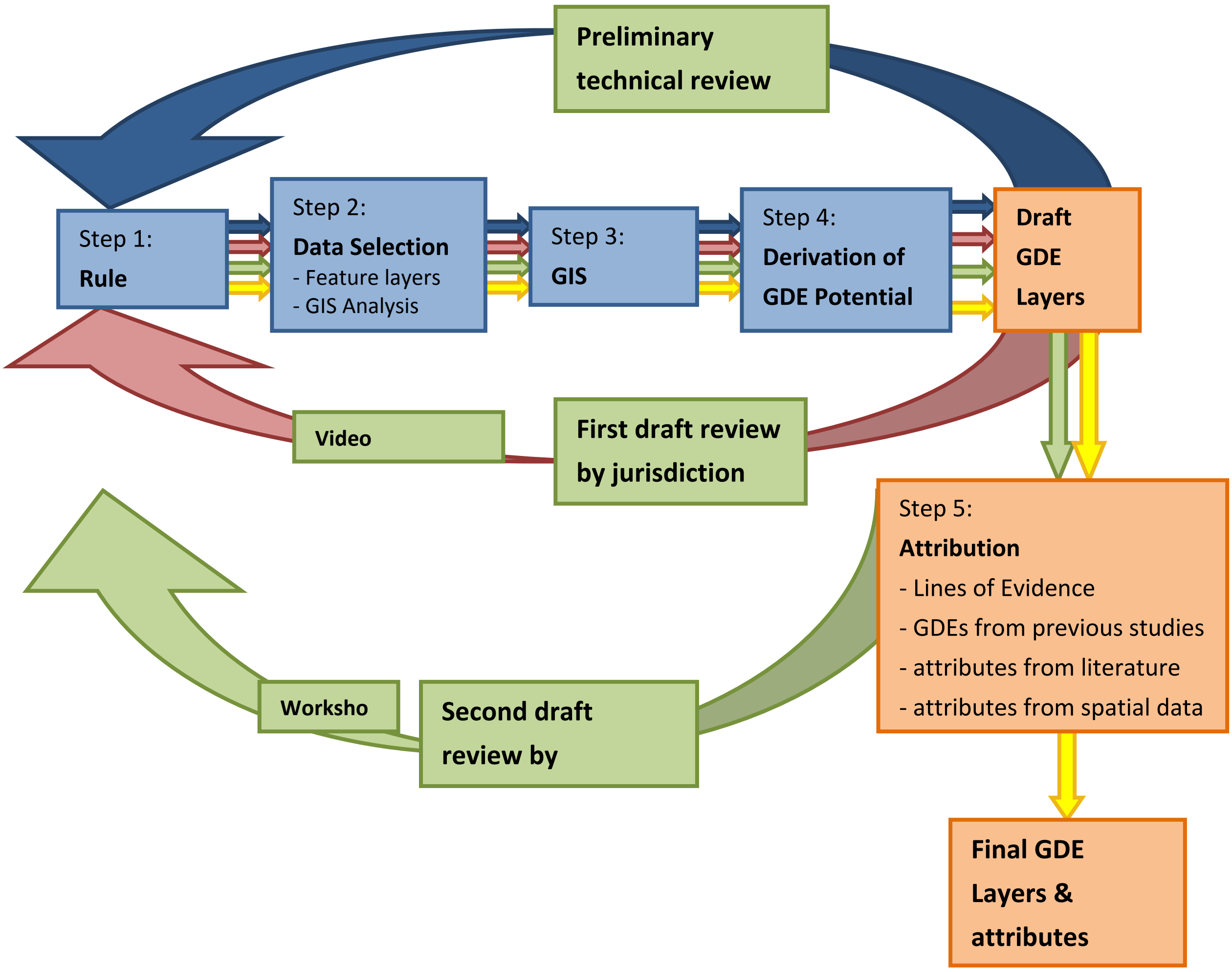
GDEs identified in previous studies were added to the GDE layers in the final stages of the methodology. The categories mapped in the Atlas for GDEs identified in previous studies are:

- Identified in previous study, fieldwork
- Identified in previous study, desktop

Information on GDEs identified in previous studies was taken from existing literature or spatial data and placed in the GDE Atlas. A GDE potential classification (i.e. high, moderate or low potential) could not be assigned to GDEs identified in previous studies. However, GDEs identified

by fieldwork may be considered a more reliable and accurate method of identification than those identified by desktop studies, since there are fewer assumptions and less extrapolation required to identify GDEs by fieldwork.

There are seven steps in the methodology used to map potential GDEs. These steps are outlined in Figure 7 and are described in greater detail in the following sections.



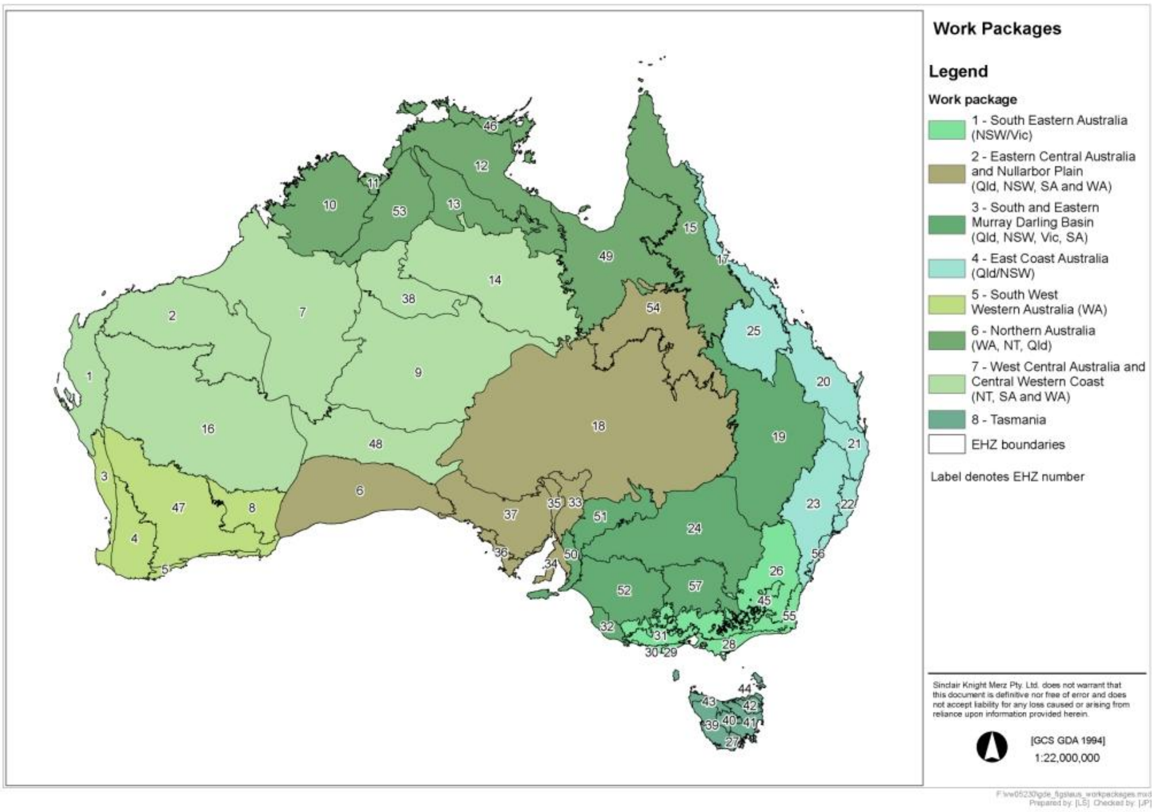
- **Figure 7 Task 5 process diagram. Orange boxes represent the Task 5 products, green boxes indicate reviews of interim products and blue boxes represent steps in the analysis.**

Figure 7 shows the iterations and review points during development of the GDE layers. The many iterations of the mapping and the wide consultation on the layers enabled a more detailed and

accurate conceptual understanding of the landscapes to be developed, and also enabled the identification of additional datasets for use in the GIS analysis.

To apply the methodology, eight separate GIS analysis regions (called work packages) were established. Each work package consisted of multiple EHZs, which were developed in Task 3 and defined areas where hydrogeological process and ecosystem function were likely to be similar. Figure 8 shows the work packages and EHZs. It was assumed that the interaction between groundwater and ecosystems is controlled by similar processes within each work package, and could therefore be modelled by the same broad analysis rules.

Where exceptions to the rules, or unique situations occurred within a work package, more detailed analysis could be undertaken by splitting up the work package along EHZ boundaries, bioregion boundaries, rainfall isohyets, or any other boundary that appropriately defined the extent of the exception. As such, work packages provided the initial areas within which GIS analysis was carried out, and where required, a more detailed approach was implemented by applying rules to a smaller EHZ area. Sections 4.3 to 4.7 describe the methodology used to identify and map potential GDEs. Sections 6 to 13 detail how this methodology was applied in each work package.



- **Figure 8 Work packages used in GIS analysis**

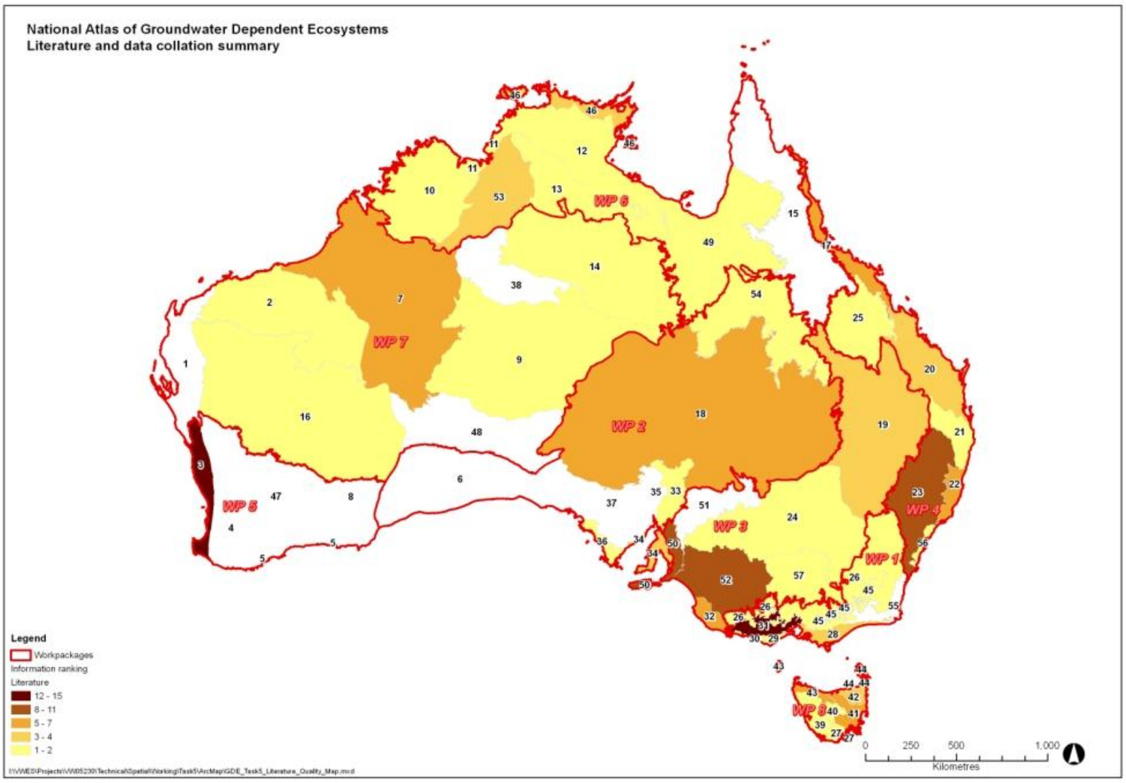
4.3. Step 1: Literature review and development of GIS Analysis rules

Approximately 200 reports and papers were reviewed in Task 2 of the GDE Atlas project. The purpose of this review was to gain an understanding of how groundwater and ecosystems interact in different landscapes across Australia, and what factors control this interaction. From this understanding, a set of rules describing the potential for groundwater/ecosystem interaction was developed for each work package.

Figure 9 shows the approximate number of reports reviewed in each EHZ. Although there were no reports available to review in 13 EHZs, every work package had reports reviewed. This allowed broad analysis rules to be developed for all landscapes in Australia.

Generally, there were a set of broad analysis rules that could be applied across all work packages. These were necessarily more generic, such as areas of shallow groundwater being more likely to support GDEs, or ecosystems adjacent to known springs being more likely to use groundwater. Where available, the literature was used to inform rules that were more specific to individual EHZs or work packages, such as vegetation types that are likely to use groundwater. Literature also sometimes enabled targeted rules to be applied to specific landscapes or ecosystems within a work package or EHZ. For example, rules that described the likely presence of cracking clay soils in the Lake Eyre Basin.

The conceptual understanding of the landscapes, and the GIS analysis rules developed in this step are the basis of the identification of GDEs, and fundamentally control the accuracy and completeness of the resulting GDE mapping. The following steps in the Task 5 process (sections 4.4 to 4.7) describe how these GIS analysis rules were implemented.



▪ **Figure 9 EHZs (numbered) with shading to indicate the number of reports reviewed for each EHZ. Reports could be reviewed for every work package, but there were 13 EHZ where no reports were available.**

4.4. Step 2: Data Selection

The ability to implement the rules developed in step 1 was dependent on the availability of relevant spatial data. Spatial data was provided by agencies from each jurisdiction and selected for use in development of the GDE layers in this step of the methodology.

Two types of spatial data were required:

- Feature layer datasets, and
- GIS analysis datasets

Feature layers were the datasets that contained the linework to delineate ecosystems. These datasets mapped all ecosystems, whether they were GDEs or not. Two types of feature layers were required:

1) Maps of ecosystems that could be identified as GDEs that rely on the surface expression of groundwater – effectively all surface water ecosystems such as rivers, wetlands and springs; and
2) Maps of ecosystems that could possibly be identified as GDEs that rely on the subsurface presence of groundwater – all vegetation polygons.

Since no new linework was created for the GDE Atlas, the quality of the feature layers controlled the completeness of the GDE Atlas mapping. Ecosystem polygons that were not mapped in the feature layers do not exist in the final GDE mapping. The absence of a feature layer in certain locations meant that GDE mapping could not be done for those areas. More detail on the gaps in feature layers (and consequent gaps in GDE mapping) for each work package is given in sections 6 to 13.

The datasets used as the feature layers were selected based on their spatial coverage (coverage of a very small area was unworkable for a national mapping project) and their attributes (preferred feature datasets had attributes that were also useful in the analysis). Where feature datasets overlapped, an 'authority layer' was selected and used in preference to the other layers that covered the same area. The authority layer was generally a more detailed dataset, with smaller polygons and more detailed attributes, although still with at least regional coverage. The two final GDE layers consist of a selection of polygons from the vegetation, wetland, river, and spring polygons within the feature layers.

GIS analysis datasets were also selected based on their coverage, and the usefulness of their attributes. These datasets were used to analyse each ecosystem polygon (from the feature layers) to assess the potential for each polygon to be interacting with groundwater. Effectively, the GIS analysis datasets were used to implement each GIS analysis rule.

The extent of the GIS analysis dataset limited the spatial extent where each rule could be applied. The absence of an appropriate GIS analysis dataset in certain locations meant the rule could not be implemented. Therefore, not all GIS analysis rules were applied across the whole work package. These data gaps were recognised and recorded for each work package in sections 6 to 13.

Abrupt changes or anomalies in the GDE mapping in certain areas may be related to variations in coverage and content of the GIS analysis datasets. For example, depth to watertable mapping was available for limited areas, and it strongly controlled the identification of GDEs. The mapped 'GDE potential' results therefore vary across the boundaries of this dataset. Similarly, attribution of vegetation types commonly varied between datasets, and this caused variations in GDE potential results across dataset boundaries.

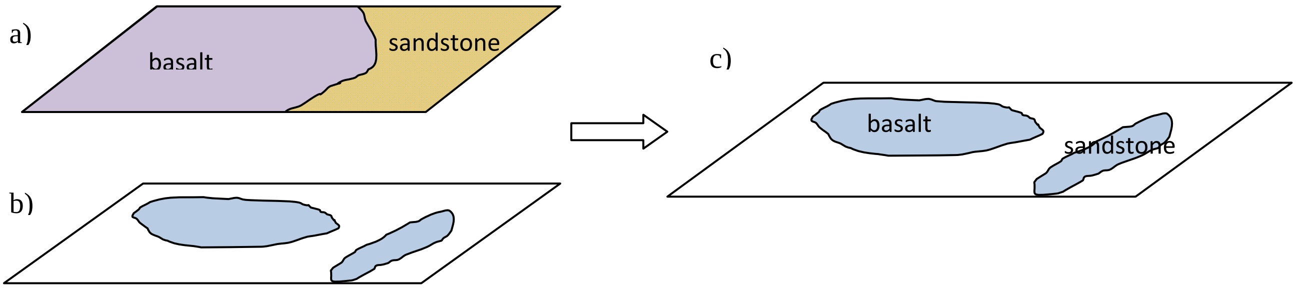
Once the feature layer datasets and the GIS analysis datasets needed for each analysis rule had been selected, the datasets were combined by GIS analysis as described in Step 3.

4.5. Step 3: GIS analysis

The purpose of the GIS analysis was to apply information from each GIS analysis dataset, to ecosystem polygons intersected within the feature layer. The GIS analysis task was undertaken using the ESRI geospatial product ArcGIS 9.3.

Before the GIS analysis occurred, all ecosystems mapped within the feature datasets were converted into polygons. Data mapped as lines (for example river mapping) and data mapped as points (such as springs mapping) were buffered by 12.5 m (resulting in a total width of 25 m). Buffering was necessary so that all features could be included in the same spatial layer in the final GDE Atlas, and so that all features in the final layers could be searched using a single query. The size of the buffer was selected so that the buffered ecosystem was a similar size to the pixels in the remote sensing layers (25m × 25m).

The GIS analysis process involved overlaying the feature layer datasets with the GIS analysis datasets, and tagging the intersected feature polygons with the attributes from the GIS analysis dataset. For example, if a GIS analysis rule stated that wetlands within a certain geology (say basalt) were more likely to be connected to the watertable than wetlands in other geology types, a GIS analysis dataset of geology was overlain on the feature layer for the area. The attribute within the GIS analysis dataset that described the geology was added to each ecosystem polygon intersected from the feature layer. Figure 10 represents this process. Attributes from every GIS analysis dataset were added to the intersected ecosystem polygons from the feature layers. The added information allowed ecosystem polygons to be compared in Step 4 to assess the relative potential that groundwater interaction was occurring, based on the geology underlying each wetland.



- **Figure 10 Attributes from the GIS analysis datasets (a) were added to the feature ecosystem they intersect within the feature layer datasets (b). The result is that the features (ecosystems) gain an attribute which describes the potential for groundwater interacting to be occurring (c), according to the GIS analysis rule.**

It was common for a feature ecosystem to intersect more than one attribute in a GIS analysis dataset. For example, a single ecosystem polygon may intersect several different types of geology, or different groundwater depths, or different landscapes. Rather than splitting each ecosystem polygon along the boundaries in the GIS analysis dataset, the majority value was assigned to each feature polygon. For example, if a river reach overlaid both sandstone and basalt, the river was not split so that each geology attribute could be applied to the intersected section of the river. Instead, the geology that intersected the majority of the river reach was applied to the whole river reach. So if 51% of a river reach was underlain by basalt, and the other 49% was underlain by sandstone, the attribute joined to the river polygon would be basalt. Figure 11 demonstrates the 'majority rules' approach. This approach avoided splitting polygons, which was necessary to constrain the volume of polygons, and therefore the size of the database.

The majority rules approach was used for most GIS analysis datasets, including:

- The ID layer
- Geology layers
- Depth to watertable layers
- Landscape elevation layers
- Aquifer layers
- Soil Water Holding Capacity (SWHC) mapping
- GDEs that rely on subsurface/surface presence of groundwater (when intersected with GDEs that rely on the surface/subsurface presence of groundwater, i.e. the other GDE mapping layer)

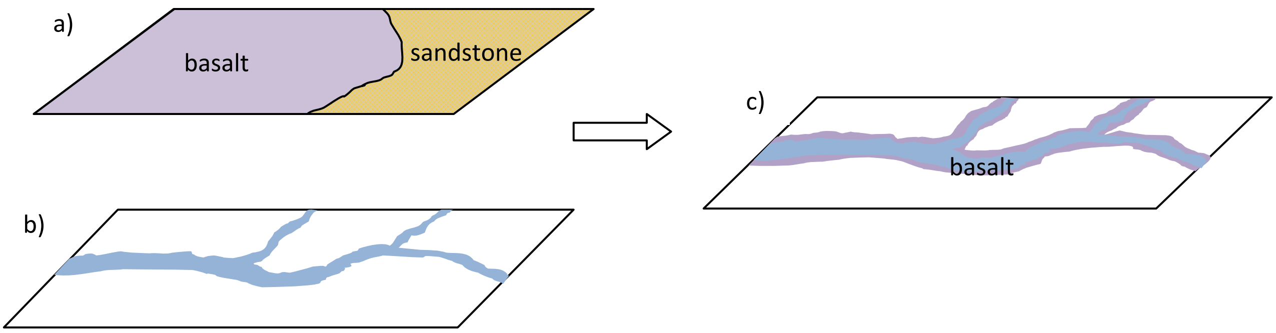


Figure 11 A 'majority rules' approach was used to apply attributes from the GIS analysis datasets (a) to the feature ecosystems (b and c).

The only GIS analysis datasets not assigned to the feature polygons by majority rules were GIS analysis datasets that mapped springs, and open water mapping (from Landsat and MODIS analysis). Springs and open water are small features, and so they would rarely occupy the majority

of an ecosystem polygon. Any intersect with a spring or open water was recorded for the ecosystem polygon.

Each GIS analysis rule (from Step 1) required attributes from the appropriate GIS analysis datasets to be joined to the feature polygons in the ways described above. As a result, several additional attributes were joined to every feature polygon. The number of attributes joined to each feature depended on the number of rules being analysed, and the number of analysis datasets available to implement the rules. The output of this step was a ‘permutation table’ for each feature layer. An example of a permutation table is shown in Figure 12.

Permutations tables list every possible combination of the attributes from the GIS analysis datasets. Figure 12 shows an example of a permutation table for a vegetation feature layer for GDEs that rely on the subsurface presence of groundwater (i.e. vegetation). Each row is an individual combination, or permutation of GIS analysis attributes. The rules sets for this example would be:

- Rule 1: Vegetation that demonstrates an ET that is higher than rainfall is more likely to be using groundwater. The GIS analysis dataset used to implement this rule is ‘IDE likelihood’.
- Rule 2: Vegetation that intersects with a spring is likely to be using groundwater. The GIS dataset used to implement this rule is ‘Springs’.
- Rule 3: Vegetation is more likely to be using groundwater in areas where the watertable is shallow. The GIS analysis dataset used to implement this rule is ‘DTWT’.
- Rule 4: Vegetation growing in areas where water stored in the unsaturated zone is limited, is more likely to be using groundwater. The GIS analysis dataset used to implement this rule is ‘SWHC’.
- Rule 5: Certain vegetation communities are more likely to access groundwater than others. The GIS analysis dataset used to implement this rule is ‘DOMSPECIES’ (note that this is also the feature dataset that other attributes are assigned to in this example).

The CASE number in the first column of Figure 12 is the number that labels the specific combination of GIS analysis attributes, or the specific permutation. The number of cases depends on the number of rules, the number of datasets available to implement the rules, and the number of GIS analysis attributes within each GIS analysis dataset. There were often hundreds of thousands of permutations. The FREQ column shows how many ecosystem polygons had that specific permutation.

Each CASE is a unique combination of GIS analysis attributes from the GIS analysis datasets

FREQ shows the number of polygons which have each particular CASE (or combination of attributes)

GIS analysis dataset for each rule

GIS analysis attributes

		Rule 1	Rule 2	Rule 3	Rule 4	Rule 5
CASE	FREQ	IDE likelihood	SPRING	DTWT	SWHC	DOMSPECIES
1	1	10		2	62	Acacia aneura var. (NC) woodland
2	1	8		2	87	Eucalyptus camaldulensis var. woodland
3	3	2	Y	20	256	Typha domingensis sedgeland
4	2	5		10	164	Casuarina pauper (mixed) woodland
5	1	3		2	49	Muehlenbeckia florulenta shrubland >1m
6	34	6		20	312	Callitris glaucophylla woodland
7	1	10	Y	30	237	Eucalyptus camaldulensis var. woodland
8	1	9		5	141	Sclerolaena tricuspis shrubland <1m

- **Figure 12 Permutations table, showing all GIS analysis datasets in the columns, and each possible permutation (or combination) of the analysis attributes in the rows. Each permutation is called a 'case' and can be applied to more than one polygon**

Large feature datasets with many GIS analysis datasets often resulted in very large permutation tables. Several feature datasets (such as the Victoria EVC layer, and the Queensland wetlands layer) were split into sections to allow the GIS analysis and permutations tables to be a more manageable size.

4.6. Step 4: Derivation of GDE potential

Several steps were involved in calculating a GDE potential for each ecosystem. These were:

- Normalisation of GIS analysis attributes
- Weighting of each GIS analysis rule

- Calculation of GDE potential
- Categorisation of GDE potential
- Validation
- Definition queries to remove ecosystems that cannot be GDEs
- Calculation of Lines of Evidence

Each of these steps is described in detail in this section.

4.6.1. Normalisation of GIS analysis attributes

The GIS analysis attributes in the permutations tables had to be normalised. The purpose of normalising GIS analysis attributes was to obtain a standard set of numbers (instead of words, or numbers with varying ranges) that could be used in a calculation to derive the GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3 to each GIS analysis attribute, which indicated the likelihood that the attribute indicated groundwater interaction. The normalised values were:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a ‘blank’) = attribute gives no information on groundwater interaction.

The normalised values were assigned to attributes in consultation with jurisdictions and subconsultatnts for the project.

Figure 13 shows the example of the permutation table used above, with normalised values included for each GIS analysis attribute. These normalised values were used in the calculation of GDE potential (described in section 4.6).

The ability to normalise GIS analysis attributes was fundamental in determining the potential for groundwater interaction. If the attributes could not be normalised, the GIS analysis rules could not be implemented, and no statement of the potential for groundwater interaction could be made. In these cases, the ecosystem polygons were not included in the mapped GDE layers, since there was no information to inform on groundwater use. These ecosystems remained in the Polygon IDE layers either because there was limited coverage of additional GIS analysis datasets; or because the attributes within the GIS analysis datasets could not be completely normalised.

If the majority of attributes in a GIS analysis dataset could not be normalised, the GDE potential was calculated using few datasets and was therefore less reliable than if several datasets had been normalised and used in the calculation. This is explained further in section 4.6.7, which discusses Lines of Evidence.

Normalisations were reviewed for consistency between the various vegetation feature datasets. The same vegetation type was often described differently in different vegetation feature datasets. For example, essentially the same vegetation ecosystem may straddle the boundary of two feature layers and be categorised as 'Rainforest' in one, and 'Dry rainforest' in the other. Relating these similar vegetation types across boundaries of feature datasets and assigning the same normalised value to both makes the resulting GDE potential maps more consistent across feature dataset boundaries. Where consistent normalisations could not be achieved the boundaries between different feature datasets may be evident in the final mapping of GDE potential.

GIS analysis attributes

GIS analysis dataset for each rule

Normalised values for each GIS analysis attribute

		Rule 1		Rule 2		Rule 3		Rule 4		Rule 5	
CASE	FREQ	IDE likelihood	IDE Norm	SPRINGs	SPRG Norm	DTWT	DTWT Norm	SWHC	SWHC Norm	DOMSPECIES	DOMSP Norm
1	1	10	3			2	3	62	3	Acacia aneura var. (NC) woodland	1
2	1	8	3			2	3	87	3	Eucalyptus camaldulensis var. woodland	3
3	3	2	0	Y	3	20	1	256	1	Typha domingensis sedgeland	3
4	2	5	0			10	2	164	1	Casuarina pauper (mixed) woodland	1
5	1	3	0			2	3	49	3	Muehlenbeckia florulenta shrubland >1m	3
6	34	6	0			20	1	312	1	Callitris glaucophylla woodland	2
7	1	10	3	Y	3	30	1	237	1	Eucalyptus camaldulensis var. woodland	3
8	1	9	3			5	3	141	3	Sclerolaena tricuspis shrubland <1m	3

Figure 13 Permutation table showing the normalised value (orange columns) for each GIS analysis attribute. The normalised values were used in the calculation to derive GDE potential.

4.6.2. Weighting GIS analysis rules

Some GIS analysis rules provide a better indication of the potential for groundwater interaction than others. For example, a shallow depth to groundwater more strongly suggests that overlying vegetation could be a GDE than does the landscape elevation. To account for this variation in the ability of each rule to indicate groundwater interaction, weightings were applied to each rule. This allowed the rules that were considered to be more effective at identifying groundwater interaction to have a greater influence on the final GDE potential result.

Weightings accounted for the varying efficacy of both GIS analysis rules (where one rule was a better indicator of groundwater interaction than another), and also, of GIS analysis datasets (where one analysis dataset may be more appropriate to the rule being analysed than another). An example of this is where a depth to groundwater contour layer could be used, or whether only point depth to groundwater data was available. The point data was considered less suitable for implementing the depth to groundwater rule and was therefore weighted lower.

The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not comparable *between* feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently for example, where one dataset was more suitable than another.

4.6.3. Calculation of GDE potential

The potential of an ecosystem being a GDE was calculated by combining the normalised values for each of the rules. The calculation used to combine the normalised datasets is shown in Equation 1. For the example permutation table in Figure 13 the equation used to calculate GDE potential is shown in Equation 2.

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

- **Equation 1 Calculation of GDE potential using the normalised values for each attribute**

$$\frac{(\text{IDE Norm} \times \text{weighting}) + (\text{SPRING Norm} \times \text{weighting}) + (\text{DTWT Norm} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

- **Equation 2 GDE potential calculation for the permutation table example in Figure 15**

The implications of this approach to calculating GDE potential were:

- The maximum result was a 3, which would indicate high potential for groundwater interaction.
- Where there was only a single GIS analysis dataset available for an ecosystem polygon, the confidence was entirely dictated by the normalised value of that dataset. This means that if the feature was assigned a 3 from normalisation of the only dataset which applied to it, then the overall GDE potential result was a 3. Therefore the weightings (described in section 4.6.2 below) were irrelevant where there was only one dataset available for a particular ecosystem polygon. Stated another way, if the only available dataset indicated a high likelihood for groundwater use, then that value was used as the GDE potential.

This GDE potential calculation was done in excel tables, by importing each permutation table, adding normalisations, and applying the calculation above. Within these tables, weightings were applied to each rule (as described in section 4.6.2 below) and results could be split into high/medium/low GDE potential categories as described in section 4.6.4.

4.6.4. Categorisation of GDE potential

The steps above resulted in a GDE potential for each ecosystem polygon as an integer between 0 and 3. To enable mapping of these results, GDE potentials were qualitatively described using the following categories:

- High potential for groundwater interaction
- Moderate potential for groundwater interaction
- Low potential for groundwater interaction

Defining the numerical range of each category required an understanding of the rules and in particular, which rules and outcomes were most indicative of groundwater interaction. Validation of the results using existing data (as described in section 4.6.5) was also important in determining the range of each GDE potential category.

Polygons that had a calculated GDE potential of 0 were not considered as GDEs (because there was no information that indicated potential for groundwater use) and were therefore shown in the IDE layer only, and not in the GDE layer. Every other ecosystem polygon was assigned either a high, moderate or low potential for groundwater interaction. This approach means that no ecosystem polygon was defined as having no potential for groundwater interaction to be occurring. Rather, a low potential indicates that groundwater use is unlikely, and a high potential indicates that groundwater use is likely.

After the GDE potential integers had been assigned into a high/moderate/low GDE potential category, the results were mapped to the ecosystem polygons in the feature layers and reviewed. Changes to weightings and normalisations often occurred at this stage of the review.

4.6.5. Validation of GDE potential results

Assigning normalised values, weightings, and GDE potential categories splitting results into high/moderate/low GDE potential categories called for an element of judgement, but was validated where possible using GDEs identified in previous studies (from the literature). Cross referencing the GDEs identified using the methodology in sections 4.3 to 4.6.4 with GDEs that were known to interact with groundwater provided a useful check for the derived GDE potential results. If the GIS analysis rules had modelled the groundwater/ecosystem interaction accurately, the GDEs identified in previous studies would have a derived result of ‘high potential for groundwater interaction’. GDE potential of ‘high’. Validation using GDEs identified in previous studies was used to determine:

- How the derived GDE potential results were split into high/medium/low GDE potential categories, and
- The relative weightings appropriate for each GIS analysis rule/dataset.

4.6.6. Definition Queries to exclude ecosystems that cannot be GDEs

Most of the feature layer datasets contained polygons that were not considered to be GDEs. For example in vegetation mapping there were often polygons attributed as ‘bare earth’, ‘rock’, ‘water’, ‘marine’ and other attributes that were not vegetation. These features were removed from the vegetation GDE Layers. Non-natural landscapes were also removed, such as ‘plantations’, or ‘irrigated land’. Likewise, in feature layers that map rivers, a blank water regime indicated a feature that is not a river, and a ‘connector’ is a spatial artefact, not an actual feature. In wetland mapping, features attributed as ‘reservoirs’ or ‘dams’ were removed since they are man-made. ‘Estuarine’ and ‘marine’ features were also removed since these were not part of the scope.

A spatial definition query was applied to the feature layers in order to exclude these features from the GDE mapping. Definition queries for each feature layer are listed in sections 6 to 13.

4.6.7. Lines of Evidence used to derive each GDE potential result

'Lines of evidence' was adopted as a pragmatic way to indicate the reliability of the GDE potential category derived for each polygon. It indicates the amount of evidence (number of GIS analysis rules that could be applied) used in determining the GDE potential for each ecosystem polygon.

For example, consider a case where two polygons were identified as having a high potential to be GDEs. For one polygon, this result was based on depth to watertable data, vegetation type and geology. For the other this result was based only on its low-lying position in the landscape. The 'High potential for groundwater interaction' result for the first polygon has three lines of evidence, whereas there is only one for the second. Therefore, although the GDE potential result is the same for both polygons, the first can be considered more reliable than the second because it is based on more data.

The Lines of Evidence in the GDE Atlas is displayed as:

1) Polygons where the results was derived using only 1 rule
2) Polygons where the result was derived using 2 rules
3) Polygons where the result was derived using a combination of 3 rules
4) Polygons where the result was derived using a combination of 4 rules
5) Polygons where the result was derived using a combination of 5 rules
6) Polygons where the result was derived using a combination of 6 rules
7) Polygons where the result was derived using a combination of 7 rules

Even though there were frequently 5 or 6 rules for a work package, there was rarely the data available to apply those 5 or 6 rules. This was due to: i) limited coverage of analysis datasets, ii) incomplete normalisation of analysis datasets, iii) attributes within the analysis datasets that give no indication of potential groundwater use (and are therefore normalised as '0').

Several assumptions are invoked by using Lines of Evidence as an indicator of reliability:

- The more evidence (data) available, the more likely that the GDE potential of an ecosystem has been correctly identified.
- Each rule is of equal reliability (no rule makes the result more reliable than the other rules).
- Differences in scale and accuracy of GIS analysis datasets which impacts how effective intersects between features does not impact the reliability of results.

While these assumptions are not always true, a more complex measure of reliability would not enhance the usability of the Atlas, since the Atlas is a management tool designed for use in the early stages of the planning process to indicate the location of potential GDEs. If a situation that

required the identification of GDEs had a high level of risk, further verification of the information in the Atlas is always recommended. Conversely, if a situation in which the Atlas was used had a low level of risk, then the low measures of reliability may be acceptable.

4.7. Step 5: Attribution of potential GDE polygons

Attribution of the potential GDE polygons involved both assigning the attributes of GDEs identified in previous studies (from the literature review in Task 2) and transferring attributes from existing datasets into the GDE Atlas attribute table (developed in Task 1, Appendix A). These processes are described in the following sections.

4.7.1. Assigning attributes for GDEs identified in previous studies (from literature)

GDEs identified in previous studies were collated in the Task 2 literature review, and were assigned to specific ecosystem polygons within the potential GDE layers. The GDEs identified in previous studies overwrites the ‘GDE potential’ category derived for the polygons in the GIS analysis. Another layer in the GDE Atlas shows Subterranean GDEs, but this consists solely of GDEs identified in previous studies, meaning that there was no GIS analysis to identify additional Subterranean GDEs.

During the literature review, points were entered on an interim spatial interface at the approximate location of the ecosystem discussed in the literature. When the potential GDE mapping layers were developed, these points were reviewed and matched to a polygon within the GDE mapping layers. The matched polygon was then assigned the attributes recorded during the literature review in Task 2. Most importantly, this process assigned the GDE Potential attribute to the matched polygon. Depending on whether the literature presented the results of fieldwork or desktop extrapolation, the ‘Potential of ecosystem to be a GDE’ attribute field of the matched polygon was assigned either:

- GDE identified in previous study: fieldwork, or
- GDE identified in previous study: desktop

The other attributes assigned during this process were those recorded from the literature during Task 2. These included details for the following attributes (refer to Appendix A for the complete attribute table):

- Ecosystem type
- Ecosystem name
- Ecosystem salinity
- Water regime

- GDE class
- Spatial connectivity between GDE and groundwater
- Temporal nature of groundwater connection/use
- Details of the source aquifer
- Relative requirement of groundwater vs. other source
- Critical groundwater service
- Example indicative species
- Environmental groundwater requirement
- Additional information

Approximately 700 GDEs identified in previous studies were recorded during the literature review. These included rivers, springs, wetlands and vegetation for which a groundwater connection had been established in previous studies.

4.7.2. Transferring attributes from existing datasets to the derived GDE polygons

Many existing spatial datasets also contained information which could be used in the GDE Atlas attribute table. These datasets included feature datasets and GIS analysis datasets that were used in the identification of the GDEs, and also datasets that had not been used in any other part of the analysis. The datasets were used to:

- Identify GDEs that had been mapped in a spatial layer in previous studies. That is, where existing datasets mapped GDEs they were used to populate the 'Potential of ecosystem to be a GDE' attribute field of the matched polygon as either:
  - GDE identified in previous study: fieldwork, or
  - GDE identified in previous study: desktop
- Populate other attributes in the GDE Atlas attribute table, such as:
  - Attributes which were derived from national datasets (Tier 1 attributes)
  - Attributes which were derived from remote sensing (Tier 2 attributes)
  - Attributes which were derived from jurisdiction datasets (Tier 3 attributes).

This information was incorporated into the GDE Atlas by transferring the relevant attributes from existing datasets into the GDE Atlas attribute table (Appendix A).

All attributes were assigned using the ‘majority rules’ approach described in section 4.5, where the attribute assigned was the one which applied to the majority of the polygon. This avoided splitting potential GDE polygons where they straddled the boundaries within other datasets.

Tier 1 and 2 attributes could be assigned simply by intersecting the derived GDE polygons with the dataset containing the required attribute. The process for assigning Tier 3 attributes, and transferring GDEs mapped in other studies into the Atlas was more manual, since some interpretation of the attributes was required. The feature dataset was spatially intersected with each dataset that contained useable Tier 3 attributes, or identified previously mapped GDEs. Where an intersect occurred between these datasets and the ecosystems in the feature dataset, the relevant attribute was transferred into the Atlas attribute table.

Interpretation was required to accurately transfer many of the Tier 3 attributes, since the intent of the attribute may have been different in the jurisdiction dataset, compared to in the GDE Atlas attribute table. For example, if a jurisdiction dataset had the categories ‘perennial’ and ‘non-perennial’ for a wetland, this had to be reliably translated into the Atlas attribute field ‘Water Regime’ which had the options ‘Permanent; Seasonal; Intermittent; Ephemeral’. Where there was any doubt about whether the attributes in the jurisdiction data had the same meaning as the attributes in the GDE Atlas attribute table, they were not transferred into the Atlas. For this reason, no ‘source aquifer’ information was transferred from jurisdiction spatial datasets into the Atlas, as this required the assumption that the watertable aquifer was also the source aquifer. In reality, this assumption is likely to be correct in most areas, but since there was potential for inaccuracy, the information was not transferred into the Atlas.

Some datasets which mapped GDEs identified in previous studies could be entered into the Atlas spatial data model (SDM) in their entirety (if all the features in the dataset were GDEs). In these cases, the GDE Potential was assigned manually as the dataset was being loaded into the SDM.

5. Limitations of the GDE mapping methodology

As this is a National mapping project, it was necessary to trade mapping detail for broad spatial coverage in many places. This compromise raised several impacts that users should be aware of when viewing the GDE maps. These are discussed in this section.

5.1. GDEs that may not be identified in the analysis

The broad scale nature of a national mapping exercise meant that certain ecosystems were not identified as GDEs even if they use groundwater. Some of these exceptions are:

- Ecosystems that use groundwater seasonally or ephemerally, and then do not continue to grow when groundwater becomes unavailable. An example of this was vegetation growing on sheetsands in floodplains near Darwin, which used groundwater in the late wet season, but did not continue growing throughout the dry season (D. Liddle, NRETAS, pers. comm.). Since the remote sensing data was used to filter out ecosystems that did not exhibit constant growth, these ecosystems were not analysed for GDE potential.
- Ecosystems that are too small to influence a whole remote sensing pixel (25m × 25m) have a low remote sensing likelihood and were excluded on this basis.
- Ecosystems that were not mapped in the feature layers used for the analysis. Since the feature layers provide the basic linework which delineates ecosystems in the Atlas, ecosystems had to be mapped in the feature layers if they were to appear in the GDE Atlas.

The timeframe of data used to create the GDE Atlas also determined which GDEs were identified and which were not identified. Variations in climate may cause ecosystems to use groundwater at irregular or rare intervals. If groundwater interaction was not occurring within the time period of the data capture used then the ecosystem may not have been classified as a GDE. The time period of data capture was 2000 – 2010 for the remote sensing data, and since this as used as a filter, ecosystems using groundwater outside of this period were unlikely to be identified as GDEs in the Atlas.

The only way the exceptions discussed in this section could be identified as GDEs and included in the GDE maps was where other spatial datasets had classified them as GDEs. In this case, they were included as 'GDEs derived in previous studies' (for example the hanging swamps in the Blue Mountains).

The Atlas provides a snapshot and presents the potential groundwater interaction for the time period of the data used (which includes both remote sensing and jurisdiction datasets). It does not provide information on the future or past (i.e. before the time period of data used) potential for groundwater use.

5.2. Visible borders within the GDE mapping

Approximately 150 feature datasets were used to delineate ecosystems in the GDE Atlas. The borders between these datasets generally did not align seamlessly, which could result in the borders being visible in the final GDE mapping. There are two primary reasons that borders between feature datasets (often aligning with jurisdiction borders) may be visible in the Atlas. Firstly, in vegetation mapping, vegetation type may be mapped or attributed differently between feature datasets. If different normalised values were assigned to the different vegetation types between the feature datasets, this impacted the final GDE potential result.

Secondly, the use of a majority rules approach to assign attributes to ecosystem polygons may have resulted in different GDE potential results along borders between feature datasets. The attribute assigned to each ecosystem polygon depends on the size of the ecosystem polygon, and the accuracy of the datasets intersected. If adjacent polygons from different feature datasets were significantly different sizes, the attributes they were assigned may also be significantly different, resulting in different GDE potential values across the edges of the feature datasets. Similarly, if the accuracy of the feature datasets, or the GIS analysis datasets was poor, the polygons may not have intersected at all. The ecosystem polygons would therefore be assigned different attributes which may have impacted the final GDE potential result. The majority rules approach could also result in different GDE potential results where features such as roads, state borders, or map sheets split what was essentially the same polygon.

Thirdly, the linework (i.e. the ecosystem polygons) may not match up to linework in adjacent feature datasets. This may be due to the mapping scale of feature datasets being different, where one dataset maps small features at a large scale, while another maps only the large features.

Borders can also be visible within a feature dataset, at the limits of a GIS analysis dataset. The impacts of this are particularly evident when the GIS analysis dataset was weighted heavily, such that it controlled the GDE potential result. An example of this was where depth to watertable mapping existed for part of a feature layer, such as the NSW depth to watertable map. Because it had a strong influence on the result, GDE potential could be different where the data existed compared to where it did not exist. As such, visible borders in GDE mapping can also be due to the spatial extent of the GIS analysis datasets used.

5.3. Limited coverage of feature layers

Potential GDEs could not be mapped for areas not covered by feature datasets, since there was no linework to assign attributes to. Lack of coverage was mostly a problem for vegetation feature layers and manifested as gaps in the final GDE mapping.

The National Vegetation Information System (NVIS) is nation-wide mapping of vegetation for Australia; however, this was not used to fill gaps in vegetation feature layers because it contains very large polygons. The larger the polygon in the feature dataset, the less it represents the spatial variation of the underlying landscape, or of the datasets used in the analysis. Large polygons do not allow for variation (for example in watertable depth, vegetation type or ID likelihood), since the majority rules approach assigns a single attribute to the whole polygon. In many areas, the polygons contained in the NVIS dataset were so large that the degree of variation excluded would have made the resulting GDE mapping very broad. Such broad mapping would have limited use for environmental management. A possible way to overcome this would have been to split the large polygons into smaller polygons which would have maintained more detail in the attributes. However, in order to constrain the size of the database this approach was not adopted.

5.4. Incomplete feature datasets

If an ecosystem was not mapped in the feature datasets, it was not identified as a GDE in the final GDE mapping since there was no linework to delineate the ecosystem. This issue arose where feature datasets only mapped a certain type of ecosystem, such as high value ecosystems, or important wetlands. Such feature layers were only used if a more complete dataset was not available.

The presence of the remote sensing data underpinning the GDE mapping partially addresses the issue of incomplete feature layers, as it identifies areas where water in addition to rainfall is being used. The underlying remote sensing data can be viewed in the Atlas as an indication of the presence of an (unmapped) ecosystem.

5.5. Large polygons in feature layers

Although the NVIS vegetation mapping was not used in the GDE mapping, large polygons were still an issue in many areas of Australia, particularly in the desert. Large polygons are less representative of the underlying landscape and analysis datasets, for several reasons:

- Greater variation in landscape is likely to occur within a large mapped polygon, but the majority rules approach assigned a single attribute to each ecosystem polygon, which effectively disregarded this variation. Large polygons reduced the detail in many reliable (and highly variable) datasets, such as the ID layer, depth to watertable mapping, and soil water holding capacity mapping. Less variation exists within the spatial extent of a smaller polygon, and the attribute assigned was therefore more representative of the landscape and analysis data.
- The greater spatial extent of large polygons meant they were more likely to intersect small features such as springs or areas of open water. However, small features like springs or open water generally have small radius of influence (i.e. they may only support riparian vegetation

within a few metres) and therefore do not influence the entire extent of a large polygon. Springs or the presence of open water was often weighted low in feature datasets containing large polygons for this reason, however the issue persists in feature datasets containing a mixture of large and small polygons. When smaller polygons coincided with a spring or open water, they were more likely to be reliant on the water from the spring or water body and were therefore a more accurate representation of the landscape.

- The use of feature datasets resulted in mapping of ecosystems that are potentially using groundwater. In reality, only part of these ecosystems may be reliant on groundwater, such as one part of a wetland system, or the vegetation in lower-lying areas of a landscape. Since the GDE potential result is assigned to the entire polygon, it appears as though the whole polygon is a GDE even though this may not be the case. A common example of this is wetlands, which are often mapped to their largest spatial extent, but in reality, only a small part of the mapped wetland is generally inundated.

5.6. Generalisation of detailed analysis attributes

Normalisation of detailed attributes into three categories (1, 2 or 3) representing likelihood of groundwater interaction, removed some detail from the attribution. This was necessary since a national mapping project must prioritise coverage over detail.

The attributes selected for normalisation were often generalised attributes, which described broad vegetation groups, rather than more specific vegetation communities. For example, the vegetation attribute normalised in the Queensland Regional Ecosystem mapping was the DBVG2M attribute, which describes 35 categories of broad vegetation group for all of Queensland. These groups are broad, and represent a composite of species. Only parts of each broad vegetation group may actually be reliant on groundwater.

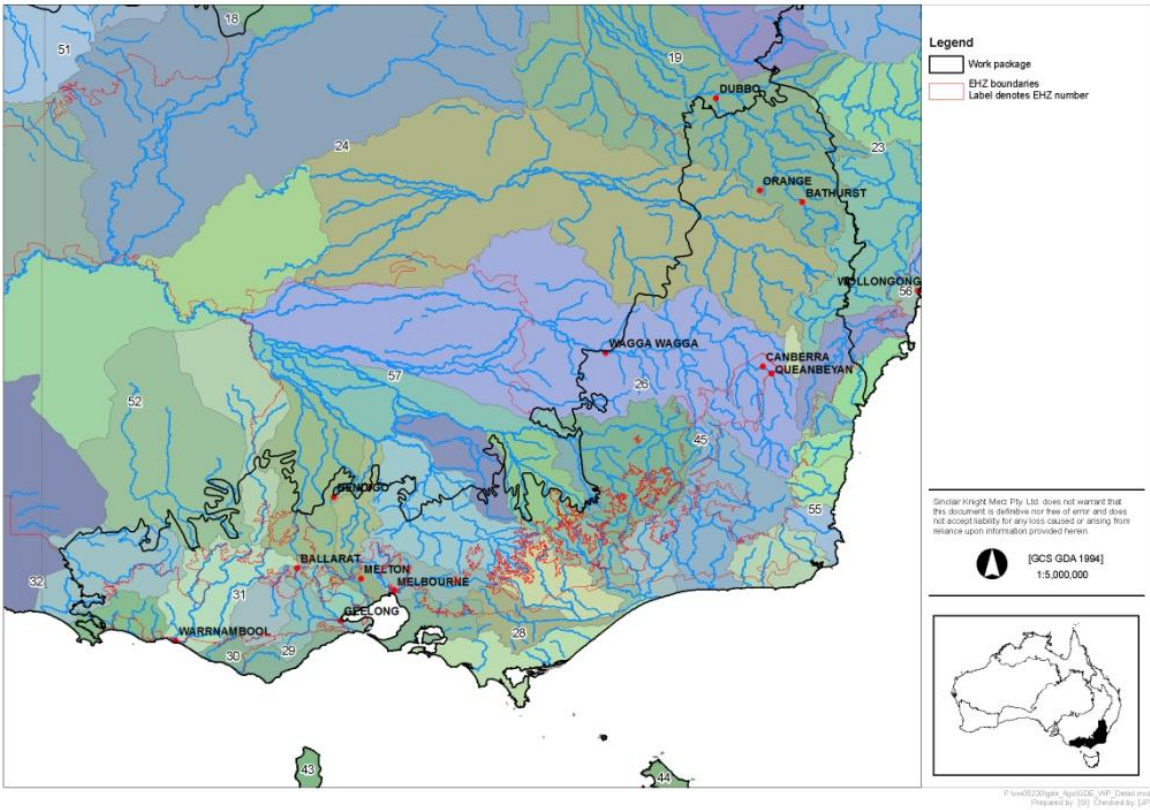
It is useful to remember that the GDE mapping displays ecosystem polygons within which groundwater interaction may be occurring. It does not suggest that the entire ecosystem polygon is reliant on groundwater.

5.7. Use of existing information that identifies GDEs

Previous studies focussed on smaller areas than the Atlas, and it is likely that they incorporated more detailed data and concepts than was possible in the Atlas. It was therefore assumed that any GDE identified in a previous study (mapped as either ‘GDE identified in previous study: fieldwork’ or ‘GDE identified in previous study: desktop’) was a more reliable identification of groundwater interaction than the potential GDEs (high, moderate and low) derived through GIS analysis for the GDE Atlas. No verification of the previous studies was undertaken however.

6. Application of Methodology in south eastern Australia (WP1)

The WP1 area is shown in Figure 14 and incorporates 7 EHZs. The area is generally mountainous with high rainfall. GDE mapping was completed for the whole work package as described in this section.



- **Figure 14 Work package 1 area showing river basins and EHZs**

6.1. Identification of Ecosystems that rely on the SUBSURFACE presence of groundwater

6.1.1. Literature review and GIS Analysis Rules

The GIS analysis rules and supporting information reviewed in the literature are outlined in this section. In general, the concepts and rules outlined here were applied to vegetation ecosystems across the whole work package. These rules were applied only to vegetation ecosystems that were found to be IDEs in Task 4. Only the vegetation ecosystems that had an ID likelihood of greater than 5 were considered to be using a source of water in addition to rainfall, and hence, only these ecosystems could be using groundwater.

Rule 1: Shallow watertables. Vegetation in landscapes with shallow watertables (<5 m) will use groundwater when required. Therefore vegetation GDEs are more likely to exist where water tables are shallow.

Benyon and Doody (2004) summarised results from a series of plantation research sites in the higher rainfall zones (>600 mm) of the Green triangle in south eastern Australia, in the western edge of WP1. The plantations exist within sandy subsoils with access to shallow, fresh, unconfined, limestone aquifers. The results indicated that where shallow watertables (<5 m) existed, plantations were able to use groundwater such that 60% of their natural water use came from groundwater during dry periods. The groundwater quality and subsurface environment provides very few limitations to deep penetration by plantation root systems. Despite this, the study suggested that in high rainfall areas (>600 mm) within the limestone terrain, groundwater use, and assumingly rooting depth, did not occur to a depth of greater than 6 metres. This suggests that while the subsoil conditions suit deep penetrating roots, the climate supplied sufficient rainfall that the trees did not need to search deeper into the regolith. Therefore, in many cases, high rainfall zones (>600 mm) may supply sufficient subsoil moisture that continued groundwater use is not required.

Groundwater use by riparian vegetation was documented in a range of studies across south eastern Australia (e.g. Horner et al., 2009; Mensforth et al., 1994; Thorburn and Walker, 1993). Within these studies it is evident that the shallower the watertable (the lesser the depth of unsaturated soil) the more groundwater is used to meet vegetation water requirements.

Mensforth et al. (1994) established that *Eucalyptus camaldulensis* (River Red Gum) across the Chowilla floodplain used groundwater during summer months, and both surface and groundwater during winter months or when fresher water sources were available. Groundwater depths at four sites investigated along Punkah Creek were all shallow (less than three metres) and had salinities ranging from 10 to 50 dS/m.

Rule 2: Vegetation type. Specific vegetation types have been shown to use groundwater and can be used to indicate where groundwater use may be occurring

The River Red Gums studied in Mensforth et al. (1994) were found to be using groundwater with salinity of up to 40 dS/m. While it was observed that high groundwater salinity may be limiting the growth of trees, Mensforth et al. (1994) suggested that the use of saline groundwater was a longer term survival mechanism for periods when no streamflow was available for prolonged periods. The rooting distribution of river red gums is a physiological adaptation that enables trees to access groundwater in the absence of a fresher water source. Such physiological adaptations indicate that certain vegetation species are more likely to use groundwater than others, and that vegetation type can therefore be used as an indicator of potential groundwater use.

Within the alpine regions of WP1, communities of Alpine sphagnum bogs and associated fens exist. Lawrence (2009) concluded that permanent waterlogging and very sluggish groundwater and surface water flow are essential for the formation and persistence of these communities. Lawrence (2009) reported that the following four landscape settings were indicative of groundwater connection:

8) Hillside peatlands - connected to groundwater through springs at the head of streams
9) Valley floors - along defined drainage lines where groundwater discharge can occur
10) Tributaries
11) Plateau and ridge locations

Landscape settings 1, 2 and 3 were all considered well connected to the groundwater system, while plateau and ridge tops were less likely to be connected. Alpine sphagnum bogs and associated fens were mapped in the GDE Atlas as 'GDEs identified in previous study, by fieldwork'.

Across the basalt plains of Victoria vegetation associated with groundwater fed saline wetlands were also found to be groundwater dependent (Dahlhaus, 2010). The saline vegetation communities were identified through field verification of species type, and hydrogeological and historical information that detailed the permanence of groundwater discharge into associated wetlands.

Rule 3: High dry period ET. Vegetation that is using groundwater can be identified by water use and growth patterns during summer months and has a higher annual ET than rainfall.

Plant water use studies (e.g. Morris et al., 1998; Prathapar and Myer, 1992) have shown that plants use any available water source, such that ET is greater where water sources in addition to rainfall and water stored in the unsaturated zone exist (e.g. irrigation or groundwater). Therefore, riparian vegetation on unregulated streams in areas of shallow watertables (non-irrigated) that maintain high ET during dry periods will most likely be using groundwater.

Eberbach (2006) measured the water use patterns of two dominant Eucalyptus species (*E. rossi* and *E. albens*) in the Great Dividing Range of NSW. The ridge top species (*E. Rossi*) and the valley floor species (*E. Albens*) were both shown to be accessing water stores (i.e. water other than rainfall) through extended dry periods. While groundwater use was not specifically measured in the study, within valley floors, in regions of shallow water tables, groundwater use will be likely.

Rule 4: Persistent water bodies. Vegetation communities that exist adjacent to persistent water bodies are likely to be accessing groundwater.

The majority of information describing GDEs that rely on the subsurface presence of groundwater relates to vegetation that is associated with permanent water bodies. Alpine fens and saline vegetation across the basalt plains were both associated with wetlands that are predominantly inundated. Riparian vegetation occurs along major rivers and adjacent floodplains where

watertables were shallow, and was often identified as being groundwater dependent. Therefore, it is reasonable to assume that vegetation associated with persistent water bodies has a high likelihood of being groundwater dependent.

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 1. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 1 GIS analysis rules to identify GDEs that rely on the subsurface presence of groundwater in WP1**

Rule	
1	Shallow water tables. Vegetation in landscapes with shallow watertables (<5 m) will use groundwater when required. Therefore vegetation GDEs are more likely to exist where watertables are shallow.
2	Vegetation type. Specific vegetation types have been shown to use groundwater and can be used to indicate where groundwater use may be occurring.
3	High dry period ET. Vegetation that is using groundwater can be identified by water use and growth patterns during summer months and has a higher annual ET than rainfall.
4	Persistent water bodies. Vegetation communities that exist adjacent to persistent water bodies are likely to be accessing groundwater.

6.1.2. Selection of datasets for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area. However there was complete coverage of vegetation feature layers in WP1, so there were no gaps in the GDE mapping.

Table 2 shows the feature layers selected to map GDEs that potentially rely on the subsurface presence of groundwater for WP1. These layers contain all the vegetation features that were analysed to establish whether a groundwater connection exists. The feature layers are either the

datasets that the rules in section 6.1.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 2 Feature layer datasets for analysis of GDEs that rely on the subsurface presence of groundwater (vegetation) in WP1**

State	Ecosystem	Dataset Name	Source or Custodian
NSW	Vegetation	er_scivi	NSW Office of Water
	Vegetation	m305_9171	NSW Office of Water
	Vegetation	south_cra.csv	NSW Office of Water
	Vegetation	Murrumbidgee	NSW Office of Water
	Vegetation	Central West Lachlan	NSW Office of Water
VIC	Vegetation	NV2005_EVCBCS	DSE
	Vegetation	Alpine Bog and wetlands	DSE

6.1.3. Selection of GIS analysis datasets for implementation of rules

Table 3 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the subsurface presence of groundwater in WP1. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 3 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the subsurface presence of groundwater, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

- **Table 3 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the subsurface presence of groundwater**

#	Rule	Data needed for analysis	Dataset name	Coverage of dataset/ rule	Implementation of rule (normalised value)
1	Depth to water table	Depth to water table maps	Vic_dtwt	Vic	Groundwater use was considered likely where watertable depth is <10m (3), possible for watertables between 10 & 20m (2), and unlikely for watertables >20m (1).
			FLAG	NSW	
2	Vegetation type is an indicator of groundwater use	Detailed vegetation mapping reflective of water use	EVC_BCS	Vic	Attributes describing vegetation types were normalised as either likely to use groundwater (3); possibly use groundwater (2), unlikely to use groundwater (1), or not sure (0). Normalisation was done using information in literature and by reviewers and jurisdictions.
			er_scivi	NSW	
			m305_9171	NSW	
			south_cra.csv	NSW	
			Murrumbidgee	NSW	
			Central West Lachlan	NSW	
3	High dry period ET	Mapping of dry period ET	IDE layer	All WP1	The likelihood from the ID layer was assigned to each vegetation polygon by majority value. That is, the likelihood value of the greatest number of pixels that intersect with the polygon, became the likelihood of the whole polygon. Likelihood values of 6, 7 & 8 gave no indication of groundwater use (0); Likelihood values of 9 & 10 suggested groundwater use was more likely (3).
4	Vegetation adjacent persistent water bodies	Mapping of permanent water	Landsat and MODIS open water	All WP1	Remote sensing of open water was used as an indicator of persistent water. Where open water intersected a vegetation polygon, the polygon was considered more likely to use groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation interacts with groundwater or not (0) (i.e. just because it did not intersect with open water doesn't mean the vegetation does not interact with groundwater.

6.1.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 3) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a

spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater interaction:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a ‘blank’) = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 3.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

6.1.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was 1, 2, or 3)}}$$

6.1.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 4 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 4 are only comparable for each feature dataset, and so may only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Landscapes with deep watertables were generally assigned a low potential for groundwater interaction.
- Vegetation that was considered unlikely to be using groundwater was generally assigned a low potential for groundwater interaction.
- Vegetation that was considered likely to be using groundwater was generally assigned a high potential for groundwater interaction.
- Vegetation in landscapes that were described in the literature as interacting with groundwater was always assigned a high potential for groundwater interaction.

- **Table 4 Weighting for each GIS Analysis rule/dataset for GDEs that rely on subsurface presence of groundwater in WP1**

Feature Layer Dataset	Rule 1		Rule 2	Rule 3	Rule 4
	Shallow watertable	Landscape elevation #	Vegetation type	High ET in dry periods	Presence of persistent water
EVC_bcs (Vic)	10	NA	5	8	3
South_cra	NA	2	3	8	3
Er_scivi	NA	2	3	8	3
M305_9171	NA	2	3	8	3
Central West Lachlan	10	NA	4	8	NA
Murrumbidgee	10	NA	4	8	NA

Landscape elevation was used as an indicator of depth to groundwater where depth to watertable maps were not available.

6.1.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This included non-natural landscapes such as settlements, pasture, and plantations, as well as natural landscapes that do not use groundwater, such as grasslands and bare earth.

All vegetation polygons that had an ID likelihood of 5 and less were removed at this stage, as these ecosystems were not likely to be accessing a source of water in addition to rainfall. The additional definition queries applied to each dataset to exclude ecosystems that could not be subsurface GDEs are listed below.

For the **EVC_bcs (Vic)** feature layer dataset a definition query was applied to the field ‘X_EVCNAME’ to exclude polygons attributed as:

- Grassland
- Bare Rock/Ground
- No EVC assigned - need editing
- Rocky Shore
- Sandy Beach
- Water Body – Fresh
- Water Body - man-made

For the **south_cra (NSW)** feature layer dataset a definition query was applied to the field ‘FE_NAME’ to exclude polygons attributed as:

- Mudflats/Saltmarshes
- Open Water
- Rock
- Sand Dune
- Wetlands

For the **er_scivi (NSW)** feature layer dataset a definition query was applied to the field ‘FIRST_MAP’ to exclude polygons attributed as:

- Coastal Freshwater Lagoon
- Seagrass Meadow (Halophila)
- Seagrass Meadow (Posidonia)
- Seagrass Meadow (Ruppia)

- Seagrass Meadow (Zostera)

For the Murrumbidgee **(NSW)** feature layer dataset a definition query was applied to the field ‘**LABEL_092’** to exclude polygons attributed as:

- None
- Grass
- grassland

For the Central West Lachlan **(NSW)** feature layer dataset a definition query was applied to the field ‘**field BVT_LAB’** to exclude polygons attributed as

- “
- Water
- Wetland
- Rocks
- town

6.2. Identification of GDEs that rely on the SURFACE expression of groundwater

6.2.1. Literature review and GIS Analysis Rules

Considerable information regarding groundwater connection with wetlands exists in WP1, and this enabled a sound conceptual understanding to be developed. This understanding was largely supported by appropriate mapping products.

SKM (2011) summarised the current understanding of groundwater connection across the Victorian extent of WP1 and identified the dominant water source for wetlands. This study developed 5 class systems to assign the dominant water source as shown in Table 5. The assignment of dominant water source was based primarily upon:

- Previous water source studies
- Landscape location
- Wetland type

A spatial layer mapped the wetlands and their dominant water source, and this was a key piece of data used in the analysis for the GDE Atlas.

Table 5 Dominant water source for Victoria wetlands (after SKM, 2011)

River fed	Wetlands located on or immediately adjacent to rivers and channels. Included all wetlands located on alluvium or floodplain geomorphic units (GMUs) (except alpine wetlands). In some areas this may have overestimated the number of river fed wetlands where alluvium or floodplain GMUs were representative of paleo-systems, not contemporary floodplain systems.
Groundwater fed	Wetlands previously indentified on the State GDE wetlands layer as either permanent, semi-permanent saline or permanent freshwater wetlands. Where the GDE layer identified freshwater wetlands located on floodplain or alluvium GMUs then primary water source was assigned as river fed. However, it is likely that some of these wetlands receive water from multiple sources. The number of groundwater fed wetlands may have been overestimated in some areas where detailed analysis has shown that many should be more correctly classified as rainfall fed (e.g. the Wimmera region).

Rainfall fed	Wetlands that were not identified as groundwater or river fed and receive the bulk of their water from direct rainfall or runoff from small local catchments, including small intermittent inflowing streams and drainage lines. However, it is acknowledged that all wetlands receive rainfall and rainfall may indeed sustain wetlands during dry periods that might otherwise be river or groundwater fed. The analysis is aimed at an assessment of climate change vulnerability at a regional scale; while rainfall may sustain floodplain wetlands, they are still vulnerable to changes in river flows associated with climate change.
Coastal	Wetlands adjacent to the coast (within 5 km) classified as saline or mapped with coastal Ecological Vegetation Classes (EVCs) dependant or tolerant of saline conditions (i.e. estuarine reedbeds, mangroves, coastal salt marsh).
Alpine*	Wetlands located in alpine areas classified as alpine bogs or wet heathlands within sub-alpine and montane EVC groups.

*Alpine landscapes (sphagnum bogs and associated fens) were included in the subsurface GDE mapping rules

Other investigations for individual wetlands across the work package identified groundwater connection through various methods, as well as common field attributes of groundwater connected wetlands. Groundwater connection for wetlands in the basalt plains was identified though the chemical signature of surface waters (Barton et al., 2006; Bennetts et al., 2006; Turnbull, 2006 and Fitzpatrick et al., 2007). Gipple et al. (2006), Mensforth (1996) and Fawcett (2005) observed the presence of shallow watertables, upward groundwater gradients and indicative vegetation types in groundwater connected wetlands.

In the NSW wetland feature dataset, highland peat fens and bogs were not identified. To compensate, the NSW soils database organic and peat soil classification was used as a surrogate, such that if peat soils were mapped within a wetland, it was likely to be a groundwater fed fen or bog.

CSIRO (Parsons et al., 2008) mapped rivers in the Murray-Darling Basin (MDB) as either gaining groundwater, or losing flow to the shallow aquifer. Where rivers were identified as losing to the shallow aquifer, adjacent wetlands were considered unlikely to be connected to the groundwater system. In NSW the Mitchell landscape geomorphic layer was used to extrapolate the identification of a losing river to wetlands in the same geomorphic unit, and in Victoria the Geomorphic Management Units were used.

From the above review several rules arise regarding where wetland GDEs are most likely to occur. These are summarised in Table 6.

Local fractured rock groundwater flow systems feed the headwaters of the majority of rivers in WP1. Therefore, the majority of rivers within WP1 have a baseflow component (Lacey, 1996; Nathan and Weinmann, 1993).

Groundwater connection with the Avon River in Gippsland was established by Goode (2009). River stretches that intersected shallow watertables in the alluvial systems were found to be dominantly gaining. In the eastern region of WP1, artesian groundwater pressures and highly permeable basalt stony rise flows result in strong groundwater connection with Darlot Creek (Gippel et al., 2009).

The spatial variability of groundwater connection for the major rivers within the Murray Darling basin was established in CSIRO's Surface-groundwater connectivity assessment report (Parsons et al., 2008). All major rivers in WP1 were assessed as gaining – these include the Avoca, Loddon, Campaspe, Goulburn, Murrimbidgee and Macquarie Rivers.

Based upon existing literature and mapping, the primary concepts describing groundwater connection with rivers in work package 1 are:

- All major rivers within the MDB component of WP1 are likely to be gaining
- Rivers that intersect local fractured rock aquifers within the central highland regions of WP1 are likely to be gaining
- Major rivers in the Gippsland Basin that intersect the alluvial system are gaining
- Rivers that intersect karstic and basalt stony rise geology are gaining

Effectively, all rivers within WP1 are considered to be gaining at some point in time.

The GIS analysis rules used to identify GDEs that rely on the surface expression of groundwater are summarised in Table 6. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

Table 6 GIS analysis rules to identify GDEs that rely on the surface expression of groundwater

Rule	
	WETLANDS
1	Persistence of surface water. Wetlands that are inundated for prolonged periods, especially through prolonged dry periods, are likely to be connected to groundwater.
2	Wetland type. Previous work (Dahlhaus, 2010) has identified that specific wetland types are indicative of groundwater discharge.

Rule	
3	Dominant Source of Water. In Victoria, the dominant source of water of wetlands has previously been established.
4	Presence of active vegetation during summer periods. During dry periods, active vegetation within and surrounding wetlands indicates shallow groundwater levels. This can be inferred to suggest groundwater is likely to be connected to the wetland, however may not discharge enough to cause inundation.
5	Shallow watertables. Wetlands that exist within areas of shallow watertable are likely to be connected to the groundwater.
6	GDEs that rely on the subsurface presence of groundwater. Vegetation identified as 'GDEs that rely on the surface presence of groundwater' indicate the presence of shallow watertables and potential diffuse groundwater discharge into adjacent wetlands.
7	Losing landscapes. Wetlands that occur in the same geomorphic setting as losing rivers are less likely to be connected to groundwater.
8	Substrate. Wetlands that contain peaty soils are likely to have been formed through groundwater discharge.
	RIVERS
1	Depth to watertable. Rivers and streams within regions of shallow water tables are more likely to be connected than in regions of deeper water tables.
2	GDEs that rely on the subsurface presence of groundwater. Vegetation identified as 'GDEs that rely on the surface presence of groundwater' indicate the presence of shallow watertables and potential diffuse groundwater discharge into adjacent rivers.
3	Losing landscapes. Where major rivers have been mapped as losing (Parsons et al., 2008) other rivers within the same landscape unit are also likely to be losing.

6.2.2. Selection of datasets for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 7 below shows the feature layers selected to map GDEs that rely on the surface expression of groundwater for WP1. These layers contain all the river, wetland and spring features that were analysed to establish whether a groundwater connection exists. These are either the datasets that the rules in section 6.2.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 7 Feature layer datasets for analysis of GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs) in WP1**

State	Ecosystem	Dataset Name	Source or Custodian
VIC	Wetland	WETLAND_1994	DSE
	Springs	Mineral Springs	DSE
	River	HY_WATERCOURSE	DSE
NSW	Wetland	NSW_WETLANDS_2006	DECC
	River	TOPO_HYDROLINE	DECC

6.2.3. Selection of GIS analysis datasets for implementation of rules

Table 8 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the surface expression of groundwater in WP1. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of each GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

- **Table 8 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the surface expression of groundwater (wetlands, rivers)**

#	RULES	Data needed for analysis	Dataset name	Coverage of dataset/ rule	Implementation of rule (and normalised value)
WETLANDS					
1	Persistent water	Mapping of persistent water	Landsat and MODIS open water	All WP1	Remote sensing of open water was used as an indicator of persistent water. Where open water intersected a wetlands polygon, the polygon was considered more likely to contain open water, and for this to contain groundwater (3). Where no intersect is recorded, the rule gives no indication whether the wetland/river interacts with groundwater or not (0), (i.e. Wetlands could still be interacting with groundwater even though open water is not present).
2	Wetland type is an indicator of groundwater use	Detailed wetland mapping reflective of water use	Wetland 1994 (Victoria)	Vic Rule could not be analysed in NSW	Wetland classes (Victoria Only) of Deep Marsh, Permanently Saline, Semi Saline and Shallow Marsh red Gum are all indicative of groundwater connection (3). Remaining wetland classes provided no indication on groundwater connection (0).
3	Wetlands with dominant water source	Detailed wetland mapping reflective of water use	Wetland 1994 (Victoria)	Vic Rule could not be analysed in NSW	The assignment of dominant water source of wetlands was used as an indicator of the likelihood of groundwater connection. Wetlands with a dominant water source of Groundwater and Alpine are very likely to have groundwater connection (3). The other 3 classes, River fed, Rainfall fed, and Coastline, while less likely do not discount groundwater connection (2).

4	High dry period ET of vegetation within or adjacent wetland	Mapping of dry period ET	IDE Layer	All WP1	Wetlands that have an IDE rating 8 or higher are considered to have ET pattern during dry periods that is indicative of groundwater connection (3). Wetlands with a lower IDE value provided no information on connection (0).
5	Depth to water table	Depth to water table mapping	Vic_dtwt Gwslices6	Vic NSW	Groundwater interaction is considered likely where watertable depth is <5m (3), possible for watertables between 5 & 10m (2), and unlikely for watertables >10m (1).
6	The presence of subsurface GDEs	Mapping of GDEs that rely on subsurface GW	Potential GDE layer	All WP1	Where a 'high potential' subsurface GDE intersects with a wetland/river, this was assumed to increase the potential for a wetlands/river GDE to exist (3).
7	Wetlands that exist adjacent losing rivers	Maps of gaining/losing sections of rivers (Parsons et al., 2008)		All WP1	In a landscape where rivers are losing, wetlands are likely to be above (disconnected from) the watertable in that landscape. Each wetland in landscapes where losing rivers were mapped, was considered unlikely to be connected to groundwater (1). Each wetland in landscapes where gaining rivers were mapped, was considered likely to be connected to groundwater (3).
8	Wetlands that contain peaty soils	Soils mapping	NSW soils layer	NSW Rule could nto be analysed in Vic	The Peaty soils attribute in NSW soils mapping provided an indication of groundwater connection (used as a surrogate for maps of alpine fens within NSW). Wetlands intersecting the class were normalised 3. The other soil classes provided no content on connection.
RIVERS					
1	Depth to watertable	Depth to watertable mapping	Vic_dtwt Gwsclices6	Vic NSW	Groundwater interaction is considered likely where watertable depth is <5m (3), possible for watertables between 5 & 10m (2), and unlikely for watertables >10m (1).

2	The presence of GDEs that rely on subsurface presence of groundwater	Mapping of GDEs that rely on the subsurface presence of groundwater	Potential GDE layer	All WP1	Where a 'high potential' subsurface GDE intersects with a wetland/river, this was assumed to increase the potential for a wetlands/river GDE to exist (3).
3	Losing rivers in landscapes where major rivers have been mapped as losing (Parsons et al., 2008)	CSIRO connectivity mapping	CSIRO connectivity mapping	MDB component of WP1 (Vic, NSW)	In a landscape where rivers are losing, wetlands are likely to be above (disconnected from) the watertable in that landscape. Each wetland in landscapes where losing rivers were mapped was considered unlikely to be connected to groundwater (1). Each wetland in landscapes where gaining rivers were mapped was considered likely to be connected to groundwater (3).
		Maps of geomorphic units	Mitchell Landscapes Bioregions, Subregion	NSW Vic	

Using the datasets listed in Table 8, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

6.2.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 8) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater interaction:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 8.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

6.2.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

6.2.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 9 and Table 10 show the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not

comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 9 and Table 10 are only comparable for each feature dataset, and so should only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Shallow depth to groundwater generally results in high GDE potential
- Dominant water source of groundwater generally results in high GDE potential

Table 9 Weighting for each GIS Analysis rule/dataset for GDEs that rely on surface expression of groundwater in WP1 (wetlands)

Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7	Rule 8
	Presence of open water	Wetland type	Dominant water source	Active vegetation (ET)	Shallow watertable	Presence of veg GDE	Losing landscapes	Peaty soils
Wetlands_1994 (Vic)	5	8	8	5	10	6	3	NA
NSW_wetlands_2006	4	NA	NA	5	10	4	4	4

Table 10 Weighting for each GIS Analysis rule/dataset for GDEs that rely on surface expression of groundwater in WP1 (rivers)

Feature Layer Dataset	Rule 1	Rule 2	Rule 3
	Shallow watertable	Presence of GDE that relies on subsurface presence of groundwater	Losing landscapes
HY_WATERCOURSE (Vic)	8	8	8
TOPO_HYDROLINE	8	8	8

6.2.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This includes non-natural landscapes such as reservoirs, dams and irrigated land. It also excludes features that are artefacts of mapping, and do not represent actual features in the landscape.

The definition queries applied to each dataset to exclude ecosystems that cannot be surface GDEs are listed below.

For the **Wetland_1994 (Vic)** feature layer dataset a definition query was applied to the field ‘X_SUBCATEG’ to exclude polygons attributed as:

- No sub category
- Island
- Intertidal flats
- Impoundment
- Sewage
- Dam
- Pond

For the **NSW_wetlands (NSW)** feature layer dataset a definition query was applied to the field ‘SUBGROUP’ to exclude polygons attributed as:

- Sewage Treatment Pond
- Reservoir
- Quarry
- Non-Wetland
- Dam

6.3. Attribution of GDEs derived in previous studies (from literature)

GDEs were identified in the literature review in Task 2. These were matched to polygons in the vegetation, river, and wetland feature layers where possible. The majority of these GDEs could be matched to existing polygons, which were attributed as either ‘GDE identified in previous study: fieldwork’; or ‘GDE identified in previous study: desktop’. The Tier 3 attributes recorded in the literature review were also entered into the GDE Atlas attribute table for the GDEs identified in previous studies.

6.4. Transfer of attributes from existing spatial datasets to GDE polygons

Tier one attributes were populated in the GDE Atlas attribute table using national datasets where available. Jurisdiction’s spatial datasets also contained information which could be used in the GDE Atlas attribute table, to either:

- Identify GDEs that had been mapped in a spatial layer in previous studies, and/or
- To populate other attributes in the GDE Atlas attribute table for GDEs that were derived in Task 5.

6.4.1. Datasets used to map GDEs identified in previous studies

In work package 1, the spatial datasets used to attribute GDE polygons as either GDE identified in previous study: fieldwork; or GDE identified in previous study: desktop are shown in Table 11. These datasets were either used to attribute polygons within the feature layer datasets, or entered in their entirety as feature layer datasets. Either way, the information from these datasets was incorporated into the GDE Atlas to show where GDEs were identified in previous studies.

- **Table 11 Spatial datasets used to map GDEs identified in previous studies (both desktop and fieldwork studies)**

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
VIC			
Victorian Mineral springs data sets	Springs	All	Victorian Mineral springs data sets
Alpine Fens and Bogs (EVC class within EVC_BCS)	Vegetation	All	EVC_BCS (Vic)
00_mdb_SW-GW_v06_lcc (CSIRO GW/SW interaction mapping)	Baseflow	CLASS = gaining	HY_WATERCOURSE (Vic)
NSW			
ADMIN_HighPriority_GDEPoint_Jan2011	Springs	All	ADMIN_HighPriority_GDEPoint_Jan2011
ADMIN_HighPriority_GDEPoly_Jan2011	Wetlands	Wetlands	ADMIN_HighPriority_GDEPoly_Jan2011

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
00_mdb_SW-GW_v06_lcc (CSIRO GW/SW interaction mapping)	Baseflow	CLASS = gaining	TOPO_HYDROLINE (NSW)
GDEs IDENTIFIED IN PREVIOUS STUDY: FIELDWORK			
VIC			
New_Salt	Vegetation	All	EVC_BCS (Vic)
Potential_baseflow_refuges_values_polygon	Baseflow	All	HY_WATERCOURSE (Vic)

6.4.2. Datasets used to populate attributes in the GDE Atlas attribute table

Information from jurisdiction's spatial data was incorporated into the GDE Atlas by transferring the relevant attributes into the GDE Atlas attribute table. A summary of the data used to populate each attribute is shown in Appendix A.

6.5. Data gaps and recommendations

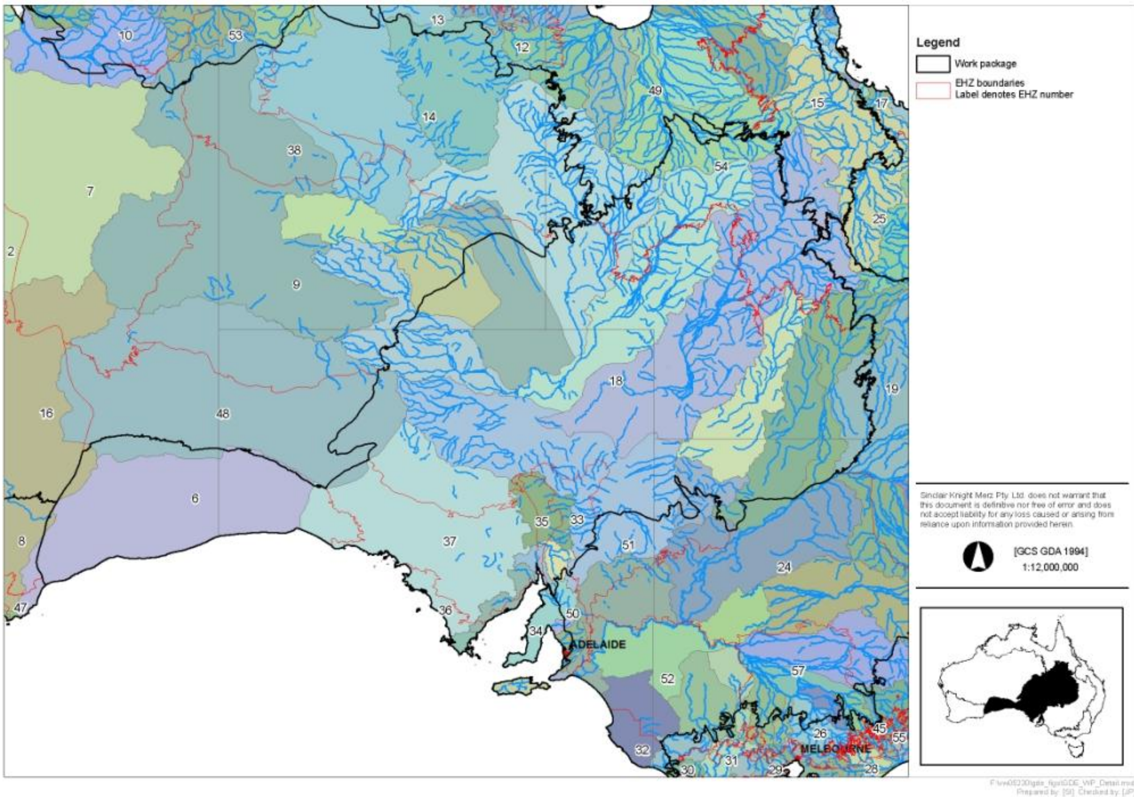
The current state wide wetland map for NSW provides no indication of the hydrology and hydrogeology of the system. In particular, it lacks descriptions of wetland type and water regime. It is recommended that the wetland layer be attributed with the ANAE style classification framework, particularly an attribute which describes water regime.

Alpine fens and bogs are known GDEs and exist across the Alpine bioregion. However at the completion of project no spatial extents of the fens and bogs for the NSW component were available. It is recommended that when identified or developed, the fens and bog extents in NSW are included in the Atlas as 'GDEs identified in previous study: fieldwork'.

7. Application of methodology in eastern central Australia and the Nullarbor Plain (WP2)

The WP2 area is shown in Figure 15 and incorporates 7 EHZs. The area is generally semi-arid to arid, with very few permanent surface water features. Many perennial plant species are adapted to survive in dry locations, and many species are indicative of groundwater discharge environments (particularly saline discharge environments).

Mapping of potential GDEs was completed for the majority of the area. Mapping of GDEs that rely on the subsurface presence of groundwater could not be completed for the NT and a small part of NSW due to a lack of appropriate vegetation mapping. Other mapping options were considered to fill these gaps, however they were not adopted as they were inconsistent with the national approach. Likewise, mapping of GDEs that rely on the surface expression of groundwater could not be completed in the WA part of this area since no wetland feature dataset was available.



- **Figure 15 Work package 2 area showing river basins and EHZs**

7.1. Identification of GDEs that rely on the SURFACE expression of groundwater

7.1.1. Literature review and GIS analysis rules

In general, the concepts and rules outlined here were applied to surface water ecosystems (rivers, wetlands, springs) across the whole work package. However, some more specific rules were applied to parts of the Lake Eyre Basin area (in EHZ18) and these are also described.

Rule 1: Areas with persistent surface water are likely to receive inputs from groundwater with the exception of waterbodies in the EHZ18 part of the Lake Eyre Basin.

Rationale: The EHZs of work package 2 exist almost solely within an area of Australia classed as semi-arid (<500 mm average annual rainfall) and arid (<250 mm). Persistence of water in waterholes, rivers or wetlands in these areas is often used as an indicator of groundwater discharge due to the relatively high evaporation rates and limited precipitation and surface water inputs in semi-arid/arid environments. Virtually all long-lasting surface water in the arid landscapes of central Australia is thought to have some dependency on groundwater discharge (Box et al., 2008).

Silcock (2009) found that the majority of permanent waterholes in the Georgina River catchment were influenced by groundwater, and the majority of these were thought to be spring-fed. Without groundwater contributions, there would only be four permanent waterbodies across the entire Georgina River catchment. There are relatively few permanent waterbodies within the Georgina River catchment compared to within the Cooper Creek and Diamantina River catchments. This may be due to the Georgina River catchment having generally shallower waterholes, less frequent inundation or the absence of cracking clay soils which trap water at the surface.

Groundwater inflows were reported in the Warburton River, formed after the junction of the Georgina and Diamantina Rivers in South Australia, which results in many of its waterholes being hyper-saline (Silcock, 2009). Groundwater may also contribute to waterhole persistence in the NT section of the Toko Range (Box et al., 2008), which is located in a similar environment immediately north of WP2.

Rule 2: Where cracking clay soils exist, waterbodies are less likely to be groundwater fed.

Rationale: Some studies undertaken in arid-zone catchments within WP2 have shown that in certain locations, the presence of persistent surface water does not necessarily indicate groundwater connection. A study (Silcock, 2009) identified permanent waterbodies in the Cooper Creek and Georgina-Diamantina catchments and reported that there were no deep waterholes with signs of groundwater inflows on the Cooper or Diamantina Rivers. The only groundwater influence on permanent waterholes in these rivers is thought to occur after large floods when bank/floodplain storage may discharge back into the waterbodies as the flood waters recede (J. Costelloe, pers.comm., July 2008; Hamilton et al., 2005; Costelloe et al., 2007). The persistence of water in

these catchments is more likely to be controlled by the depth of the waterbody, frequency of inundation, and loss processes, than it is by groundwater inflows (Silcock, 2009).

In the absence of groundwater connection, waterholes generally have to be at least 3-4 metres deep to persist through dry periods (Silcock, 2009), however this concept cannot be incorporated into the analysis since there is no data on depth of waterbodies.

Another factor which enables surface water to persist in dry periods without the influence of groundwater is the presence of low permeability material beneath the waterholes. This can include deeply scoured rockholes, and also the deep cracking clay soils which are present in the arid region and effectively preclude any interaction between groundwater and the surface waterhole (B. Lynch, pers.comm., January 2012). Within the mid to lower reaches of Cooper Creek, waterbodies frequently have a clay base that seals when wetted, and prevents groundwater/surface water interaction (Knighton and Nanson, 1994; Gibling et al., 1998). Costelloe (2007) suggests that the presence of these clays is commonplace across the broader LEB, and means that groundwater discharge to waterbodies in the area is limited. The Costelloe et al. (2007) study assessed 10 waterholes in the mid to lower reaches of the Diamantina River, Cooper Creek and Neales River, and could not find any evidence that groundwater contributed to persistent water in waterholes within these rivers.

Box et al. (2008) acknowledges that the ‘lack of groundwater interaction sits in sharp contrast to waterbodies in central Australia, where virtually all long-lasting surface water have some dependency on groundwater discharge’. Spatial data which shows the presence of the cracking clay soils is needed to enable this concept to be incorporated into the GIS analysis rules. Such data exists in Queensland and the NT, but not in the other areas (in SA and NSW) where literature reports the presence of cracking clay soils.

Expert opinion (in a workshop on the area) suggests that the presence of cracking clay soil is not confined to the study areas of the Cooper Creek and Georgina-Diamantina catchments (Silcock, 2009) and the mid-lower reaches of the Cooper, Neales and Diamantina catchments (Costelloe et al., 2007). Rather, it was thought that these soils are relatively common across the whole Lake Eyre Basin and therefore, connection between surface waterbodies and groundwater is unlikely in those areas. Although the Lake Eyre Basin extends north into EHZ54 and south into EHZ33 and 34, none of the studies reviewed or the discussions in the workshops indicated the presence of cracking clay soils in these areas. Because of this, it was assumed that cracking clay soils limit groundwater discharge to surface water only within the EHZ18 part of the Lake Eyre Basin, or where cracking clay soils are specifically mapped in the available datasets.

While this lack of connection between groundwater and surface water may occur over a broader area than the Lake Eyre Basin, it was agreed at a steering committee meeting for the GDE Atlas (in February 2012) that the impact of cracking clay soils would only be incorporated into the analysis for areas where either i) the literature specifically reported a lack of groundwater/surface water

interaction (as in the mid-lower reaches of the Lake Eyre Basin) or where cracking clay soils were mapped (as in Queensland and the NT).

Rule 3: Waterbodies intersecting a known spring location are more likely to be GDEs.

Rationale: Spring locations are surface expressions of groundwater discharge and are therefore GDEs.

Mudd (2000) states that a typical mound spring consists of a central discharge point (pool of water), outer rim of reeds and vegetation, and an outflow channel. A wetland and small creek may be formed at the outflow. Most water is discharged via a fault below the mound spring location. Therefore vegetation that occurs around them, such as the outer rim of reeds, is likely to be groundwater dependent.

In the Georgina River catchment, although permanent waterholes are rare, they exist predominantly due to the presence of a spring. There is little data on the stony ranges in the arid zone, however there are some cases where Tertiary springs are known to feed substantial rockholes. Some long term farmers suspect there are more spring-fed waterholes than are currently known, since the waterholes have never been dry despite not being particularly deep (Silcock, 2009). In the Cooper Creek, Diamantina River, and Neales Creek catchments there are also a small number of waterholes that are permanent due to being spring-fed (Costelloe et al., 2007).

Although this rule is a reliable indicator of GDEs, the data available to analyse the rule may be incomplete. That is, springs mapping may not show all of the springs that actually exist. For this reason, the rule cannot be used as the sole indicator of groundwater connection since it gives no information on the majority of persistent waterbodies. The other rules in this section are required to provide information on potential groundwater connection for a greater number of ecosystems in the area.

Rule 4: Waterbodies in areas with shallow watertables (<5 m) are more likely to interact with groundwater.

Rationale: Discharge from shallow groundwater can mitigate evaporative losses and increase the persistence of waterbodies (Bernardo & Alves 1999). In the arid zone, these may take the form of ‘soaks’ which are defined as ‘locations where the water table comes to the surface without the force associated with springs’ (Box et al., 2008).

The height of the watertable relative to the surface water body determines how long flow persists after rain ceases. This continuation of flow is the result of groundwater discharging into the watercourse until the watertable has declined to an elevation lower than the base of the waterbody.

Most streams in the arid zone are dominated by rainfall runoff and quick flow during rain events. However, groundwater discharge from shallow aquifers can sustain flow after rainfall ceases.

Where the watertable is in close proximity to the surface it can be assumed that groundwater discharge to the surface is more likely.

It should be noted that mapped depth to watertable contours in WP2 are often based on sparse data since groundwater bores are rare, particularly in the northern parts of the work package. The data may therefore be relatively unreliable in these areas.

Rule 5: Rivers flowing through fractured rock aquifers in the Adelaide Geosyncline (in EHZ33) and through the GAB aquifers across the whole work package are likely to receive groundwater inputs.

Rationale: Due to the incised nature of the fractured rock aquifers in the Adelaide Geosyncline, rivers that intersect faults within the aquifers are likely to gain baseflow. Although there are no datasets that distinguish fractured rock aquifers from unfractured aquifers, it is assumed that all formations within the Adelaide Geosyncline groundwater province (AWRA, 2000) are fractured enough to potentially provide baseflow to rivers. This analysis is only applied to EHZ33.

The outcropping GAB aquifers frequently contribute baseflow to rivers which flow over them. The analysis therefore uses the presence of outcropping GAB aquifers as an indicator of potential baseflow to rivers. The GAB aquifers which are likely to contribute baseflow are listed in Table 12.

- **Table 12 Great Artesian Basin aquifers, as listed in the Queensland GAB WRP (Queensland Gov, 2006)**

GAB Aquifers		
Westbourne Formation	Warang Sandstone	Toolebuc Formation
Adori Sandstone	Clematis Sandstone	Injune Creek Group
Birkhead Formation	Rewan Formation	Helby Beds
Hutton Sandstone	Wallumbilla Formation	Gilbert River Formation
Evergreen Formation	Cadna-owie Formation	Garraway Beds
Boxvale Sandstone Member	Wyandra Sandstone Member	Eulo Queen Group
Precipice Sandstone	Hooray Sandstone	
Moolayember Formation	Ronlow Beds	

Only the Wallumbilla Formation, Toolebuc Formation, Hooray Sandstone and Gilbert River Formation outcropped in WP2, according the GA National Geology mapping.

To summarise, the rules used to analyse for the presence of GDEs that rely on the surface expression of groundwater are shown in Table 13. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 13 GIS analysis rules to identify GDEs that rely on the surface expression of groundwater in WP2**

Rule	
1	Areas with persistent surface water are likely to receive inputs from groundwater with the exception of waterbodies within the EHZ18 part of the Lake Eyre Basin.
2	Where cracking clay soils exist, waterbodies are less likely to be groundwater fed.
3	Waterbodies intersecting a known spring location are more likely to be GDEs
4	Areas with shallow water tables are more likely to receive inputs from groundwater.
5	Rivers flowing through fractured rock aquifers in the Adelaide Geosyncline (in EHZ33) and through the GAB aquifers are likely to receive groundwater inputs.

7.1.2. Selection of datasets for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 14 below shows the feature layers selected to map GDEs that rely on the surface expression of groundwater for WP2. These layers contain all the river, wetland and springs features that were analysed to establish whether a groundwater connection exists. These are either the datasets that the rules in section 7.1.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 14 Feature layer datasets for analysis of GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs) in WP2**

State	Ecosystem	Dataset Name	Source or Custodian
SA	Wetlands	Harding 2010 State-wide GDE Classification/Wetlands_GDE_Classification_v1	DFW
	Rivers	Harding 2010 State-wide GDE Classification/Watercourse250K_GDE_Classification_v1	DFW
	Springs and waterholes	SA Data Request/Gazetteer_AquaticEcosystems	DFW

State	Ecosystem	Dataset Name	Source or Custodian
	Springs and waterholes	Springs_FlindersLEB	DFW
NSW	Wetlands	NSW_Wetlands_2006	DECC
	Springs	ADMIN_HighPriority_GDEPoint_Jan2011	DECC
	River	Basemap rivers	Geoscience Australia
WA	River	Hydrography_linear_heirachy	DOW
		No springs or wetlands available for WA	
NT	Wetlands	Wetlands Inventory 2000 - 2001 /snt_allwb_g94	NRETAS
	Rivers	NT_RIV_CKS	NRETAS
		No springs mapped in the NT in WP2[13]	
QLD	Wetlands	QLD_WETLAND_SYSTEM_100K_A	DERM
	Rivers	Basemap rivers	Geoscience Australia
	Springs	HYD_SPRING v3	DERM

Note that WA did not have a wetlands feature dataset that covered the WP2 area. Although a rivers feature layer was available for the WA area of WP2, there were no analysis datasets available to implement the rules (see section 7.1.3). Therefore, no analysis for GDEs that rely on the surface expression of groundwater occurred in the WA portion of WP2.

7.1.3. Selection of GIS analysis datasets for implementation of rules

Table 15 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the surface expression of groundwater in WP2. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the

[13] There is reasonable evidence that there are no springs in the NT portion of WP2 (A. Duguid, pers. comm.)

dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 15, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

The availability of GIS analysis datasets was limited in WP2, and hence, few of the analysis rules could be implemented. The scarcity of GIS analysis datasets meant that information on groundwater connection was only available for a few features in many of the feature datasets. The wetlands and rivers where no data was available are included in the IDE mapping layer only, not in the GDE layer. This exception does not occur where state-wide GIS analysis datasets exist, such as the depth to watertable mapping in SA.

Table 15 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the surface expression of groundwater

#	RULES	Data needed for analysis	Dataset name	Coverage of dataset/ rule	Implementation of rule (and normalised value)
1	Areas with persistent surface water are likely to receive inputs from groundwater with the exception of waterbodies within EHZ18 in the Lake Eyre Basin.	Wetland system mapping with permanency attributes	Wetlands_GDE_Classification_v1 QLD_WETLAND_SYSTEM_100K_A Wetlands Inventory 2000 - 2001 /snt_allwb_g94	All SA All Qld All NT Rule could not be analysed in NSW (no permanence attribute), WA (no wetlands dataset)	Where a permanent water regime occurs, it is more likely that groundwater maintains the water regime during low rainfall periods (3). A seasonal water regime indicates it is possible that groundwater maintains the presence of water after rainfall has ceased (2), and an intermittent or episodic water regime suggest rainfall dependence rather than groundwater interaction (1). Permanence attributes such as 'non-permanent' give no information about how long the presence of water remains after rainfall ceases, and so give no information about potential groundwater contributions (0).
		River mapping with permanency of flow attribute	NT_Riv_Crk_250p Watercourse_250K_GDE_Classification_v1 Basemap rivers	NT SA NSW, WA, Qld	
		Landsat open water[A]	WP2 Landsat (SA, NT, NSW, WA)	Whole WP (not used in Qld)	Remote sensing data was not used for Qld since a more comprehensive Landsat analysis for Qld was used to develop the WTRREGIME_ attribute. This was used instead. For WA, SA, NT, NSW remote sensing of open water was used as an indicator of persistent water. Where Landsat open water intersected a wetlands/river polygon, the polygon was considered more likely to contain open water, and for this to contain groundwater (2). Where no intersect is recorded, the rule gives no indication whether the wetland/river interacts with groundwater or not (0), i.e. just because it doesn't intersect with open water doesn't mean the wetlands/river won't be interacting with groundwater.
2	Where cracking clay soils exist,	Cracking clay soils mapping	QLD_WETLAND_SYSTEM_100K_A National geology	Qld NT	Ideally, mapping of cracking clay soils would be used to exclude persistent waterbodies from being considered as GDEs. Where

#	RULES	Data needed for analysis	Dataset name	Coverage of dataset/ rule	Implementation of rule (and normalised value)
	waterbodies are less likely to be groundwater fed.				this mapping was available (Qld) it was used to override the persistence of water rule, such that water regime did not have an influence on the final result in these areas. Where cracking clay soil mapping was not available, it was assumed that cracking clay soils occurred in the mid-lower reaches of the LEB (i.e. the EHZ18 part of the LEB). The persistence of water was disregarded in this area, such that water regime did not have an influence on the final result.
		River basins mapping	National river basins	SA, NSW	
		EHZs	GDE Atlas EHZs	SA, NSW	
3	Waterbodies intersecting a known spring location are more likely to be GDEs.	Springs datasets	GABSprings_GWPROJECTS SA_GAB_SPRINGS_2KM_BUFFER_DECEMBER_2010 Springs_FlindersLEB Gazetteer_AquaticEcosystems (SPRG only) ADMIN_HighPriority_GDEPoint_Jan2011 HYD_SPRING_v3 GAB_Watercourse_springs Spring REs	SA SA SA SA NSW QLD QLD QLD Rule could not be analysed in WA, NT	The springs datasets are intersected with the wetlands/river polygons. Where a spring falls within a wetlands/river polygon, a positive result is recorded for the intersect. Where a positive result for the intersect is recorded, the surface water feature is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the surface water feature is using groundwater or not (0), i.e. just because it doesn't intersect with a spring doesn't mean the wetlands/river won't be interacting with groundwater.
4	Areas with shallow water tables are more likely to receive inputs from groundwater.	Depth to water table	Wetlands_GDE_Classification_v1 (DTWZONE) SA_Gwater_shallow_SWL (SWL_MIN) HYDSTRA_SWL_MIN Drill_SWL	Used for SA wetlands[B] Used for SA rivers[B] NT NT Rule could not be analysed in NSW,	The SA state wide mapping of wetlands includes attributes which define depth to water table and confidence rating of the wetland being a GDE (which is based on depth to watertable). For the GDE Atlas analysis, the 'depth to water' attribute from the SA wetlands mapping is used, however the GDE rating is not used since additional data is being used to determine GDE potential in the Atlas.

#	RULES	Data needed for analysis	Dataset name	Coverage of dataset/ rule	Implementation of rule (and normalised value)
				Qld, WA	Groundwater interaction is considered likely where watertable depth is <5m (3), possible for watertables between 5 & 10m (2), and unlikely for watertables >10m (1).
5	Rivers flowing through fractured rock aquifers in the Adelaide Geosyncline and through the GAB aquifers are likely to receive groundwater inputs.	Groundwater Province mapping	GWATER_PROVINCES	EHZ 33 (SA)	Where rivers flow over the fractured rock aquifers of the Adelaide geosynclines, they are more likely to be receiving baseflow (3). Although the Adelaide Geosyncline extends into EHZ18 to the north, this rule was not used there since waterbodies in the LEB are less likely to be GDEs due to the presence of cracking clay soils.
		Aquifer mapping	National geology, GAB aquifers	Qld, NSW, NT, SA	Where rivers flow over the GAB aquifers, they are more likely to be receiving baseflow (3). All other aquifers give no indication of likelihood for groundwater inputs (0).

A – open water is only used where there is no other water regime attribute to indicate persistence. MODIS open water was not used due as reflectance from dry lake beds falsely identified water in some areas. Landsat was a more reliable indicator of open water in WP2.

B - the depth to water table data used for analysis of SA wetlands differs from that used to analyse SA rivers. Because of this, and because the depth to watertable data is weighted most heavily, results conflict in places where the two depth to watertable datasets are inconsistent. It was discussed whether to use the statewide depth to watertable dataset for both analysis (i.e. of rivers and of wetlands) in the workshop, and decided to maintain the depth to watertable that was specific to wetlands, since it was thought to be more verified. Some conflicts have arisen between wetlands and rivers due to the use of the different depth to watertable datasets.

7.1.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 15) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater interaction:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 15.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

7.1.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was 1, 2, or 3)}}$$

7.1.5.1. Weightings of Individual Rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 16 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not

comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 16 are only comparable for each feature dataset, and so should only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Springs always result in a wetland or river reach being assigned a high potential.
- The presence of a GAB aquifer or the Adelaide Geosyncline always results in a wetland or river reach being assigned a high or moderate potential.
- Wetlands or river reaches located on cracking clay soils, or within the EHZ18 part of the LEB, always result in a moderate or low potential.
- Shallow watertables always result in high or moderate potential, and deep water tables always result in low potential.

Table 16 Weighting for each GIS Analysis rule/dataset for GDEs that rely on surface expression of groundwater in WP2

	GIS Analysis Rules					
Feature Layer Dataset	Rule 1		Rule 2	Rule 3	Rule 4	Rule 5
	Permanent water regime	Presence of open water*	Presence of black soil, or within the LEB	Intersect with a spring	Shallow watertable	GAB aquifer/ Adelaide geosyncline
Gazetteer aquatic ecosystems (SA)	na	2	6	na	12	6
Wetlands_gde_v1 (SA)	5	5	na (see below)	11	6	4
Wetlands_gde_v1 (EHZ18, LEB, SA)	na	na	3	10	2	na
Watercourse_gde_v1, p1 (SA)	5	2	7	24	7	na
Watercourse_gde_v1, p2 (SA)	5	2	7	24	7	7
National Watercourses (Qld, NSW)	5	2	1	8	na	4

	GIS Analysis Rules					
Feature Layer Dataset	Rule 1		Rule 2	Rule 3	Rule 4	Rule 5
QLD_wetlands_100K, v2	2	na	10	15	na	4
nsw_wetlands 2006	na	2	na	8	na	na
NT_riv_cks & Wetlands Inventory 2000 - 2001 /snt_allwb_g94	5	2	8	na	8	4

* Presence of open water (from remote sensing data) was only used where there was no other attribute to indicate the water regime.

WA did not have a wetlands feature dataset that covered the WP2 area. Although a rivers feature layer was available for the WA area of WP2, there were no analysis datasets available to implement the rules (see section 7.1.3). Therefore, no analysis for GDEs that rely on the surface expression of groundwater occurred in the WA portion of WP2.

7.1.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This includes non-natural landscapes such as reservoirs, dams and irrigated land. It also excludes features that are artefacts of mapping, and do not represent actual features in the landscape.

The definition queries applied to each dataset to exclude ecosystems that cannot be GDEs that rely on the surface expression of groundwater are listed below.

For the **nsw_wetlands** feature layer dataset definition queries were applied to the field ‘SUBGROUP’ to exclude polygons attributed as:

- Dam
- Blanks (‘ ‘)

To the field ‘SKM_CLASS’ to exclude polygons attributed as:

- Reservoir

For the **Qld_wetlands_100K, v2** feature layer dataset definition queries were applied to the field ‘WTRREGIME’ to exclude polygons attributed as:

- Blanks (‘ ‘; and ‘-‘)

To the field ‘WETCLASS’ to exclude polygons attributed as:

- Blanks (‘ ‘; and ‘-‘)

To the field ‘HYDROMOD’ to exclude polygons attributed as:

- H3C1
- H3C2
- H3C3

To the field ‘HAB_L’ to exclude polygons attributed as:

- Blanks (‘ ‘; and ‘-‘)
- Marine
- Estuarine – water
- Artificial/ highly modified wetlands (dams, ring tanks, irrigation channels, drains, canals)

For the **wetlands_gde (SA)** feature layer dataset definition queries were applied to the field ‘WETLAND_SYS’ to exclude polygons attributed as:

- MAR (Marine)
- EST (estuarine)

To the field ‘WATERREGIM’ to exclude polygons attributed as:

- Intertidal flat
- Supratidal flat
- Supratidal flat & flooding

To the field ‘FEATURECOD’ to exclude polygons attributed as:

- 3236

For the **wcourse250K (SA rivers)** feature layer dataset definition queries were applied to the field ‘PERENNIAL’ to exclude polygons attributed as:

- Blanks (‘ ‘)
- Not applicable

For the **NT rivers and wetlands** feature layer dataset definition queries were applied to the field ‘PERENNIAL’ to exclude polygons attributed as:

- 8224

For the **National watercourses (Qld, NSW)** feature layer dataset definition queries were applied to the field 'PERENNIAL' to exclude polygons attributed as:

- Blanks (' ')

7.2. Identification of GDEs that rely on the SUBSURFACE presence of groundwater

7.2.1. Literature Review and GIS Analysis Rules

The GIS analysis rules and supporting information reviewed in the literature are outlined in this section. In general, the concepts and rules outlined here were applied to vegetation ecosystems across the whole work package. These rules are applied only to vegetation ecosystems that were found to be IDEs in Task 4. Only the vegetation ecosystems that had an ID likelihood of greater than 5 are considered to be using a source of water in addition to rainfall, and hence, only these ecosystems could be using groundwater.

Rule 1: Vegetation growing in areas with shallow groundwater (<10 m) is more likely to be a GDE.

Rationale: Vegetation accessing groundwater is commonly thought to exist in areas with shallow water tables, where there is a higher chance of groundwater being within the root zone. A watertable depth of less than 10m would be considered highly likely to be within reach of vegetation roots (Tanya Doody, pers. comm.). A watertable deeper than 20m is in general, unlikely to be within reach of most vegetation roots, although there is evidence of some *Eucalyptus* species with roots up to 60 m deep (Le Maitre, 1999).

Watertable mapping is available only for the SA part of WP2, and the mapping was developed by interpolating between very sparse bore locations. As such, the layer may not be particularly reliable.

Depth to watertable can sometimes be interpreted from landscape features, as shallow watertables may exist in topographic depressions. However in WP2, this concept cannot be invoked since the landscape is very flat, and the watertable is not necessarily influenced by the land surface elevation due to low and sporadic rainfall. Therefore, where specific watertable mapping is not available within the area (NSW, NT, Qld) topographic elevation cannot be used as a substitute.

Rule 2: Vegetation type is an indicator of groundwater use.

Rationale: There are physiological characteristics of certain vegetation types, such as deep root systems, that allow groundwater use in areas where water tables are deeper. Costelloe et al. (2008) found *Eucalyptus coolabah* in highly saline areas of the Lake Eyre Basin to use a combination of water stored within the unsaturated zone and groundwater during very long dry periods, and suggested that deep rooted vegetation is associated with areas of preferential recharge (e.g. localised topographic lows). Silcock (2009) suggests Melaleuca species to be indicative of soaks, particularly in limestone terrains. Where vegetation species information exists, knowledge about the likelihood of groundwater use of particular species can also be used to highlight areas of shallow watertable, and hence where other groundwater using vegetation may exist, and also of areas of potential groundwater discharge.

In an area with such infrequent rainfall, vegetation is highly adapted to its environment. Many vegetation species can indicate groundwater discharge environments (particularly saline discharge environments). Information on vegetation type is considered to be a reliable indicator of potential groundwater interaction in WP2.

Rule 3: Native vegetation that has a relatively high and constant ET in dry periods is more likely to be using groundwater.

Rationale: ET of vegetation in generally changes from high to low depending on the availability of water. If vegetation is accessing water from a secondary source (in addition to rainfall) a decline in ET during dry periods will be buffered, resulting in relatively high ET compared to vegetation that is not accessing the secondary source of water.

This rule relies on the GDE Atlas remote sensing data, however there are a few cautions for the use of this data in WP2. One is that the ratio between ET and rainfall (i.e. the ratio measured in the remote sensing layer) can be very high but it does not necessarily reflect high ET. Rather, the reason for the high ratio is the very low rainfall. Another issue is the occurrence of arid vegetation which often has waxy leaves. This results in greater reflectance, which is detected by the remote sensing but is not necessarily indicative of high ET.

Reflectance of bare earth and salt lakes is also an issue in this area, however because the remote sensing data is assigned to a mapped vegetation ecosystem polygon in the feature layers (see section 7.2.2), this issue generally does not affect the final GDE mapping. The only instance where reflectance from bare earth may result in GDEs falsely being identified, is where errors in the feature layers have mapped bare earth as a vegetation type. This issue occurs particularly with vegetation that is mapped as ‘sparse’, which allows reflectance from the underlying earth to contribute to the remote sensing data.

Because of the potential for the remote sensing to wrongly indicate that significant ET is occurring, only the highest remote sensing likelihood values were used in the analysis for this work package.

Rule 4: Native vegetation surrounding a known spring location or a GDE identified in a previous study is more likely to be a GDE.

Rationale: Springs are groundwater discharge points, and vegetation that grows around springs can be considered to rely on the spring groundwater discharge. This vegetation can be considered to rely on the groundwater that has been discharged to the surface.

Persistent water was initially considered as an indicator of potential groundwater use, however since persistent water in this area is frequently not associated with groundwater (see Rule 1 for GDEs that rely on surface expression of groundwater), the presence of persistent water has not been included in this rule. Rather, where vegetation intersected a GDE that had been identified in a previous study (either through field work or by desktop extrapolation), the vegetation was

considered to also be using groundwater. The GDEs identified in previous studies are all GDEs that rely on the surface expression of water (i.e. wetlands, waterholes and rivers). Riparian vegetation associated with these features is also likely to be using groundwater, since if groundwater is discharging into surface water bodies the watertable must be shallow, and may therefore be within reach of vegetation roots. These previously identified GDEs were also analysed separately from the results of wetland and river GDEs identified in the Atlas analysis (rule 6 below), as it is expected that they were identified through more site-specific studies, or with less extrapolation than is necessary in the Atlas. They are therefore likely to be a more reliable data source than the potential GDEs identified for the Atlas.

Rule 5: Vegetation growing in soil that has a low water storage capacity is more likely to be accessing groundwater than vegetation which grows in soil where more water is stored in the unsaturated zone.

Rationale: Vegetation frequently relies on water stored in the unsaturated zone, and it can be difficult to distinguish between vegetation that uses water stored in the unsaturated zone from vegetation that uses groundwater. A study on river red gums (*Eucalyptus camaldulensis*) in semi-arid Australia found that trees within 15 m of a stream sourced less than 30% of their water requirements from the stream, and those more than 15 m away utilised only water stored in the unsaturated zone, and groundwater sources (Mensforth et al., 1994). This indicates that riparian vegetation is predominantly reliant on either water stored in the unsaturated zone or groundwater in this area. Hence, it was important to distinguish between use of water in the unsaturated zone ans use of groundwater in order to map GDEs.

Along with a shallow watertable and ET, soil water holding capacity (SWHC) is a key piece of data that informs on whether the water requirements of vegetation can be satisfied by water stored in the unsaturated zone, or whether the vegetation will also need to rely on groundwater. Vegetation that continues transpiring through dry periods, occurs over shallow groundwater, and is in soils with a low SWHC, is likely to be groundwater dependent. Soils that have a high SWHC are more likely to hold sufficient water so that vegetation can continue transpiring at a high rate throughout dry periods without accessing groundwater. In these situations, water stored in the unsaturated zone is more readily available to the vegetation, requires less energy to obtain, and is therefore used in preference to groundwater.

Rule 6: Vegetation growing near a river or wetland GDE (derived in analysis for GDEs that rely on the surface expression of groundwater, above) is also likely to be using groundwater.

Rationale: Where a river or wetland is considered to be a GDE, it follows that the watertable must be relatively close to the surface (close enough so that discharge into the waterbody occurs). As such, the watertable is also likely to be within reach of vegetation roots, and may therefore be an additional source of water in low rainfall periods.

In other work packages, this rule was applied the opposite way. That is, vegetation GDEs were used to indicate where surface discharge to wetlands or rivers may be occurring. In this work package, surface GDEs are considered a better indicator of vegetation GDEs for a few reasons.

Firstly, there are very few permanent waterbodies in the WP2 area. If rivers or wetlands are only inundated ephemerally, they are more likely to drain to the shallow aquifer than they are to receive groundwater inputs from the shallow aquifer. As such, while vegetation either side of the waterbody may be reliant on this recent infiltration (and could be considered a GDE), the waterbody itself has only been inundated due to runoff and is therefore not a GDE. If the presence of the vegetation GDE was incorporated into the analysis, the losing waterbody would incorrectly be identified as a GDE.

Secondly, depth to watertable mapping is relatively unreliable in this area due to the paucity of bores which results in watertable contours being interpolated over large distances between bore locations. Using the presence of a wetland or river GDE (which was estimated conservatively) reduces the reliance on depth to watertable mapping as an indicator of where vegetation GDEs may exist. The surface GDE dataset also has the advantage of covering the entire work package.

Thirdly, the remote sensing in this area over identifies vegetation GDEs due to the very high ET:P ratio. This is misleading however, as the ratio is so high due to the very low rainfall. Some arid region plants have adaptations that mean they can continue transpiring throughout a dry period without using groundwater. Also, the waxy leaves of some desert species increases the reflectance and causes the IDE results to be higher, therefore making some vegetation types more likely to be identified as a GDE, when in reality, their ET may not be very high.

Because of the uncertainties involved in identifying vegetation GDEs in WP2, and because of the relatively conservative approach taken to identify river and wetland GDEs, it is considered better to use river and wetland GDEs as an indicator of shallow watertables, and thereby to increase the potential for vegetation to also be accessing shallow groundwater in these locations.

Rule 7: Vegetation growing in areas where cracking clay plains exist is more likely to rely on trapped surface water or water stored in the unsaturated zone than groundwater.

Rationale: Cracking clay soils are common in WP2, especially in the Lake Eyre Basin. These soils are very low permeability and can hold water for long periods of time, and also limit throughflow of groundwater. Therefore, vegetation that grows in cracking clay soils is less likely to access groundwater than vegetation growing in other soil types. Vegetation in cracking clay soils is more likely to access the moisture within the soil, or the surface water trapped by the soils. This rationale is also used in the analysis for river and wetland GDEs, as the cracking clay soils can result in persistent water bodies which cannot be assumed to be GDEs. Similarly, where cracking clay soils are mapped, the potential for vegetation to be using groundwater is lower.

It was thought that cracking clay soils were relatively common across the whole Lake Eyre Basin. Because of this, it was assumed that cracking clay soils limit groundwater discharge to surface water within the EHZ18 part of the Lake Eyre Basin, or where cracking clay soils are specifically mapped in the available datasets.

To summarise, the rules used to analyse for the presence of GDEs that rely on the subsurface presence of groundwater are shown in Table 17. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 17 GIS analysis rules to identify GDEs that rely on the subsurface presence of groundwater in WP2**

Rule	
1	Vegetation growing in areas with shallow groundwater is more likely to be a GDE.
2	Vegetation type is an indicator of groundwater use.
3	Native vegetation that has a relatively high and constant ET in dry periods is more likely to be using groundwater.
4	Native vegetation surrounding a known spring location or a known GDE is more likely to be a GDE.
5	Vegetation growing in soil that has a low water storage capacity is more likely to be accessing groundwater than vegetation which grows in soil where more water is stored in the unsaturated zone.
6	Vegetation growing near river or wetlands GDEs is also likely to be using groundwater.
7	Vegetation growing in areas where cracking soil plains exist is more likely to rely on trapped surface water or water stored in the unsaturated zone than groundwater.

7.2.2. Selection of data for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 18 below shows the features layers selected to map GDEs that rely on the subsurface presence of groundwater for WP2. These layers contain all the vegetation features that were analysed to establish whether a groundwater connection exists. The feature layers are either the datasets that the rules in section 7.2.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 18 Feature layer datasets for analysis of GDEs that rely on the subsurface expression of groundwater (rivers, wetlands, springs) in WP2**

State	Ecosystem	Dataset Name	Source or Custodian
SA	Vegetation	SA VEG DATA	DFW
NSW	Vegetation	murray_darling_M305_VISmap_917	DECC
WA	Vegetation	Pre_european clipped to State_remveg	DECC
NT	No coverage	N/A	N/A
QLD	Vegetation	gde_working.GDE_O.re06b_CS_Qld	DERM
	Vegetation	gde_working.GDE_O.re06b_NW_Qld	DERM
	Vegetation	gde_working.GDE_O.re06b_SW_Qld	DERM
	Vegetation	IQ_QLD_REGECOPRECL_DCDB_A	DERM

There was no useable vegetation layer available for the NT part of WP2. Therefore, no mapping of GDEs that rely on the subsurface presence of groundwater (i.e. vegetation) could be completed in this area. Although various landsystem and land unit maps existed which could have potentially been used in the analysis, they each covered a relatively small area (such as a single cattle station). Due to time constraints, the Atlas required maps with greater coverage (regional or state coverage) and could not incorporate the large number of maps with limited coverage.

The vegetation mapping available for NSW did not cover all of the NSW WP2 area, therefore, there are also small areas of NSW in WP2 where no vegetation ecosystems could be analysed for potential groundwater interaction.

7.2.3. Selection of GIS Analysis Datasets for implementation of rules

Table 19 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the subsurface presence of groundwater in WP2. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

- **Table 19 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the subsurface expression of groundwater**

#	RULES	Datasets needed for analysis	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	Vegetation growing in areas with shallow groundwater is more likely to be a GDE.	Depth to water table mapping	SA_GWater_shallow_SWL	SA only Rule could not be analysed in NSW, Qld, NT, WA	Groundwater use is considered likely where watertable depth is <10m (3), possible for watertables between 10 & 20m (2), and unlikely for watertables >20m (1).
2	Vegetation type is an indicator of groundwater use.	Vegetation mapping	SA_VEG_DATA murray_darling_M305_VISmap_917 gde_working.GDE_O.re06b_CS_Qld gde_working.GDE_O.re06b_NW_Qld gde_working.GDE_O.re06b_SW_Qld IQ_QLD_REGECOPRECL_DCDB_A Pre-european	All of SA Most of NSW Qld Qld Qld Qld WA	Attributes describing vegetation types were normalised as either likely to use groundwater (3); possibly use groundwater (2), unlikely to use groundwater (1), or not sure (0). Normalisation was done from literature and by reviewers and jurisdictions.
3	Native vegetation that has a relatively high and constant ET in dry periods is more likely to	IDE layer	IDE layer	All WA, SA, NT, Qld, NSW	The probability from the RS layer is assigned to each vegetation polygon by majority value. That is, the probability of the greatest number of pixels that intersect with the polygon becomes the probability of the whole polygon.

#	RULES	Datasets needed for analysis	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
	be using groundwater.				Probabilities of 6, 7 & 8 give no indication of groundwater use (0); probabilities of 9 & 10 suggest groundwater use is more likely (3).
4	Native vegetation surrounding a known spring location or a GDE mapped in a previous study is more likely to be a GDE.	Springs datasets	GABSprings_GWPROJECTS Springs_FlindersLEB Gazetteer_AquaticEcosystems (SPRG) ADMIN_HighPriority_GDEPoint_Jan2011 HYD_SPRING_v3	SA SA SA NSW Qld Rule could not be analysed in WA	The springs datasets and the previously mapped GDE datasets are intersected with the vegetation polygons. Where the spring/previously mapped GDE falls within the vegetation polygon, a positive result is recorded for the intersect. Where a positive result for the intersect is recorded, vegetation is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or not (0), i.e. just because it doesn't intersect with a spring/previously mapped GDE, doesn't mean the vegetation won't be using groundwater. Due to the large size of many vegetation polygons, and the likelihood that groundwater discharging from a spring/previously identified GDE may in reality only be influencing a small part of that vegetation polygon, this rule is weighted quite low.
		GDEs mapped in previous studies	Hydro_Pool_or_dam_ 15m Hydro_Pool_or_dam_greater_than_15m Hydro_Baseflow_MLR LEBwaterholes_Perm_GW&SW RIPARIAN_Baseflow_Light_2001 RIPARIAN_Baseflow_Broughton_2001 ADMIN_HighPriority_GDELine_Jan2011 ADMIN_HighPriority_GDEPolygon_Jan2011 GAB_Watercourse_Springs	SA SA SA SA SA SA NSW NSW Qld	
5	Vegetation growing in soil that has a low water storage capacity is more likely to be accessing groundwater than vegetation which grows in soil where	Soil Water Holding Capacity mapping	SOILS_AWHC SOILISMAP_MARKMITCHELL QLD_combinedoils_2M	southern SA NSW QLD Rule could not be analysed in WA or northern	Where vegetation is growing in soils that hold sufficient water, there is no need for the vegetation to use groundwater, as it usually requires less energy to use the water stored in the unsaturated zone. Therefore, where the water holding capacity of soil is high, vegetation is unlikely to access groundwater (1), and where it is low, vegetation may require groundwater to maintain growth in dry periods (3).

#	RULES	Datasets needed for analysis	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
	more water is stored in the unsaturated zone.			SA	
6	Vegetation growing near river or wetland GDEs is also likely to be using groundwater.	Mapping of derived river and wetland GDEs	Derived mapping of GDEs that rely on the surface expression of groundwater (i.e. The output of section 7.1)	NT, SA, Qld, NSW Rule could not be analysed in WA	Where a high potential river or wetland GDE was identified, this suggests groundwater is shallow and therefore vegetation is more likely to also be a GDE (3). Moderate and low potential GDEs are not considered in the analysis for this rule.
7	Presence of cracking clays indicate vegetation is more likely to rely on trapped surface water or water stored in the unsaturated zone than groundwater	Mapping of cracking clay soils	RE06b Pre-european	Qld WA Rule could not be analysed in NSW, SA	Where cracking clay soils are present, the overlying vegetation ecosystem was considered less likely to use groundwater (1). Where there was no cracking clay soil mapped, this rule gives no indication of groundwater use (0).

Using the datasets listed Table 19, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6. Because there was no appropriate vegetation feature layer for the NT, the analysis in Table 19 could not be carried out in the NT.

7.2.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 19) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater use:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 19.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

7.2.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was 1, 2, or 3)}}$$

7.2.5.1. Weightings of Individual Rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 20 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 20 are only comparable for each feature dataset, and so may only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Depth to watertable weighted so that deep watertables always result in a low GDE potential
- Vegetation type weighted heavily so that acacia aneura and other shallow rooted acacias have low GDE potential, and other vegetation types that are more commonly associated with groundwater are assigned a high GDE potential
- Springs weighted so that intersecting vegetation polygons have GDE potential of either moderate or high
- The presence of cracking clay soil weighted so that intersecting vegetation polygons have GDE potential of either low or moderate

Table 20 Weighting for each GIS Analysis rule/dataset for GDEs that rely on subsurface expression of groundwater in WP2

	GIS Analysis Rules						
Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7
	DTW	Vegetation species	IDE	Presence of spring/ known GDE	Soil water holding capacity	Presence of surface GDE	Presence of cracking clay soils
Iq_qld_regc (QLD Remveg)	NA	15	2	24	3	2	12
qld_veg (RE06b)	NA	15	2	24	3	2	12
murray_darling (NSW)	NA	10	2	24	5	7	NA
SA_VEG (EHZ 6, 33, 34, 35, 36, 37)	10	11	2	26	4	2	5

	GIS Analysis Rules						
Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7
SA_VEG (EHZ 18)	12	12	2	40	6	2	12
Pre-european (WA)	2 (land-scape)	6	2	NA	NA	NA	NA

* Presence of open water (from remote sensing data) was only used where there was no other attribute to indicate the water regime.

The NT does not have a suitable vegetation feature layer, so no analysis could be undertaken for GDEs that rely on the subsurface presence of groundwater. Because there are very few analysis datasets available for WA, the weightings rely largely on the vegetation type for the overall potential value, with the remote sensing and the landscape making relatively minor contributions to the potential.

The limited availability of GIS analysis datasets meant that few of the analysis rules could be implemented. The scarcity of GIS analysis datasets meant that information on groundwater connection was only available for a few features in many of the feature datasets. The vegetation polygons for which no data was available are included in the IDE mapping layer only, not in the GDE layer. This exception does not occur where state-wide GIS analysis datasets exist, such as the depth to watertable mapping in SA.

7.2.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This included non-natural landscapes such as settlements, pasture, and plantations, as well as natural landscapes that do not use groundwater, such as grasslands and bare earth.

All vegetation polygons that had an ID likelihood of 5 and less were removed at this stage, as these ecosystems were not likely to be accessing a source of water in addition to rainfall. The additional definition queries applied to each dataset to exclude ecosystems that could not be subsurface GDEs are listed below.

For the **murray_darling (NSW)** feature layer dataset a definition query was applied to the field ‘DESCRIPTIO’ to exclude polygons attributed as:

- Barren
- Crops & Annual Pastures
- Grassland
- Grassland (contains isolated chenopods)

- Native Grassland
- Settlement
- Water
- Eragrostis -v.sparse
- Grass – sparse

For the **RE06b (Qld)** feature layer dataset a definition query was applied to the field 'DBVG2M' to exclude polygons attributed as:

- 30
- 31
- 32
- 33
- 35
- Ocean
- Sand
- Water

In the field 'RE' to exclude polygons attributed as:

- Canal
- Estuary
- estuary/12.1.3
- non-rem
- Ocean
- Sand
- Water

For the **SA_VEG (SA)** feature layer dataset a definition query was applied to the field 'BROAD_VEGD' to exclude polygons attributed as:

- hummock grasslands
- tussock grassland
- Grassland

In the field 'DOMSPECIES' to exclude polygons attributed as:

- Blank (' ')

In the field 'MVG_NAME' to exclude polygons attributed as:

- Cleared/modified native vegetation, non-native vegetation

- Hummock Grassland
- Mangrove
- Tussock Grassland

For the **pre-european (WA)** feature layer dataset a definition query was applied to the field ‘SOURCE_DES’ to exclude polygons attributed as:

- Bare areas; drift sand
- Bare areas; claypans
- Bare areas; salt lakes
- Blank (‘ ‘)

7.3. Attribution of GDEs derived in previous studies (from literature)

GDEs were identified in the literature review in Task 2. These were matched to polygons in the vegetation, river, wetland feature layers where possible. The majority of these GDEs could be matched to existing polygons, which were attributed as either 'GDE identified in previous study: fieldwork'; or 'GDE identified in previous study: desktop'. The Tier 3 attributes recorded in the literature review have also been entered into the GDE Atlas attribute table for the GDEs identified in previous studies.

7.4. Transfer of attributes from existing spatial datasets to GDE polygons

Tier one attributes were populated in the GDE Atlas attribute table using national datasets where available. Jurisdiction's spatial datasets also contained information which could be used in the GDE Atlas attribute table, to either:

- Identify GDEs that had been mapped in a spatial layer in previous studies, and/or
- To populate other attributes in the GDE Atlas attribute table for GDEs that were derived in Task 5.

7.4.1. Datasets used to map GDEs identified in previous studies

In work package 2, the spatial datasets used to attribute GDE polygons as either 'GDE identified in previous study: fieldwork'; or 'GDE identified in previous study: desktop' are shown in Table 21. These datasets were either used to attribute polygons within the feature layer datasets, or entered in their entirety as feature layer datasets. Either way, the information from these datasets was incorporated into the GDE Atlas to show where GDEs were identified in previous studies.

Table 21 Spatial datasets used to map GDEs identified in previous studies (both desktop and fieldwork studies)

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
SA			
Hydro_Pool_or_dam__15m	Permanent pools	Dry season pool	Watercourse250K_GDE_Classification_v1
Hydro_Pool_or_dam_greater_than_15m	Permanent pools	Dry season pool	Watercourse250K_GDE_Classification_v1
Hydro_Baseflow_MLR	Baseflow rivers	Dry season baseflow	Watercourse250K_GDE_Classification_v1 Wetlands_gde_v1 (SA)

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
RIPARIAN_Baseflow_Light_2001	Baseflow rivers	Permanent Baseflow/ Probable Baseflow	Watercourse250K_GDE_Classification_v1
RIPARIAN_Baseflow_Broughton_2000	Baseflow rivers	Permanent Baseflow/ Probable Baseflow	Watercourse250K_GDE_Classification_v1
Pools_willochra	Permanent pools	All	Watercourse250K_GDE_Classification_v1 Wetlands_gde_v1 (SA)
Willochra_baseflow	Baseflow rivers	Baseflow	Watercourse250K_GDE_Classification_v1 Wetlands_gde_v1 (SA)
Pool_Baseflows	Permanent pools	All	Watercourse250K_GDE_Classification_v1 Wetlands_gde_v1 (SA)
Gazetteer_AquaticEcosystems	Springs	SPRG	Gazetteer_AquaticEcosystems
Springs_FlindersLEB	Springs	All	Springs_FlindersLEB
NSW			
ADMIN_HighPriority_GDEPoint_Jan2011	Springs	All	ADMIN_HighPriority_GDEPoint_Jan2011
QLD			
GAB_watercourse_springs	Baseflow rivers	All	Major Watercourses
Spring REs	vegetation & wetlands	Selected REs[B]	QLD_WETLAND_SYSTEM_100K RE06b
HYD_SPRING_v3	Springs	Unvisited springs[A]	HYD_SPRING_v3
GDEs IDENTIFIED IN PREVIOUS STUDY: FIELDWORK			
NSW			
ADMIN_HighPriority_GDEPoly_Jan2011	Wetlands	Wetlands	NSW_wetlands
QLD			
HYD_SPRING_v3	Springs	Visited springs[A]	HYD_SPRING_v3

A – Visited and unvisited springs were distinguished using the POINT_ID attribute, as advised by DERM.

B – Spring REs were identified by DERM.

7.4.2. Datasets used to populate attributes in the GDE Atlas attribute table

Information from jurisdiction's spatial data was incorporated into the GDE Atlas by transferring the relevant attributes into the GDE Atlas attribute table. A summary of the data used to populate each attribute is shown in Appendix A.

7.5. Data gaps and recommendations

An appropriate feature layer for vegetation ecosystems was not available for the NT, which prevented any mapping of GDEs that rely on the subsurface presence of groundwater to be

undertaken. Although some vegetation data exists in this area, it did not have extensive coverage and so could not be used in the GDE Atlas. A recommendation for future work is to create a vegetation feature layer from the various vegetation maps that currently exist. If this does not result in a sufficiently extensive layer, NVIS vegetation mapping (www.environment.gov.au/erin/nvis) also covers the area. However, it contains large polygons which may need to be split into smaller polygons to enable meaningful GDE potential results to be derived.

A feature layer delineating wetlands in WA was not available for mapping of GDEs that rely on the surface expression of groundwater. Future mapping should determine whether any wetlands mapping exists for the area and if not, Geodata (Geodata 250K, Feature Class: Lakes, Swamps, Flats) may be considered as a substitute. The limited number of GIS analysis datasets available in WA lowered the reliability (lines of evidence) of the mapping of GDEs that rely on the subsurface presence of groundwater. Useful datasets include mapped spring locations, previously identified GDE locations, as well as soil water holding capacity and depth to watertable contours. Soil water holding capacity maps are also currently unavailable in northern SA.

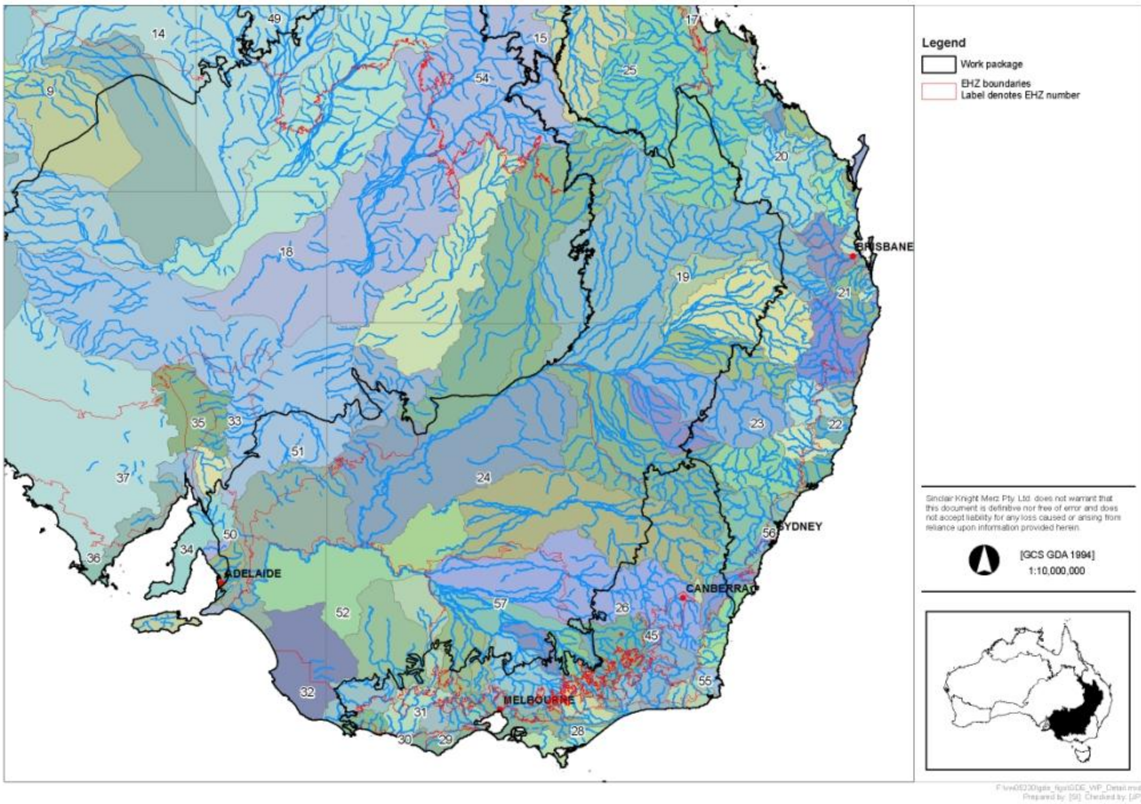
The use of depth to watertable contour maps in the analysis for Queensland, NSW, NT and WA would significantly improve the GDE maps. This is a key data source for mapping of GDEs. In an area as flat as WP2, groundwater does not imitate land surface contours and as such, topography maps could not be used as a substitute for depth to watertable maps. Further work on the GDE mapping from WP2 would therefore significantly benefit from the development and inclusion of depth to water mapping. The depth to watertable mapping used in SA was a valuable analysis dataset, however it was based on sparse data points and may have limited accuracy. The analysis would also benefit from more extensive mapping of cracking clay soils, which are considered to impede groundwater flow across large areas of WP2, but were only mapped for Queensland and NT.

In the Queensland RE06b vegetation mapping, the ‘DBVG2M’ attribute was normalised to indicate the relative likelihood of different vegetation groups to interact with groundwater. This is attribute describes broad vegetation groups (35 categories cover the whole of Queensland), and as such the consideration of vegetation in the GDE potential calculation was also at a very broad scale. The use of a more detailed vegetation attribute such as ‘RE’ would have provided more information to distinguish the potential groundwater interaction for smaller, more uniform ecosystems. It is recommended that an update of the Queensland maps for GDEs that rely on the subsurface presence of groundwater incorporate normalisations for the more detailed ‘RE’ attribute.

8. Application of Methodology in the southern and eastern MDB (WP3)

The WP3 area is shown in Figure 16 and incorporates 7 EHZs. The area incorporates most of the Murray-Darling Basin, which is heavily developed for agriculture, and therefore has large areas with limited native vegetation. Watercourses are frequently supplemented or non-perennial. Rainfall decreases from around 1000mm in the east of the work package, to 200 mm in the west and the climate is described as having a hot, dry summer and a cold winter.

Mapping of potential GDEs was completed for the majority of the area, however there were two small areas in NSW where GDEs that rely on the subsurface presence of groundwater could not be mapped, due to a lack of vegetation mapping. Complete mapping coverage for GDEs that rely on the surface expression of groundwater was possible in the area.



■ **Figure 16 Work package 3 area showing river basins and EHZs**

8.1. Identification of GDEs that rely on SUBSURFACE presence of groundwater

8.1.1. Literature review and GIS analysis rules

The GIS analysis rules and supporting information reviewed in the literature are outlined in this section. In general, the concepts and rules outlined here were applied to vegetation ecosystems across the whole work package. These rules are applied only to vegetation ecosystems that were found to be IDEs in Task 4. Only the vegetation ecosystems that had an ID likelihood of greater than 5 are considered to be using a source of water in addition to rainfall, and hence, only these ecosystems could be using groundwater.

Rule 1: Vegetation which demonstrates an ET that is higher than rainfall is more likely to be using groundwater.

Rationale: Vegetation water use studies (e.g. Morris et al., 1998; Prathapar and Myer, 1992) have shown that plants use any available water source, such that ET is greater where water sources in addition to rainfall and water stored in the unsaturated zone exist (e.g. irrigation or groundwater). Therefore, riparian vegetation on unregulated streams in areas of shallow watertables (non-irrigated) that maintain high ET during dry periods will most likely be using groundwater.

Rule 2: Vegetation is more likely to be using groundwater where watertables are shallow (<10 m).

Rationale: Vegetation accessing groundwater is exists in areas with shallow water tables, where there is a higher chance of groundwater being within the root zone (Morris et al., 1998; Prathapar and Myer, 1992). A watertable depth of less than 10m would be considered highly likely to be within reach of vegetation roots (Tanya Doody, pers. comm.). A watertable deeper than 20m is in general, unlikely to be within reach of most vegetation roots, although there is evidence of some *Eucalyptus* species with roots up to 60 m deep (Le Maitre, 1999).

Groundwater generally has a higher salinity than rainwater and water stored in the unsaturated zone, making it more energy intensive for vegetation to use. Water in the unsaturated zone is also stored shallower in the soil profile than groundwater, which means it requires less energy for vegetation to uptake the water stored in the unsaturated zone. Vegetation will therefore use fresher and shallower water sources such as water stored in the unsaturated zone or rainfall in preference to groundwater. However, where groundwater is shallow its uptake by vegetation requires less energy, and additionally, the unsaturated zone is thinner, meaning there is less water from the unsaturated zone available to the vegetation.

Benyon and Doody (2004) summarised results from a series of plantation research sites in the higher rainfall zones (>600 mm) of the Green triangle in south eastern Australia, in the western edge of WP1. The plantations exist within sandy subsoils with access to shallow, fresh, unconfined, limestone aquifers. The results indicated that where shallow watertables (<5 m)

existed, plantations were able to use groundwater such that 60% of their natural water use came from groundwater during dry periods. The groundwater quality and subsurface environment provides very few limitations to deep penetration by plantation root systems. Despite this, the study suggested that in high rainfall areas (>600 mm) within the limestone terrain, groundwater use, and assumingly rooting depth, did not occur to a depth of greater than 6 metres. This suggests that while the subsoil conditions suit deep penetrating roots, the climate supplied sufficient rainfall that the trees did not need to search deeper into the regolith. Therefore, in many cases, high rainfall zones (>600 mm) may supply sufficient subsoil moisture that continued groundwater use is not required.

Rule 3: Vegetation growing in areas of low soil water holding capacity is more likely to use groundwater.

Rationale: Vegetation frequently relies on soil water stored in the unsaturated zone, and it can be difficult to distinguish between vegetation that uses water stored in the unsaturated zone from vegetation that uses groundwater. Along with a shallow watertable and ET, soil water holding capacity (SWHC) is a key piece of data that informs on whether the water requirements of vegetation can be satisfied by water stored within the unsaturated zone, or whether the vegetation will also need to rely on groundwater. Vegetation that continues transpiring through dry periods, occurs over shallow groundwater, and is in soils with a low SWHC, is likely to be groundwater dependent. Soils that have a high SWHC are more likely to hold sufficient water so that vegetation can continue transpiring at a high rate during dry periods without accessing groundwater. In these situations, water stored within the unsaturated zone is more readily available to the vegetation, requires less energy to obtain, and is therefore used in preference to groundwater.

Rule 4: Certain vegetation communities/species have higher potential for using groundwater.

Rationale: Despite common links with shallow watertables in relatively fresh environments, physiological adaptations of vegetation (such as deep root systems or high salt tolerance) can facilitate use of high salinity groundwater and/or groundwater use in areas where watertables are relatively deep. Smith et al. (2006) used assumed rooting zone depths to assess the risk to terrestrial vegetation of changes in groundwater levels. The rooting zones were based on the ideas that the majority of woodland systems have rooting depths <17 m; that larger, taller trees generally have deeper root systems; and maximum rooting depths for Eucalyptus species is 30 m (based on those recorded in previous studies).

Mensforth and Walker (1996) found *Melaleuca hamaturorum* (trees that are salt and water tolerant) at Keith (SA) used groundwater for parts of the year; and were often found to fringe permanent or seasonal wetlands/swamps that occur in areas of saline groundwater discharge points. Similar GDEs are likely to occur throughout the Mallee, particularly in remnant dunes and interdunal flats where wetlands/swamps typically form. River Red Gums (*Eucalyptus camaldulensis*) have been found to use groundwater opportunistically through summer and extended dry periods. Mensforth

et al. (1994) established that River Red Gums across the Chowilla floodplain use groundwater during summer months and both surface and groundwater during winter months. When fresher sources were available, these were used in preference to groundwater. Groundwater depths at each of the four sites investigated along Punkah Creek were all less than three metres and had salinities ranging from 10 to 50 dS/m. Significantly, the River Red Gums were able to use groundwater of salinities up to 40 dS/m. It was suggested that the key process of groundwater dependency is the presence of fresh lenses of groundwater that sit above the more saline regional system. The use of saline groundwater may be in part due to the rooting distribution of the trees which was thought to be a longer term survival mechanism, for periods when no streamflow is available for prolonged periods (Mensforth, 1994).

Holland (2002) reported River Red Gums to be relatively salt and water intolerant, compared to their Black Box cousins (*Eucalyptus largiflorens*). River Red Gums typically occur closer to the river where fresh surface water from flooding and rainfall buffers the saline regional groundwater, while Black Box are more commonly seen further from the river in more saline zones of the floodplain. To the north of the work package area, *Eucalyptus coolabah* in highly saline areas of the Lake Eyre Basin were also found to use a combination of water stored in hte unsaturated zone and groundwater in very long dry periods (Costelloe et al., 2008). However, in the east of the work package in the Lower Murrumbidgee, vegetation is thought to rely mainly on rainfall and periodic flooding from the Murrumbidgee River and hence have a low dependency on groundwater (Kumar, 2010). Harrington (2004) suggested River Red Gums and *Phragmites* species to be indicative of groundwater interaction in the Lower Marne River catchment in the Mount Lofty Ranges.

Rule 5: Vegetation surrounding springs is likely to be using groundwater.

Rationale: Springs mapping shows locations where groundwater discharges to the surface. Distinct vegetation growth often occurs around springs because of the availability of groundwater that has discharged to the surface. Therefore, where springs are mapped, it can be assumed that the surrounding vegetation is using the discharged groundwater.

This rule is most effective where the mapped vegetation polygons are small, because vegetation associated with springs is often confined to a small area around the discharge point. Where vegetation polygons are large, the presence of a spring makes the whole polygon appear more likely to be using groundwater, when in reality; only a small part of that polygon is likely to be influenced by the groundwater from the spring.

Rule 6: Vegetation surrounding known GDEs is likely to also be using groundwater.

Rationale: In a general sense, where groundwater is known to occur at or near the surface, it can be assumed that vegetation in these areas also uses the groundwater. A number of datasets were supplied for the GDE Atlas project which identify potential GDEs. These datasets were either created and verified through field work, or they were created by GIS analysis and extrapolation.

They show rivers and wetlands that have previously been identified as GDEs. If surface water systems have a baseflow component, it follows that the watertable must be relatively close to the surface, and as such, vegetation in the area could also be using the groundwater.

Rule 7: Certain landscapes or topography are more indicative of shallow groundwater, and are therefore more likely to support GDEs.

Rationale: In the absence of depth to watertable mapping, local topographic depressions can be used to indicate areas of shallow watertables. The use of this rule assumes that the watertable surface is a more subdued imitation of the land surface, such that the watertable is close to the surface in areas of low topography, and deeper in more elevated areas. As described in rule 2 above, vegetation found in landscapes with shallow groundwater is more likely to be using groundwater as it is within the root zone, and the unsaturated zone is thinner (less stored water available).

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 22. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 22 GIS analysis rules for GDEs that rely on the subsurface presence of groundwater**

Rule	
1	Vegetation which demonstrates ET that is higher than rainfall is more likely to be using groundwater
2	Vegetation is more likely to be using groundwater where watertables are shallow (<10 m)
3	Vegetation growing in areas of low soil water holding capacity is more likely to use groundwater.
4	Vegetation surrounding known GDEs (GDEs identified in previous studies) is likely to also be using groundwater
5	Vegetation surrounding springs or other known GDEs is likely to also be using groundwater
6	Certain vegetation communities/species have higher potential for using groundwater

Rule	
7	Certain landscapes or topography are more indicative of shallow groundwater, and are therefore more likely to support GDEs. (This rule is only applied when an existing DTW mapping is not available)

8.1.2. Selection of datasets for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area. However in WP3 there was complete coverage of vegetation feature layers, so there were no gaps in the GDE mapping.

Table 23 shows the features layers selected to map GDEs that rely on the subsurface presence of groundwater for WP3. These layers contain all the vegetation features that were analysed to establish whether a groundwater connection exists. The feature layers are either the datasets that the rules in section 8.1.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 23 Feature layer datasets for analysis of GDEs that rely on the subsurface presence of groundwater (vegetation) in WP3**

State	Ecosystem	Dataset Name	Source or Custodian
SA	Vegetation	SA VEG DATA	DENR
VIC	Vegetation	NV2005_EVCBCS	DPI
NSW	Vegetation	murray_darling_M305_VISmap_917	DECC
	Vegetation	Namoi	NSW Office of Water
	Vegetation	Central West Lachlan	NSW Office of Water
QLD	Vegetation	gde_working.GDE_O.re06b_CS_Qld	DERM
	Vegetation	gde_working.GDE_O.re06b_SE_Qld	DERM

8.1.3. Selection of GIS analysis datasets for implementation of rules

Table 24 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the subsurface presence of groundwater in WP3. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 24, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

Table 24 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the subsurface presence of groundwater

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name (& where used)	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	Vegetation which demonstrates ET that is higher than rainfall is more likely to be using groundwater	WP3 remote sensing (RS) layer	WP3 remote sensing (RS) layer	Whole WP	The probability from the RS layer is assigned to each vegetation polygon by majority value. That is, the probability of the greatest number of pixels that intersect with the polygon becomes the probability of the whole polygon. Probabilities of 6 & 7 give no indication of groundwater use (0); probabilities of 8, 9, 10 suggest groundwater use is more likely (3). Limitation: the variation of ET:P within a polygon is lost. The larger the polygon, the less representative the probability is of the actual land surface.
2	GDEs are more likely to occur where watertables are shallow	Depth to watertable mapping	GWater_Shallow_SWL Basin in a box Vic_dtwt	All of SA. SW and central NSW. All of Vic. Rule cold not be analysed in Qld.	Groundwater use is considered likely where watertable depth is <10m (3), possible for watertables between 10 & 20m (2), and unlikely for watertables >20m (1).
3	Vegetation growing in areas of low soil water holding capacity (SWHC) is more likely to use groundwater.	Soils data	Qld_Combinedsoils_2M SOILISMAP_MARKMITCHELL SOILS_AWHC	All of QLD in WP area. All of NSW in WP area. Sthn agricultural area in SA. Rule could not be analysed in Vic.	Qld: 'low' SWHC is where AWC (field capacity) – AWC (wilting point) = <9mm (3); 'high' SWHC capacity is where AWC (field capacity) – AWC (wilting point) = >9mm (1). NSW: 'low' SWHC is where PAWC is <50mm (3); 'moderate' is where PAWC is between 50 & 250mm (2); 'high' is where PAWC is >250mm (1). SA: 'low' SWHC is where AWHC is E & D (<40mm); 'moderate' is where AWHC is C & B (40 – 100mm); 'high' is where AWHC is A (>100mm).

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name (& where used)	Coverage of dataset/rule	Implementation of rule (and normalised value)
4	Vegetation surrounding known (GDEs derived in a previous study) GDEs is likely to also be using groundwater	Previously mapped GDE datasets	STREAMS_ORD_EMLRCOPY MOSQCK_PERMPOOLS MOSQCK_BASEFLOWZONES HYDRO_POOL_OR_DAM__15M HYDRO_BASEFLOW_MLR RIPARIAN_Baseflow_Light_2001 RIPARIAN_Baseflow_Broughton_2000 Pool_Baseflows Pools_willochra Willochra_baseflow Mambpools GAB_Watercourse Springs ADMIN_HighPriority_GDEPoly_Jan 2011 CSIRO_mdb_SW-GW_v06_lcc	SA SA SA SA SA SA SA SA SA SA SA QLD NSW Vic, Qld, NSW	The previously mapped GDE datasets are intersected with the vegetation polygons. Where the majority of the previously mapped GDE falls within the vegetation polygon, a positive result is recorded for the intersect. Where a positive result for the intersect is recorded, vegetation is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or not (0), i.e. just because it doesn't intersect with a spring/previously mapped GDE, doesn't mean the vegetation won't be using groundwater.
5	Vegetation surrounding springs is likely to also be using groundwater	Springs datasets	GABSprings_GWPROJECTS Springs_FlindersLEB Gazetteer_AquaticEcosystems HYD_SPRING_V3 Spring REs ADMIN_HighPriority_GDEPoint_Jan2011 Springs	SA SA SA QLD QLD NSW VIC	The springs datasets are intersected with the vegetation polygons. Where the spring falls within the vegetation polygon, a positive result is recorded for the intersect. Where a positive result for the intersect is recorded, vegetation is more likely to be using groundwater from the spring (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or not (0), i.e. just because it doesn't intersect with a spring, doesn't mean the vegetation won't be using groundwater. Due to the large size of many vegetation polygons, and the likelihood

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name (& where used)	Coverage of dataset/rule	Implementation of rule (and normalised value)
					that groundwater discharging from a spring may in reality only be influencing a small part of that vegetation polygon, this rule is weighted quite low.
6	Likely groundwater using vegetation	Vegetation mapping with attributes to identify species likely to be using groundwater and/or in likely landscapes	SA_VEG_DATA murray_darling_M305_VISmap_917 Qld_RE06B (DBVG2M) NV2005_EVCBCS Namoi Central west Lachlan	All of SA in WP area Most of NSW in WP area All of QLD in WP area All of VIC in WP area Namoi Catchment Lachlan catchment	Attributes describing vegetation types were normalised as either likely to use groundwater (3); possibly use groundwater (2), unlikely to use groundwater (1), or not sure (0). Normalisation was done from literature and by reviewers and jurisdictions.
7	Landscape or topography indicates the potential for groundwater connection (only applied when DTW not available)	Landscape type information	SA_SOILS/LAND TYPE RE06B/LANDSCAPE Mitchell Landscapes FLAG dataset	Sthn agricultural area in SA. All of Qld in WP area All of NSW in WP area Used in all states where DTWT not available & where state landscape info not available.	Both state landscapes data and FLAG data are broad scale, and require significant assumptions to be made regarding depth to watertable. They are both used where there is no depth to watertable data. Flag is only used where there is no DTWT data and where there is no state landscape data. This rule is weighted very low. Landscapes which indicate a shallow DTWT, more likely to support GDEs (3); landscapes which indicate medium DTWT, possibly support GDEs (2); landscapes which indicate deeper DTWT, unlikely to support GDEs (1).

8.1.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 24) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater use:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 24.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

8.1.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was 1, 2, or 3)}}$$

8.1.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 25 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not

comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 25 are only comparable for each feature dataset, and so may only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- In Queensland, likely groundwater using vegetation and high ET always result in a high GDE potential
- Shallow depth to watertable always results in a high of moderate GDE potential
- Deep watertables always result in a low or moderate GDE potential
- Vegetation that intersects with a previously mapped GDE usually results in a high GDE potential, depending on the depth to watertable data.

Table 25 Weighting for each GIS Analysis rule/dataset for GDEs that rely on subsurface presence of groundwater in WP3

Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7
	High ET	Shallow watertable	Low SWHC	Presence of known GDEs	Presence of springs	Vegetation type	Landscape/ topography #
RE06B (Qld)	8	NA	5	10	5	7	2/1
murray_darling (NSW)	8	15	4	10	7	8	2/1
Namoi	8	10	4	20	NA	4	NA
Central west Lachlan	8	10	4	20	NA	4	NA
SA_VEG (SA)	7	14	4	12	5	7	na
EVC1 (Vic)	6	14	na	14	8	6	na

Where a DTW layer exists (Rule 2) this rule is not applied

The resulting mapping of GDEs that rely on the subsurface presence of groundwater covers the whole of WP3 apart from some small areas in NSW. This is because the available vegetation

feature layer (murray_darling_M305_VISmap_917) does not cover those areas and hence there is no ecosystem linework available for the analysis to assign GDE potential.

8.1.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This included non-natural landscapes such as settlements, pasture, and plantations, as well as natural landscapes that do not use groundwater, such as grasslands and bare earth.

All vegetation polygons that had an ID likelihood of 5 and less were removed at this stage, as these ecosystems were not likely to be accessing a source of water in addition to rainfall. The additional definition queries applied to each dataset to exclude ecosystems that could not be subsurface GDEs are listed below.

For the **SA_VEG (SA)** feature layer dataset a definition query was applied to the field ‘BROAD_VEGD’ to exclude polygons attributed as:

- hummock grasslands
- tussock grassland
- Grassland

For the **EVC_bcs (Vic)** feature layer dataset a definition query was applied to the field ‘X_EVCNAME to exclude polygons attributed as:

- Bare Rock/Ground
- Estuarine Wetland
- Freshwater Lake Aggregate
- Permanent Open Freshwater
- Permanent Saline
- Plains Grassland
- Saline Lake Aggregate
- Semi-Permanent Saline
- Water Body - Fresh
- Water Body - man-made
- Water Body - to be determined
- Water body - salt
- Blank (‘ ‘)

For the **murray_darling (NSW)** feature layer dataset a definition query was applied to the field ‘DESCRIPTIO’ to exclude polygons attributed as:

- Barren
- Chenopod; Grass
- Chenopod shrubs on grassland
- Chenopod shrubland
- Chenopod shrubland; Grass
- Rock + or - vegetation (may or may not be barren)
- Poa;Eragrostis spp. isolated
- Poa; Eragrostis spp. very sparse
- Pine Plantation
- Other Plantation
- Permanent grass - v.sparse
- Crops & Annual Pastures
- Other;Crops & Annual Pastures
- Grassland
- Grassland (contains isolated chenopods)
- Native Grassland
- Settlement
- Water
- Eragrostis -v.sparse
- A.victoriae; grass - v.sparse
- Grass – sparse
- Blanks (‘ ‘)
- ?

In the field ‘A_GENUS1’ to exclude polygons attributed as:

- Chenopod
- Eragrostis

In the field ‘LANDCOVER’ to exclude polygons attributed as:

- 1

For the **Namoi (NSW)** feature layer dataset a definition query was applied to the field ‘Veg1’ to exclude polygons attributed as:

- Quarry

- Settlements
- Urban
- Wetland
- Water
- Agriculture
- Man Made
- Mine
- Grassland
- Plantation
- Cropping
- fen cline
- exotic
- weeds
- cleared
- treeless
- regrowth
- house
- other
- unknown
- roadside
- unlabeled
- untyped
- trial
- excluded
- altered
- pasture
- improved
- house
- nil
- not recorded
- code assessed
- roadside
- no code
- present

For the Central West Lachlan **(NSW)** feature layer dataset a definition query was applied to the field ‘**field BVT_LAB’** to exclude polygons attributed as

- “
- Water
- Wetland
- Rocks
- town

For the **RE06b (Qld)** feature layer dataset a definition query was applied to the field ‘DBVG2M’ to exclude polygons attributed as:

- 30
- 31
- 32
- 33
- 35
- Ocean
- Sand
- Water

In the field ‘RE’ to exclude polygons attributed as:

- Canal
- Estuary
- estuary/12.1.3b
- estuary/3.1.3
- estuary/3.1.4
- estuary/3.3.66×1b
- nil
- non-rem
- Ocean
- Sand
- Water
- sand/2.2.1
- Blanks (‘ ‘)

8.2. Identification of GDEs that rely on SURFACE expression of groundwater

8.2.1. Literature review and resulting GIS analysis rules

Much of the literature available related to the South Australian portion of WP3, and as such most of the discussion and rules below were drawn from these reports. In the eastern Victorian, NSW and southern QLD parts of WP3 fewer reports were generally available.

Rule 1: Where shallow watertables occur (<5 m), groundwater is more likely to be discharging into wetlands and rivers.

Rationale: In south east SA, broad scale assessments based on: i) depth to watertable mapping; ii) likely connection with the Tertiary Limestone Aquifer (TLA); and iii) conceptualisation of specific wetlands, found numerous wetlands to have high likelihood of being in connection with the regional (and occasionally a perched) groundwater system (Cook, 2008; Wood, 2008; Sheldon, 2009; SKM, 2010). Groundwater interaction in this region is more likely in the coastal lakes, karst systems and in the bulk of wetland chains and floodplains (particularly deep geomorphic depressions above the TLA) occupying the flats between limestone ridges (Wood, 2008; Sheldon, 2009). Those most likely to be disconnected from or losing to the groundwater system in the south east SA region were thought to occur in the south, the border zones, and the elevated topographies of the Mount Burr and Naracoorte Ranges (Sheldon, 2009).

Landscape geomorphology and hydrology is an important factor in determining the position and distribution of wetlands; typically occurring in open depressions, steeply dissected hills or within gullies or as perched wetlands on plateau regions (Harding, 2005a). It follows that where such landscape features or landscape positions can be linked to very shallow water tables or areas of groundwater discharge, they are more likely to be groundwater dependent. Haese et al. (2008) for instance reported regional groundwater discharge from unconfined and confined Tertiary limestone aquifers into the Coorong and throughout the upper south east of SA to occur at low lying points in the landscape; in flats and interdunal swales.

The literature identified several locations in South Australia where wetlands are unlikely to receive groundwater inputs due to the depth of watertables. These areas are in the Northern agricultural districts of SA (Seaman, 2002), in south east SA, the border zones, and the elevated topographies of the Mount Burr and Naracoorte Ranges (Sheldon, 2009). The only exceptions to this are the relatively few wetlands identified by Harding (2005b) which occur in areas where watertables may be shallow (i.e. creek-line floodplains and some brackish drainage depressions) but the wetlands are thought to be entirely dependent on runoff or streamflow. Since there are relatively few of these exceptions to the rule they have not been captured in the analysis.

In the eastern Victorian, NSW and southern QLD parts of WP3 fewer reports were generally available. Macumber (1991) reported a regional groundwater discharge zone to exist on the riverine plains in the central and lower Loddon Plain, which typically manifests as brackish/saline spring-fed effluent streams and lakes, and diffuse discharge through shallow watertables.

Rule 2: Waterbodies close to springs are more likely to receive groundwater inputs.

Rationale: In upland areas, (e.g. on the Fleurieu Peninsula (EHZ50)), Harding (2005b) reported some wetlands to have formed as a result of groundwater interactions (natural springs) at the top of catchments. The study assessed the groundwater dependency of 138 wetlands on the Fleurieu peninsula based on the vegetation present and their position in the landscape (i.e. assessment of the run-off potential, the presence of vegetation communities such as peat-based swamp species, and the water regimes). They conclude that depth to watertable was a key factor in wetland presence and that the majority of the wetlands were groundwater or spring-fed (from groundwater originating as a spring beyond the wetland boundary). The relatively few wetlands found to be entirely dependent on local runoff or stream flow included creek-line floodplains and some brackish drainage depressions (Harding, 2005b).

Macumber (1991) reported that brackish/saline spring discharge contributed to streamflow and lakes in a regional groundwater discharge zone on the riverine plains in the central and lower Loddon Plain.

Rule 3: Certain swamp vegetation communities indicate likely groundwater inflows.

Rationale: Certain wetland vegetation communities or species are often seen to be indicative of shallow watertables. Harding (2005) found swamps comprising communities typical of waterlogged soils or peat soils in areas of low rainfall and high summer evaporation rates to be potentially groundwater dependent. The swamp communities identified include:

- *Leptospermum lanigerum* shrubland with sedge understorey *Leptospermum lanigerum* shrubland with sedge and fern understorey;
- *Leptospermum continentale* shrubland with sedge understorey;
- *Leptospermum continentale* shrubland with sedge and fern understorey;
- *Leptospermum continentale/Sprengelia incarnata* shrubland with sedge understorey;
- Mixed Leptospermum shrubland with emergent *Viminaria juncea* or *Acacia retinodes* and sedge understorey;
- *Melaleuca decussata* shrubland with sedge understorey;
- *Leptospermum continentale/Viminaria juncea* shrubland with sedge understorey;
- *Leptospermum continentale/Melaleuca squamea* shrubland with sedge understorey;
- Mixed sedgeland (e.g. Lignum – *Muehlenbeckia florulenta*); and
- Phragmites and/or Typha grassland with emergent *Viminaria juncea, Acacia retinodes* and sedge understorey.

In general, leptospermum can be considered a strong indicator of groundwater discharge environments (pers. comm., N. Carboon 2/02/2012). Another vegetation type that indicates groundwater interaction is samphire, which grows in groundwater discharge zones in the Mallee (Grinter and Mock, 2008).

In the Mallee, groundwater discharge is thought to occur due to structural and topographic controls, such as along faults, and results in large saline complexes or small ephemeral wetlands in interdunal flats and swales (Macumber, 1991). In this region, salinity is often considered an indicator of groundwater/surface water connection due to the relatively high salinity of the regional groundwater system. The presence of halophytic vegetation can be indicative of shallow watertables, especially in the Mallee where groundwater maybe the primary source of water during dry periods and salinisation is widespread (Grinter and Mock, 2009; Macumber, 1991).

Rule 4: A permanent water regime is indicative of groundwater discharge which maintains flow/water during the dry season.

Rationale: The permanency of a water body is commonly seen as an indication of groundwater contribution in low rainfall areas, and during dry periods in temperate climates where evaporation rates are high. Green (2008) found the majority of permanent pools and wetlands in the Eastern Mount Lofty Ranges to be dependent on groundwater and other studies in the area support this concept, where seasonal or permanent boggy wetlands are thought to be indicative of groundwater dependence (Fass, 2004; Harding, 2005). However, in higher rainfall and low evaporation areas such as the Adelaide Geosyncline, the high water storage capacity of the surrounding landscape (e.g. the boggy wetland ecosystems noted above) may provide enough water to maintain inundation during drier periods.

Perennially flowing rivers are also commonly thought to be associated with groundwater inflows, although the literature describes some exceptions to this concept. Green (2010) highlights that surface water flows may persist through summer in creek systems without connection to the deeper groundwater system even in the semi-arid environments of southern SA. Contribution of groundwater is highly dependent on groundwater levels, which may vary significantly seasonally, and on the extent of native vegetation present, which can influence the capacity of the catchment to store water and help maintain flows (Green, 2010). For instance in the Rocky River catchment of Kangaroo Island, summer flow is sustained by water stored in the surface water system and extensive fringing swamp zones (Banks, 2010a). Although Banks (2010a) reports that contributions to river baseflow from the regional fracture rock aquifer is minimal in uncleared pristine catchments, swamp systems are likely to be maintained by shallow perched Quaternary aquifers. Clearance of catchments is thought to reduce the capacity for water to be stored in surface water features of the landscape (Banks, 2010; Green, 2010).

Rule 5: Certain geological formations are more likely to contribute baseflow to rivers.

Rationale: Geology is also thought to influence the likelihood and level of groundwater contributions. VanLaarhoven (2006) reports that within both fractured rock and Permian Sand aquifers, wetlands and other water-dependent ecosystems on are often dependent both on surface and groundwater contributions. However, for those on fractured rock aquifers the relative contribution of groundwater was dependent on season and the location of rock fractures and fractured rock highs (Harrington, 2004), and varies both temporally and spatially. Conversely, groundwater contributions to ecosystems on Permian Sand aquifers are likely to be more permanent and consistent.

Banks (2010) and Green (2008) found groundwater to be a significant component of streamflow in the Western and Eastern Mount Lofty Ranges respectively; typically flowing from fractured rock aquifers of high topographies to low Quaternary alluvium aquifers, discharging along creek lines. This is a common conceptualisation in upland areas, with relatively large groundwater inflows to river systems particularly along fault zones, where they exist. Larger groundwater contributions to streamflow are expected where reaches cross formations with higher fracture density (Banks, 2010; Banks, 2010a). In some catchments of the Mount Lofty Ranges, gaining reaches are reported to be more likely in catchments consisting of Permian glacial and fluvioglacial deposits and Quaternary floodplain deposits than fractured rock, while in others there is no direct correlation between geology or topography and groundwater discharge zones (Harrington, 2004a; Green, 2008; Banks, 2010a).

Limited data exists to identify the geological formations discussed in the literature (i.e. Permian sands and fluvioglacial deposits, Quaternary floodplain deposits, and fractured rock aquifers). In particular, identifying the fractured rock aquifers is difficult since geology mapping generally does not convey the level of fracturing. Because of this, the Groundwater Provinces (AWRA, 2000) dataset was used to pick out areas most likely to contain fractured rock environments with fracturing. Since the information reviewed only relates to the Adelaide Geosyncline, this rule has only been implemented for the Adelaide Geosyncline groundwater province in this draft of the mapping. Note that this rule does not apply equally to other ‘surface’ ecosystems (e.g. Wetlands).

Rule 6: Waterbodies within riverine landscapes associated with losing rivers are not likely to be in connection with groundwater.

Rationale: Several quantitative and qualitative studies were undertaken to identify river reaches as either loosing flow to groundwater or gaining flow from groundwater (e.g. CSIRO connectivity mapping; Banks, 2010; Banks, 2010a; Banks et al., 2010b; Harrington, 2004; Green, 2008, 2010). Mapping and flux assessments undertaken in numerous catchments of the Murray Darling Basin in Victoria, NSW and Queensland suggest large scale connection of main river reaches with the regional groundwater system (CSIRO SW_GW mapping). Generally, gaining reaches were identified mostly in the upper catchment headwaters (the majority of which are not covered in this work package), with losing conditions occurring predominantly on the alluvial plains in NSW and

Victoria. It is assumed that wetlands within the alluvial plains associated with losing rivers, are also dominantly losing and therefore are not GDEs.

Rule 7: Waterbodies which are close to GDEs that rely on the subsurface presence of groundwater (i.e. vegetation GDEs) are more likely to be GDEs, since the watertable would generally be shallow in these areas.

Rationale: Where vegetation is identified to be using groundwater the watertable must be relatively shallow, and it is therefore more likely that groundwater discharge to waterbodies could occur in the area. Therefore the presence of a GDE that relies on subsurface presence of groundwater can be used to identify potential groundwater discharge points, which result in GDEs that rely on the surface expression of groundwater.

The number of studies in certain areas of this work package shows heterogeneity in landscape, however, a general conceptual understanding of where rivers and wetlands that receive groundwater inflows was developed. A permanent water regime, the presence of alluvial aquifers, steep valley locations (particularly in fractured rock systems (Banks, 2010)) are more indicative of groundwater inputs. Additional indicators of likely groundwater inflows are shallow watertables and the presence of known springs.

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 26. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 26 GIS analysis rules to identify GDEs that rely on the surface presence of groundwater in WP3**

Rule	
1	Waterbodies close to known springs are more likely to receive groundwater inputs
2	Where shallow watertables occur, groundwater is more likely to be discharging into wetlands and rivers.
3	Certain swamp vegetation communities indicate likely groundwater inflows
4	A permanent water regime is indicative of groundwater discharge which maintains flow/water during the dry season.

Rule	
5	Certain geological formations are more likely to contribute baseflow to rivers (fractured rock in the Adelaide geosynclines, and outcropping GAB aquifers)
6	Waterbodies within riverine landscapes associated with losing rivers are not likely to be in connection with groundwater.
7	Waterbodies which are close to subsurface GDEs are more likely to be GDEs, since the watertable would generally be shallow in these areas.

8.2.2. Selection of datasets for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 27 shows the feature layers selected to map GDEs that rely on the surface expression of groundwater for WP3. These layers contain all the river, wetland and spring features that were analysed to establish whether a groundwater connection exists. These are either the datasets that the rules in section 8.2.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 27 Feature layer datasets for analysis of GDEs that rely on the surface presence of groundwater (rivers, wetlands, springs) in WP3**

State	Ecosystem	Dataset Name	Source or Custodian
SA	Wetlands	Harding 2010 Statewide GDE Classification/Wetlands_GDE_Classification_v1	DFW
	River	Harding 2010 Statewide GDE Classification/Watercourse250K_GDE_Classification_v1	DFW
	Springs	GAB Springs/GABSprings_GWPROJECTS	DFW
	Springs	SA Data Request/Springs_FlindersLEB	DFW
	Springs and waterholes	SA Data Request/Gazetteer_AquaticEcosystems	DFW
VIC	Wetlands	WETLAND1994	DPI
	Rivers	National Watercourses	DPI
	Springs	springs	DPI

State	Ecosystem	Dataset Name	Source or Custodian
NSW	Wetlands	NSW_Wetlands_2006	DECC
	Springs	ADMIN_HighPriority_GDEPoint_Jan2011	DECC
	River	National Watercourses	Geoscience Australia
QLD	Wetlands	QLD_WETLAND_SYSTEM_100K_A (V2)	DERM
	Rivers	National Watercourses	Geoscience Australia
	Springs	HYD_SPRING_V3	DERM

There is full coverage of feature layers in WP3 for wetlands, rivers and springs mapping. Mapping of GDEs that rely on the surface expression of groundwater could therefore be completed for the whole work package.

8.2.3. Selection of GIS analysis datasets for implementation of rules

Table 28 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the surface expression of groundwater in WP3. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 28, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

Table 28 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the surface expression of groundwater

#	RULES	Datasets needed for analysis	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	Waterbodies surrounding known springs	Springs datasets	Springs_FlindersLEB Gazetteer_AquaticEcosystems GABsprings_GWPROJECTS ADMIN_HighPriority_GDEPoint_Jan2011 HYD_SPRING_V3 Spring REs GAB_Watercourse_Springs Springs	SA SA SA NSW QLD QLD QLD VIC	The springs datasets are intersected with the wetlands/river polygons. Where the spring falls within a wetlands/river polygon, a positive result is recorded for the intersect. Where a positive result for the intersect is recorded, vegetation is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or not (0), i.e. just because it doesn't intersect with a spring doesn't mean the wetlands/river won't be interacting with groundwater.
2	GW discharge is more likely to occur in areas where the watertable is shallow	Depth to watertable mapping	GWater_Shallow_SWL, SWL_MIN (used for rivers) Wetlands_GDE_Classification_ v1, DTW_ZONE (used for wetlands) Basin in a box Victoria DTWT mapping	SA SA (note: there are conflicts btw the 2 DTWT maps for SA) Southern part of NSW MDB Vic	The state wide mapping of wetlands includes attributes which define depth to water table and confidence rating of the wetland being a GDE (which is based on depth to watertable). For the GDE Atlas analysis, the 'depth to water' attribute from the SA wetlands mapping is used, however the GDE rating is not used since additional data is being used to determine GDE potential in the Atlas. Groundwater interaction is considered likely where watertable depth is <5m (3), possible for watertables between 5 & 10m (2), and unlikely for watertables >10m (1).
3	Certain swamp vegetation communities indicate groundwater inflow.	Mapping of swamp vegetation	SA_VEG_DATA, DOMSPECIES Wetlands_1994, wetland category	SA Vic Rule could not be analysed in NSW, Qld	Attributes describing vegetation types were normalised as either likely to use groundwater (3); possibly use groundwater (2), unlikely to use groundwater (1), or not sure (0). Normalisation was done from literature and by reviewers and jurisdictions. For SA, the vegetation mapping was used (since the intent of this dataset is to map all vegetation, including swamp veg). For Vic, the attributes in the wetlands data was used, incorporating the EVC could

#	RULES	Datasets needed for analysis	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
					be a possibility. NSW wetlands data did not contain attributes that indicate GW presence. The broad scale data for Qld is being used for the project, which also does not indicate specific GW dependent swamp communities (the REs would have to be normalised to achieve this.)
4	Permanence of water (or attributes relating to GW source)	Wetland system mapping with permanency / source attributes	Wetlands_GDE_Classification_ v1, WTRREGIM Watercourse_GDE_ Classification_v1, PERENNIALITY QLD_WETLAND_SYSTEM_100K _A, WTRREGIME_ National watercourses, PERENNIAL	SA Qld Rule could not be analysed for NSW, Vic wetlands Whole WP	Where a permanent water regime occurs, it is more likely that groundwater maintains the water regime during low rainfall periods (3). A seasonal water regime indicates it is possible that groundwater maintains the presence of water after rainfall has ceased (2), and an intermittent or episodic water regime suggests rainfall dependence rather than groundwater use (1). Permanence attributes such as 'non-permanent' give no information about how long the presence of water remains after rainfall ceases, and so give no information about potential groundwater contributions (0).
		Landsat open water	WP3 Landsat (SA, VIC, NSW)	Whole WP	Remote sensing data was not used for Qld since a more comprehensive Landsat analysis for Qld was used to develop the WTRREGIME_ attribute. This was used instead. For NSW, SA, Vic, remote sensing of open water was used as an indicator of permanent presence of water. Where Landsat or MODIS open water intersected a wetlands/river polygon, the polygon was considered more likely to contain open water, and for this to contain groundwater (3). Where no intersect is recorded, the rule gives no indication whether the wetland/river interacts with groundwater or not (0), i.e. just because it doesn't intersect with a open water doesn't mean the wetlands/river won't be interacting with groundwater.
		MODIS open water	WP3 MODIS (SA, VIC, NSW)	Whole WP	

#	RULES	Datasets needed for analysis	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
5	Certain geological formations are more likely to contribute baseflow to rivers	Mapping of fractured rock aquifers (not available)			
		Groundwater Provinces	Groundwater Provinces	Whole WP (but only analysed for Adelaide Geosyncline, where we have information)	Because the Adelaide Geosyncline contains fractured rock aquifers which contribute baseflow to rivers, where a river intersects the Adelaide Geosyncline, it is more likely to receive baseflow (3).
		Mapping of GAB aquifers	National geology	Whole WP	GAB aquifers are listed in the Qld GAB WRP. These aquifers are more likely to contribute baseflow to rivers than other geological formations (3).
6	Waterbodies in landscapes that contain losing rivers are less likely to be GDEs	Mitchell Landscapes CSIRO connectivity mapping	CSIRO connectivity mapping Mitchell Landscapes Bioregions, Subregion	NSW,Vic,Qld NSW Qld, Vic Rule could not be analysed in SA	In a landscape where rivers are losing, wetlands are likely to be above (disconnected from) the watertable in that landscape. Each wetland in landscapes where losing rivers were mapped was considered unlikely to be connected to groundwater (1). Each wetland in landscapes where gaining rivers were mapped was considered likely to be connected to groundwater (3).
7	Wetlands with surrounding likely vegetation GDEs	Subsurface GDEs	Subsurface GDE mapping	Whole WP	Where a ‘high potential’ subsurface GDE intersects with a wetland/river, this was assumed to increase the potential for a wetlands/river GDE to exist (3).

8.2.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 28) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater interaction:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a ‘blank’) = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 28.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

8.2.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

8.2.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 29 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative

differences between weightings controlling the GDE potential result. Weightings are not comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 29 are only comparable for each feature dataset, and so should only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Depth to watertable weighted so that deep watertables always result in a low or moderate GDE potential, depending on the other data; and shallow watertables always result in a high or moderate GDE potential.
- Springs weighted so that intersecting vegetation polygons have high GDE potential.
- In Victoria, water source attribute weighted heavily, so that groundwater source always results in high GDE potential.
- The presence of loosing streams (as mapped in the CSIRO GW-SW interaction project (Parsons, et al., 2011)), was weighted so that intersecting GDE polygons resulted in a low GDE potential.
- The presence of gaining streams (as mapped in the CSIRO GW-SW interaction project (Parsons et al., 2011)), was weighted so that intersecting GDE polygons resulted in a high GDE potential.

- **Table 29 Weighting for each GIS Analysis rule/dataset for GDEs that rely on surface expression of groundwater in WP3**

	GIS Analysis Rules							
Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4		Rule 5	Rule 6	Rule 7
	Presence of a spring	Depth to water-table	Swamp vegetation community	Persistent water regime	Open Water (remote sensing)	Geological formation contributing baseflow	Loosing streams/ wetlands in same landscape not GDEs	Presence of a sub-surface GDE
nsw_wetlands (NSW)	10	10	NA	NA	5	NA	10/4	5
qld_wetlands (QLD)	14	NA	NA	8	NA	8	10/4	5
Wetlands_gde (SA)	12	10	8	6	4	NA	NA	4

	GIS Analysis Rules							
Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4		Rule 5	Rule 6	Rule 7
Wetlands_1994 (VIC)	NA	14	7	14 (GW source attribute)	3	NA	NA	4
SA Rivers (SA)	70	14	7	7	3	8	NA	4
National watercourses (NSW, Qld, Vic)	36	10	4	6	4	8	14/2	5

8.2.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This includes non-natural landscapes such as reservoirs, dams and irrigated land. It also excludes features that are artefacts of mapping, and do not represent actual features in the landscape.

The definition queries applied to each dataset to exclude ecosystems that cannot be GDEs that rely on the surface expression of groundwater are listed below.

For the **nsw_wetlands** feature layer dataset definition queries were applied to the field 'SUBGROUP' to exclude polygons attributed as:

- Reservoir
- Blanks (' ')

For the **Qld_wetlands_100K, v2** feature layer dataset definition queries were applied to the field 'WTRREGIME' to exclude polygons attributed as:

- TI (tidal)
- Blanks (' '; and '-')

To the field 'WETCLASS' to exclude polygons attributed as:

- Estuarine
- Marine

- Blanks (‘ ‘; and ‘-‘)

To the field ‘HYDROMOD’ to exclude polygons attributed as:

- H2M1
- H2M6
- H2M7
- H2M8
- H3C1
- H3C2
- H3C3

To the field ‘HAB_L’ to exclude polygons attributed as:

- Blanks (‘ ‘; and ‘-‘)
- Marine
- Estuarine – water
- Artificial/ highly modified wetlands (dams, ring tanks, irrigation channels, drains, canals)

For the **wetlands_gde (SA)** feature layer dataset definition queries were applied to the field ‘WETLAND_SYS’ to exclude polygons attributed as:

- MAR (Marine)
- EST (estuarine)

To the field ‘WATERREGIM’ to exclude polygons attributed as:

- Intertidal flat
- Supratidal flat

For the **wetlands_1994 (Vic)** feature layer dataset definition queries were applied to the field ‘X_CATEGORY’ to exclude polygons attributed as:

- Salt works
- Sewerage pond

To the field ‘X_SUBCATEG’ to exclude polygons attributed as:

- Impoundment
- Intertidal flats

For the **watercourses_gde (SA)** feature layer dataset definition queries were applied to the field ‘PERENNIAL’ to exclude polygons attributed as:

- Blanks (‘ ‘)
- Not Applicable

For the **national_watercourses (Vic, NSW, Qld)** feature layer dataset definition queries were applied to the field 'PERENNIAL' to exclude polygons attributed as:

- Blanks (' ')

8.3. Attribution of GDE identified in previous studies (from literature)

GDEs were identified in the literature review in Task 2. These were matched to polygons in the vegetation, river, and wetland feature layers where possible. The majority of these GDEs could be matched to existing polygons, which were attributed as either 'GDE identified in previous study: fieldwork'; or 'GDE identified in previous study: desktop'. The Tier 3 attributes recorded in the literature review have also been entered into the GDE Atlas attribute table for the GDEs identified in previous studies.

8.4. Transfer of attributes from existing spatial datasets to GDE polygons

Tier one attributes were populated in the GDE Atlas attribute table using national datasets where available. Jurisdiction's spatial datasets also contained information which could be used in the GDE Atlas attribute table, to either:

- Identify GDEs that had been mapped in a spatial layer in previous studies, and/or
- To populate other attributes in the GDE Atlas attribute table for GDEs that were derived in Task 5.

8.4.1. Datasets used to map GDEs identified in previous studies

In work package 3, the spatial datasets used to attribute GDE polygons as either 'GDE identified in previous study: fieldwork'; or 'GDE identified in previous study: desktop' are shown in Table 30. These datasets were either used to attribute polygons within the feature layer datasets, or entered in their entirety as feature layer datasets. Either way, the information from these datasets was incorporated into the GDE Atlas to show where GDEs were identified in previous studies.

- **Table 30 Spatial datasets used to map GDEs identified in previous studies (both desktop and fieldwork studies)**

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
SA			
MOSQCK_PERMPOOLS	Permanent pools	All	Watercourse250K_GDE_Classification_v1
MOSQCK_BASEFLOWZONES	Baseflow rivers		Watercourse250K_GDE_Classification_v1
Hydro_Pool_or_dam__15m	Permanent pools	Dry season pool	Watercourse250K_GDE_Classification_v1
Hydro_Pool_or_dam_greater_than_15m	Permanent pools	Dry season pool	Watercourse250K_GDE_Classification_v1
Hydro_Baseflow_MLR	Baseflow rivers	Dry season baseflow	Watercourse250K_GDE_Classification_v1

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
RIPARIAN_Baseflow_Light_2001	Baseflow rivers	Permanent Baseflow/ Probable Baseflow	Watercourse250K_GDE_Classification_v1
RIPARIAN_Baseflow_Broughton_2000	Baseflow rivers	Permanent Baseflow/ Probable Baseflow	Watercourse250K_GDE_Classification_v1
Pools_willochra	Permanent pools	All	Pools_willochra
Willochra_baseflow	Baseflow rivers	Baseflow	Willochra_baseflow
Pool_Baseflows	Permanent pools	All	Watercourse250K_GDE_Classification_v1
Gazetteer_AquaticEcosystems	Springs	SPRG	Gazetteer_AquaticEcosystems
Springs_FlindersLEB	Springs	All	Springs_FlindersLEB
NSW			
ADMIN_HighPriority_GDEPoint_Jan2011	Springs	All	ADMIN_HighPriority_GDEPoint_Jan2011
QLD			
GAB_watercourse_springs	Baseflow rivers	All	Major Watercourses
Spring REs	vegetation & wetlands	Selected REs[B]	QLD_WETLAND_SYSTEM_100K RE06b
HYD_SPRING_v3	Springs	Unvisited springs[A]	HYD_SPRING_v3
VIC			
EVCBC2005	Vegetation	EVC NAME= SAMPHIRE SHRUBLAND and SAMPHIRE SHRUBLAND/saline land mosaic	EVCBC2005
Wetlands_1994	Wetlands	PWS = groundwater	Wetlands_1994
ALL			Major Watercourses
MDB_SW_GW_V06_LCC	Baseflow rivers	Gaining	
GDEs IDENTIFIED IN PREVIOUS STUDY: FIELDWORK			
NSW			
ADMIN_HighPriority_GDEPoly_Jan2011	Wetlands	Wetlands	NSW_wetlands
QLD			
HYD_SPRING_v3	Springs	Visited springs[A]	HYD_SPRING_v3

A – Visited and unvisited springs were distinguished using the POINT_ID attribute, as advised by DERM.

B – Spring REs were identified by DERM.

8.4.2. Datasets used to populate attributes in the GDE Atlas attribute table

Information from jurisdiction's spatial data was incorporated into the GDE Atlas by transferring the relevant attributes into the GDE Atlas attribute table. A summary of the data used to populate each attribute is shown in Appendix A.

8.5. Data gaps and recommendations

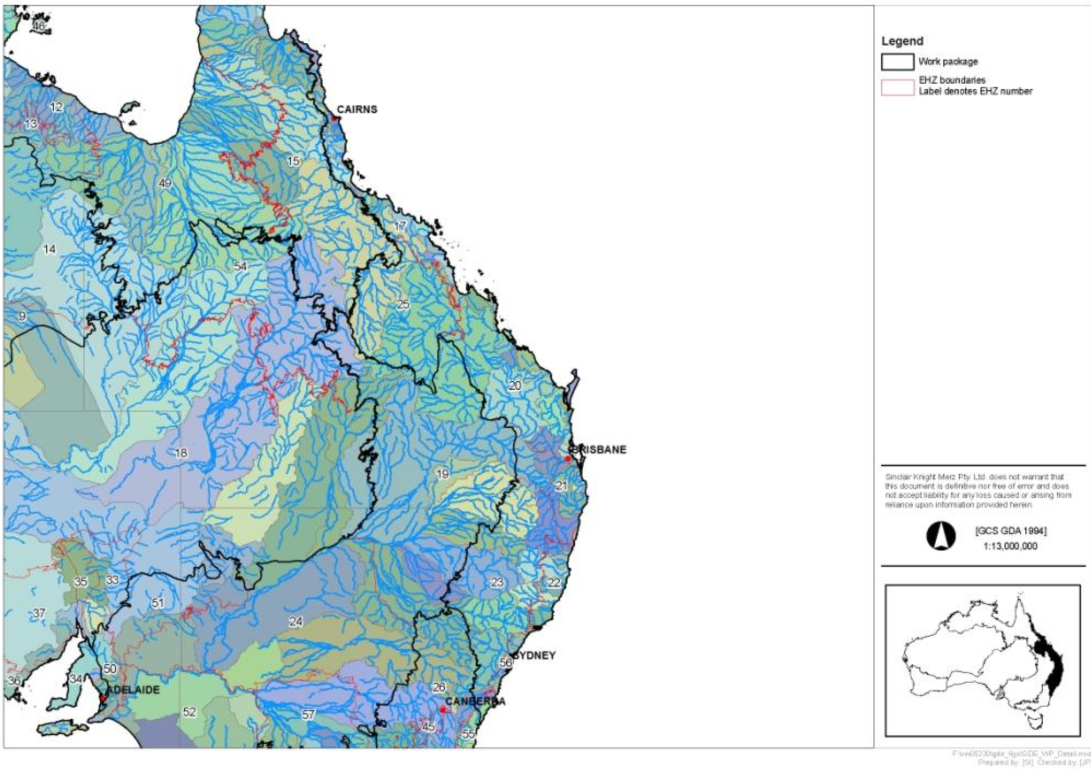
Greater coverage of depth to watertable contour maps would significantly improve the GDE maps. There was no depth to watertable information available for Queensland and the NSW depth to watertable map covered only the southern part of the MDB. The 'depth to watertable' rule (rule 2 for GDEs that rely on the subsurface presence of groundwater) is considered to provide a reliable indication of the potential for groundwater interaction and as such, it was weighted heavily in the analysis and therefore strongly influenced the results. This has resulted in the boundary of the NSW depth to watertable dataset being visible in the resulting GDE map. Statewide coverage of depth to watertable contours is required so that all of the GIS analysis rules can be applied across NSW. This would remove the boundaries within the GDE mapping that are due to incomplete coverage of GIS analysis datasets.

9. Application of Methodology in east coast Australia (WP4)

The WP4 area is shown in Figure 17 and incorporates 7 EHZs. WP4 spans three distinct climate regions according to the Bureau of Meteorology's Major Seasonal Rainfall Zones (http://www.bom.gov.au/climate/environ/other/seas_group.shtml). The climate in the north of WP4 is classified as summer dominant, where rainfall occurs almost exclusively in summer and the winter is dry. One of the highest rainfall areas in Australia is the region around Cairns, which receives more than 3,200 mm/yr rainfall on average. Further south (approximately between Rockhampton and Sydney) the climate is characterised by a wet summer and a low winter rainfall. On the southern margin of WP4, rainfall is generally more uniform across the year, although there are still distinct seasons where evaporation exceeds rainfall and water availability for vegetation is therefore limited.

The WP4 area captures the coastal strip, mountainous hinterland, and the inland foothills which grade into the Great Artesian and Murray Darling Basins. As such, there is a large range in topography as well as rainfall within the work package.

Mapping was completed for the majority of the work package area, however there was an area in the western part of NSW which was not covered by vegetation mapping. This lack of mapping coverage meant that GDEs that rely on the subsurface presence of groundwater could not be mapped in that area. Complete mapping coverage for GDEs that rely on the surface expression of groundwater was possible.



- **Figure 17 Work package 4 area showing river basins and EHZs**

9.1. Identification and mapping of GDEs that rely on the SUBSURFACE presence of groundwater

9.1.1. Literature review and GIS Analysis Rules

The GIS analysis rules described in this section were based on the conceptual understanding gained during the literature review. The literature reviewed provided information on GDEs which rely on the subsurface presence of groundwater for the Pioneer Valley, Burnett Basin, Isaac Connors alluvial system, Callide catchment, and Stradbroke Island off the coast of Brisbane. In NSW, literature was reviewed for the Gosford/Wyong area, the Nambucca, Hastings, Macleay Coffs, Bellinger, Tweed, Brunswick, Richmond, and Clarence River catchments, the Port Stephens area, the Wallis Lake catchment, and the Alstonville Plateau.

Rule 1: Shallow watertable (<10 m) indicates possible groundwater use.

Rationale: In general, where shallow watertables (<10 m) occur, vegetation is more likely to be accessing groundwater than in areas where groundwater levels are deep.

In the Pioneer Valley, studies have shown that the rooting depth of major vegetation communities appear to reflect historical watertable fluctuations, and several types of vegetation were found to use groundwater where the watertable is within 10 m of the surface

(Cook, et al., 2006a; Howe, et al., 2006). On Stradbroke Island, root depth is expected to be less than 10 m, and with the watertable typically around 20m below the surface, most vegetation is unlikely to be a GDE (Overton, 2006). Vegetation frequently relies on soil water in the unsaturated zone, particularly where groundwater is deep (and the unsaturated zone is thick). It can be difficult to distinguish vegetation that uses water stored in the unsaturated zone from vegetation that uses groundwater (Cook, et al., 2006a; Howe, et al., 2006), however it is reasonable to assume that a watertable depth of less than 10 m increases the likelihood of overlying vegetation being a GDE.

Research in the Burnett basin also uses watertable depth as an indicator of groundwater dependence, suggesting that groundwater dependent vegetation is largely restricted to low-lying coastal areas where the watertable is shallow. This study reports that where the depth to groundwater is greater than 3 m, vegetation is likely to rely on water stored in the unsaturated zone rather than groundwater (Parsons, et al., 2005). Several vegetation types were assessed for groundwater use at different sites within the Burnett Basin, and dependence was found to be bases on the depth (availability) of groundwater. Hence vegetation type is not they key determinant of an ecosystem being a GDE.

Investigations in the Callide catchment suggest that the relationship between depth to groundwater and groundwater use is: where depth to groundwater is < 5m, groundwater dependency of remnant terrestrial ecosystems is high; where depth to groundwater is 5-10 m, groundwater dependency of remnant terrestrial ecosystems is proportional; where depth to groundwater is >10 m, groundwater dependency of remnant terrestrial ecosystems is opportunistic (SKM, 2008).

Virtually all the vegetation in Tomago was identified as having some level of dependence on the groundwater based on the depth of the underlying watertable. Vegetation in Tomaree was assessed as having approximately 53% of vegetation dependent upon groundwater, since watertables are deeper in this area (HWC, 2006). In general, vegetation communities in the Tomago/Tomaree areas, are considered likely to be GDEs where they are located above shallow water tables, with low water-holding capacity soils (Griffith2008). On the Alstonville Plateau, where groundwater is close to the surface it plays an important role in maintaining vegetation activity throughout the dry season (Brodie, et al., 2001).

In summary, depth to groundwater is considered a key indicator of groundwater dependency. A range of watertable depths between 3 and 10 m have been suggested as the maximum depths for assuming groundwater dependence of overlying vegetation. In the absence of watertable mapping, topography is used to approximate the watertable, which necessitates the assumption that the depth to the watertable is a more subdued imitation of the topography. For mapping of GDEs that rely on the subsurface presence of groundwater, it is assumed that an area of low-lying relief means the watertable is in closer proximity to vegetation roots. Such an assumption has some support in the literature: in coastal and near coastal environments of dunes and

interdunal flats in the Tomago/Tomaree region, vegetation GDEs are likely to occur in topographic depressions and interdunal/barrier swales. Similarly, a sloping or elevated landscape is characterised by a larger unsaturated zone separating the watercourse and the watertable, meaning that the likelihood of vegetation using groundwater is lower.

Rule 2: Low soil water holding capacity (SWHC) suggests that vegetation is more likely to access groundwater.

Rationale: Vegetation frequently relies on soil water in the unsaturated zone, and it can be difficult to distinguish between vegetation that uses either water stored in the unsaturated zone or groundwater (Cook, et al., 2006a). Along with a shallow watertable, SWHC is a key piece of data that informs on whether the water requirements of vegetation can be satisfied by water stored in the unsaturated zone, or whether the vegetation will also need to rely on groundwater. Vegetation that occurs over shallow groundwater, in soils with a low SWHC, is likely to be groundwater dependent (Griffith & Wilson, 2008).

Research in the Burnett basin suggests that groundwater dependent vegetation is largely restricted to low-lying coastal areas which have low soil water holding capacity (Parsons, et al., 2005). The Sandy Creek alluvial aquifer in the Pioneer Valley has also been reported as having a low SWHC, resulting in greater use of groundwater by vegetation (where it is within 10 m of the surface) (Cook, et al., 2006a).

Rule 3: Particular vegetation types are indicative of groundwater use.

Rationale: A significant volume of work has been done across WP4 assessing the groundwater use of various vegetation communities. The outcomes reported are summarised in Table 31. This table does not identify the likely groundwater dependence of all vegetation types, only those that were discussed in the literature reviewed for WP4.

- **Table 31 Likelihood of groundwater interaction for some vegetation types in WP4.**

Species / vegetation community	Likely to use GW	May use GW	Unlikely to use GW	Location and source
Corymbia clarksoniana, C. tesselaris, Melaleuca leucadendra, M. viridiflora and M. tanaris	✓			Pioneer Valley, (Cook, et al., 2006a, Howe, et al., 2006)
Eucalyptus platyphylla and Lophostemon suaveolens		✓		Pioneer Valley (Cook, et al., 2006a, Howe, et al., 2006)
Eucalyptus woodlands and non-riparian vegetation			✓	Isaac Connors (SKM, 2009)
Casuarina woodlands, Melaleuca woodlands, and Notophyll forest	✓			Stradbroke Island (Overton, 2006)

Corymbia/Eucalyptus open forest (RE 12.2.11) Notophyll vine forest/ thicket (RE 12.3.3) *M. quinquenveria / E. tereticornis* (RE 12.3.6) Eucalyptus / Corymbia / Melaleuca woodlands (RE 12.5.4)	✓			Burnett Catchment (Parsons, et al., 2005)
Saltmarshes, and riparian and floodplain rainforests (for example the Black Bean)		✓		Tweed River, Brunswick River, Richmond River (Graham, 2001c) and Clarence River catchments (Graham, 2001a)
Floodplain forests, and rainforests outside of riparian and floodplain areas			✓	Tweed River, Brunswick River, Richmond River (Graham, 2001c) and Clarence River catchments (Graham, 2001a)
All moist coastal vegetation types - Sedgelands and Wet Heaths	✓			Tweed River, Brunswick River, Richmond River (Graham, 2001c)
Coastal Woodlands and drier Banksia Scrubs		✓		Tweed River, Brunswick River, Richmond River (Graham, 2001c)
Moist Eucalypt forests			✓	Tweed River, Brunswick River, Richmond River (Graham, 2001c), Clarence River catchments (Graham, 2001a).
Wetland and sedgeland communities (including Baumea Sedgeland, Lepironia Sedgeland, Mixed Sedgeland and Phylidrum Sedgeland), shrub swamp, and swamp forest, swamp sclerophyll mallee woodland, swamp sclerophyll shrubland	✓			Port Stephens, Wallis Lake (Driscoll and Bell, 2006; Griffith and Wilson, 2008).
Wet heath communities, Sand Wallum Scrub and Apple-Blackbutt-Bloodwood-Forest	✓			Port Stephens, Wallis Lake (Driscoll and Bell, 2006; Griffith and Wilson, 2008)).
Larger woodland forest communities (dry sclerophyll forest and woodland, dry sclerophyll mallee woodland, and dry heathland)		✓		Port Stephens, Wallis Lake (Driscoll and Bell, 2006; Griffith and Wilson, 2008, Griffith and Wilson, 2001).
Dry open forests on volcanic hills (Nerong Calytrix Heath, Nerong Open Forest and Nerong Scrub)			✓	Port Stephens, Wallis Lake (Driscoll and Bell, 2006; Griffith and Wilson, 2008).

Floodplain and riparian Forests (Forest Red Gum, Pink Bloodwood, Swamp Mahogany, Blackbutt, Tallowwood, Rough barked Apple, Turpentine and Swamp Box)	✓			Nambucca, Hastings and Macleay (Graham, 2001).
Vegetation communities in floodplain environments over alluvial aquifers		✓		Nambucca, Hastings and Macleay (Graham, 2001).
Alluvial Tall Moist Forest and Coastal Wet Gully Forest (Eucalyptus saligna (Sydney Blue Gum))		✓		Gosford/Wyong (ERM, 2005)
Melaleuca biconvexa	✓			Gosford/Wyong (ERM, 2005)
Melaleuca quinquenervia and *E. robusta* dominant swamp forests	✓			Gosford/Wyong (Winning, 1996)

These comments on potential groundwater use were used to normalise the vegetation types/communities in the available vegetation mapping layers (see sections 9.1.2 to 9.1.4). In addition to this, jurisdictions have normalised vegetation types which were not mentioned in the literature. As such, all vegetation types in the vegetation feature layer datasets have now been normalised.

Rule 4: Constant vegetation activity throughout the year, or a high ET:P ratio, indicates a water source other than rainfall is being used (possibly groundwater).

Rationale: Vegetation water use studies (e.g. Morris et al., 1998; Prathapar and Myer, 1992) have shown that plants use any available water source, such that ET is greater where water sources in addition to rainfall and water stored in the unsaturated zone exist (e.g. irrigation or groundwater). Therefore, riparian vegetation on unregulated streams in areas of shallow watertables (non-irrigated) that maintain high ET during dry periods will most likely be using groundwater.

The remote sensing layer and the ID layer (described in section 3) show the likelihood that a certain ecosystem is using a water source in addition to rainfall. Where the probability is higher, it is more certain that an additional water source is being accessed. As such, probabilities of above 8 are considered to strongly indicate that a second water source is present, and probably that larger volumes of water are being utilised. It is therefore assumed that probabilities of 8 and above suggest that this second water source is more likely to be groundwater.

Rule 5: Vegetation around known GDEs (including springs and gaining rivers) is more likely to be reliant on groundwater.

Rationale: In a general sense, where groundwater is known to occur at or near the surface, it can be assumed that vegetation in these areas also uses the groundwater. A number of datasets were supplied for the GDE Atlas project which identified potential GDEs. These datasets were either created and verified through field work, or they were created by GIS analysis and extrapolation. They show rivers and wetlands that have previously been identified as GDEs. If surface water systems such as rivers and wetlands have a baseflow component, it follows that the watertable must be relatively close to the surface, and as such, vegetation in the area could also be using the groundwater.

For springs, the watertable (or the surficial aquifer) may not be supplying a vegetation GDE since the spring may be an expression of the potentiometric surface of a deeper aquifer. However surrounding vegetation is still dependent on this discharging groundwater, and so springs were included in the analysis to identify GDEs that rely on the subsurface presence of groundwater.

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 32. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 32 GIS analysis rules for GDEs that rely on the subsurface presence of groundwater**

Rule	
1	Shallow watertable (<10m) indicates possible groundwater use
2	Low SWHC suggests that vegetation is more likely to access groundwater
3	Particular vegetation types are indicative of groundwater use
4	Constant vegetation activity throughout the year indicates a water source other than rainfall is being used (possibly groundwater)
5	Vegetation surrounding known GDEs (including springs and gaining rivers) are more likely to be reliant on groundwater

9.1.2. Selection of data for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE

was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 33 shows the features layers selected to map GDEs that rely on the subsurface presence of groundwater for WP4. These layers contain all the vegetation features that were analysed to establish whether a groundwater connection exists. The feature layers are either the datasets that the rules in section 9.1.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 33 Feature layer datasets for analysis of GDEs that rely on the subsurface presence of groundwater (vegetation) in WP4**

State	Ecosystem	Dataset Name	Source or Custodian
NSW	Vegetation	murray_darling_M305_VISmap_917	OEH
	Vegetation	unensw10_12_08join_GDE94	?
	Vegetation	forest_ecosystems_lower_north_east	?
	Vegetation	south_coast_SCIVI_VISmap_2230	OEH
	Vegetation	GDE_Alstonville_Veg200mBuffer	NOW
	Vegetation	Blackville	NOW
	Vegetation	Wollemi	NOW
	Vegetation	West Blue Mountain	NOW
	Vegetation	Central West Lachlan	NOW
	Namoi	Namoi	NOW
QLD	Vegetation	RE06b	DERM

Mapping of potential GDEs that rely on the subsurface presence of groundwater was completed for the majority of the work package area, however there were four small areas in the south of WP4 in NSW which were not covered by vegetation mapping. The absence of vegetation feature datasets meant that GDEs that rely on the subsurface presence of groundwater could not be mapped in those areas.

9.1.3. Selection of GIS analysis datasets for implementation of rules

Table 34 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the subsurface presence of groundwater in WP4. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 34, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

- **Table 34 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the subsurface presence of groundwater**

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	Shallow watertable (<10m) indicates probable groundwater use	Depth to watertable mapping	Pioneer DTWT map Burnett Basin DTWT map Callide catchment DTWT map NSW gwslices 6 DTWT map	Parts of Qld All NSW	Groundwater use is considered likely where watertable depth is <10m (3), possible for watertables between 10 & 20m (2), and unlikely for watertables >20m (1).
		Land surface elevation contours	FLAG	Qld NSW, where depth to WT did not cover	FLAG landscape data is broad scale and requires significant assumptions to be made regarding depth to watertable. It is used where there is no depth to watertable data. This rule is weighted very low. Low-lying landscapes indicate a shallow DTWT, and are more likely to support GDEs (3); slope landscapes indicate medium DTWT, and possibly support GDEs (2); plateau landscapes indicate deeper DTWT, and are unlikely to support GDEs (1).
2	Low SWHC suggests that vegetation is more likely to access groundwater during the dry season	SWHC mapping	Qld_CombinedSoils_2M (Qld) coastalsoils (NSW) soilsmap_markmitchell (NSW)	Qld NSW NSW	Qld: 'low' SWHC is where AWC (field capacity) – AWC (wilting point) = <9mm (3); 'high' SWHC capacity is where AWC (field capacity) – AWC (wilting point) = >9mm (1). NSW: 'low' SWHC is where PAWC is <50mm (3); 'moderate' is where PAWC is between 50 & 250mm (2); 'high' is where PAWC is >250mm (1).
3	Particular vegetation types are indicative of groundwater use.	Vegetation mapping	Qld RE06b (Qld), DBVG2M unensw10_12_08join_GDE94 (NSW) forest_ecosystems_lower_north_east (NSW) south_coast_SCIVI_VISmap_2230 (NSW) Murray_darling_M305_VISmap_917 (NSW) Central West Lachlan	Whole WP	Attributes describing vegetation types were normalised as either likely to use groundwater (3); possibly use groundwater (2), unlikely to use groundwater (1), or not sure (0). Normalisation was done from literature and by reviewers and jurisdictions.

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
			West Blue Mountain Wollemi Blackville Namoi		
5	Constant vegetation activity throughout the year indicates a water source other than rainfall is being used (possibly groundwater)	WP4 IDE mapping	WP4 remote sensing layer	Whole WP	The probability from the RS layer is assigned to each vegetation polygon by majority value. That is, the probability of the greatest number of pixels that intersect with the polygon becomes the probability of the whole polygon. Probabilities of 6 & 7 give no indication of groundwater use (0); probabilities of 8, 9, 10 suggest groundwater use is more likely (3).
6	Vegetation around known GDEs (including springs and gaining rivers) are more likely to be reliant on groundwater	Previous GDE mapping	HYD_SPRING (Qld) Spring REs (Qld) GAB_watercourse_springs (Qld) ADMIN_HighPriority_GDEPoint_Jan2011 (NSW) ADMIN_HighPriority_GDELines_Jan2011 (NSW) ADMIN_HighPriority_GDEPoly_Jan2011 (NSW) BM_Swamps_5B_region (NSW) CSIRO MDB GW/SW interaction map	Whole WP	The previously mapped GDE and springs datasets are intersected with the vegetation polygons. Where the majority of the previously mapped GDE falls within the vegetation polygon, a positive result is recorded for the intersect. Where a mapped spring falls within the vegetation polygon, a positive result is recorded for the intersect. Where a positive result for the intersect is recorded, vegetation is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or not (0), i.e. just because it doesn't intersect with a spring/previously mapped GDE, doesn't mean the vegetation won't be using groundwater.

9.1.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 34) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater use:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 34.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

9.1.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

9.1.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 35 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not

comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 35 are only comparable for each feature dataset, and so may only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- In Queensland, likely groundwater using vegetation and high ET always result in a high GDE potential.
- In Queensland, likely groundwater using vegetation and low SWHC results in a moderate GDE potential.
- Shallow depth to watertable results in a high or moderate GDE potential, depending on the other data
- Deep watertables always result in a low or moderate GDE potential.
- Vegetation that intersects with a previously mapped GDE or a spring usually results in a high GDE potential.

Table 35 Weighting for each GIS Analysis rule/dataset for GDEs that rely on subsurface expression of groundwater in WP4

Feature Layer Dataset	Rule 1		Rule 2	Rule 3	Rule 4	Rule 5
	Shallow watertable (DTWT mapping)	Landscape elevation*	Low SWHC	Vegetation type	High ET:P	Presence of known GDEs /springs
RE06B_CS (Qld)	na	1	4	8	8	16
RE06B_CC (Qld)	10	1	4	8	8	20
RE06B_CN (Qld)	10	1	4	8	8	na
RE06B_FN (Qld)	na	1	4	8	8	na
RE06B_SE (Qld)	10	1	4	8	8	16
unensw10_12_08join_GDE94	14	1	3	4	6	24
forest_ecosystems_lower_north_east	14	1	3	6	8	18

Feature Layer Dataset	Rule 1		Rule 2	Rule 3	Rule 4	Rule 5
south_coast_SCIVI_VISmap_2230	14	1	3	6	6	18
Murray_darling_M305_VISmap_917	10	na	4	8	10	na
Central West Lachlan	10	na	4	4	8	20
West Blue Mountain	10	na	4	4	8	20
Wollemi	10	na	4	4	8	20
Blackville	10	na	4	4	8	20
Namoi	10	na	4	4	8	20

* Used only where DTWT mapping is not available

The mapping of GDEs that rely on the subsurface presence of groundwater covers the whole of WP4 apart from an area in western NSW. This is because the available vegetation feature layers do not cover that area and hence there is no ecosystem linework available for the analysis to assign GDE potential.

9.1.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This included non-natural landscapes such as settlements, pasture, and plantations, as well as natural landscapes that do not use groundwater, such as grasslands and bare earth.

All vegetation polygons that had an ID likelihood of 5 and less were removed at this stage, as these ecosystems were not likely to be accessing a source of water in addition to rainfall. The additional definition queries applied to each dataset to exclude ecosystems that could not be subsurface GDEs are listed below.

For the **RE06b (Qld)** feature layer dataset a definition query was applied to the field ‘DBVG2M’ to exclude polygons attributed as:

- 30 – 33

- 35
- Ocean
- Sand
- Water

In the field ‘RE’ to exclude polygons attributed as:

- Canal
- Estuary
- Non-rem
- Ocean
- Sand

In the field ‘DBVG1M’ to exclude polygons attributed as:

- Non-r

For the **Forest_ecosystems_lower_north_east (NSW)** feature layer a definition query was applied to the field ‘ECOSYSTEM’ to exclude polygons attributed as:

- Cleared-Partially cleared
- Natural grassland
- Sand ridge
- Settlements-Roads-Gravel pits
- Water surfaces

For the **Murray_darling_M305_VISmap_917 (NSW)** feature layer a definition query was applied to the field ‘DESCRIPTION’ to exclude polygons attributed as:

- Grassland
- Barren
- Crops and annual pastures
- Grassland with isolated chenopods
- Native grassland
- Settlement
- Water

For the **unensw10_12_08join_GDE94 (NSW)** feature layer a definition query was applied to the field ‘VEGCOMM’ to exclude polygons attributed as:

- Cleared
- Cleared2
- Native grassland

- Natural grasslands
- Rock
- Water
- Introduced
- Forestry plantation
- Forestry Plantations
- 1000 Introduced
- 165 Forestry Plantation

For the **south_coast_SCIVI_VISmap_2230 (NSW)** feature layer no definition query was applied.

For the Blackville **(NSW)** feature layer a definition query was applied to the field '**FLORISTICS**' to exclude polygons attributed as:

- Other
- Mapping
- Cleared
- Unclassified
- non native
- rock
- 0utcrop
- sparse

For the Central West Lachlan **(NSW)** feature layer a definition query was applied to the field '**field BVT_LAB** ' to exclude polygons attributed as:

- "
- Water
- Wetland
- Rocks
- town,

For the West Blue Mountain **(NSW)** feature layer a definition query was applied to the field '**field MAP_UNIT_N**' to exclude polygons attributed as

- Nill

For the Wollemi **(NSW)** feature layer a definition query was applied to the field ‘C**ode**’ to exclude polygons attributed as

- Agriculture
- Pine
- Urban
- Water
- Cleared

For the **Namoi (NSW)** feature layer dataset a definition query was applied to the field ‘Veg1’ to exclude polygons attributed as:

- Quarry
- Settlements
- Urban
- Wetland
- Water
- Agriculture
- Man Made
- Mine
- Grassland
- Plantation
- Cropping
- fen cline
- exotic
- weeds
- cleared
- treeless
- regrowth
- house
- other
- unknown
- roadside

- unlabeled
- untyped
- trial
- excluded
- altered
- pasture
- improved
- house
- nil
- not recorded
- code assessed
- roadside
- no code
- present

9.2. GDEs that rely on the SURFACE expression of groundwater

9.2.1. Literature review and GIS analysis rules

The literature describing GDEs that rely on surface expression of groundwater related mainly to the developed water resource areas in Queensland, including the Pioneer Valley, Burnett Basin, Isaac Connors alluvial system, and Callide catchment. In NSW, literature was reviewed for the Gosford/Wyong area, the Nambucca, Hastings, Macleay and Namoi River catchments, and for the Alstonville Plateau.

Rule 1: The presence of persistent surface water indicates groundwater connection.

Rationale: In the north of WP4, rainfall is concentrated in the seven months between November and May, with the remaining five months being significantly drier. High intensity rain events occur in most of the WP4 area, resulting in large volumes of run-off. Once run-off has subsided, the recharged aquifer continues to discharge into surface water bodies, allowing flow to be maintained between rain events. The waterbodies are therefore reliant on groundwater discharge to achieve a consistent flow regime, which provides habitat and water supply throughout the year.

The link between persistent flow and groundwater discharge is documented frequently in the literature. Investigations in Funnel Creek (part of the Isaac Connors alluvial system) (SKM, 2009a), Maules Creek in the Namoi catchment (Anderson and Acworth, 2009a), and spring-fed streams on the Alstonville Plateau (Brodie et al., 2001) relate permanent or near permanent flow to baseflow contributions. In all of these cases, the local geology has also been identified to have a strong influence over the occurrence of groundwater discharge and the persistence of flow.

The available watercourse mapping (National Watercourses) is thought to significantly underestimate the number of rivers that have a perennial flow regime, and this results in rivers generally being assessed as having a lower potential for groundwater interaction. To capture more rivers that are likely to flow permanently (or near permanently), geology type was incorporated as a rule (rule 3 below).

Because of the large rainfall gradients within this work package, the efficacy of this rule is likely to vary across the work package. Higher rainfall on the east side of the ranges suggests that persistent waterbodies may be able to maintain their water regime without groundwater contributions. On the west of the ranges rainfall is lower and persistent waterbodies are more likely to require supplementation by groundwater. This is discussed further in rule 2 below.

Rule 2: Persistent waterbodies occurring in bioregions west of the ranges receive less rainfall and therefore are more likely to rely on groundwater contributions to maintain a persistent water regime.

Rationale: Rule 1 (above) is most effective at identifying the potential for groundwater interaction in areas that have a distinct dry season, or in areas that have low annual rainfall. It is considered that less than 20 mm in one month is generally insufficient to cause run-off in a vegetated catchment (pers. Comm. Derek Eamus), and therefore persistent waterbodies in these areas must be sustained through groundwater contributions.

High rainfall occurs in the ranges along the east coast of Australia, however on the western side of the ranges rainfall is significantly lower. The presence of persistent water west of the ranges is therefore more likely to indicate groundwater connection. IBRA Bioregions were used to delineate the ranges from the lower rainfall regions to the west. Table 36 lists the subregions that were considered to characterise the higher rainfall areas of the ranges, where persistent waterbodies were less likely to require groundwater contributions, from the lower rainfall areas west of the ranges, where persistent waterbodies are more likely to be groundwater fed.

- **Table 36 Bioregions delineating the ranges from the lower rainfall areas to the west.**

IBRA Bioregions (sub-regions) where groundwater use is more likely (west of ranges)				IBRA Bioregions (sub-regions) where groundwater use is less likely (ranges)		
12	30	51	246	15	298	347
13	34	52	247	17	299	348
14	35	233	248	46	300	349
16	37	234	249	47	301	350
18	42	235	254	88	302	351
22	43	236	259	89	304	352
23	44	241	303	90	305	353
24	48	242	356	91	306	355
25	49	244	376	92	345	
26	50	245	378	262	346	

Rule 3: Non-permanent waterbodies may also receive groundwater contributions if they are in certain litholigical and geomorphological units.

Rationale: Non-perennial watercourses could also be potentially groundwater-fed, although in this case the connection between surface water and groundwater would not be permanent. If either river levels or the watertable fluctuate sufficiently during the year, the hydraulic gradient between the aquifer and the river may reverse, resulting in groundwater discharging to the river only when river levels are low (and watertable is high). For this reason, a non-perennial watercourse may still potentially be identified as a GDE.

Since the available watercourse mapping (National Watercourses) significantly underestimates the number of rivers that have a permanent flow regime, this rule was incorporated to capture more rivers that are likely to flow permanently but have not been attributed as such in the feature layer dataset. That is, where a non-perennial river flows over a certain type of geology, it can be assumed

to be receiving baseflow which extends the period of flow. The types of geology likely to contribute baseflow include fractured rock aquifers, particularly in elevated areas, limestone, and alluvium. This rule is supported by work in the Isaac Connors catchment which reported that groundwater from the alluvial aquifer was highly likely to be the water source for riverine wetlands, in-stream pools, hyporheic zones and baseflow systems at some locations within the catchment (SKM, 2009). Baseflow contributions from the shallow alluvial aquifer were also reported in the Ourimbah and Bungalow Creeks (ERM, 2005), Maules Creek in the Namoi catchment (Anderson, 2009a) and Wollombi Brook (LaMontagne, 2003). The Sandy Creek alluvial aquifer in the Pioneer Valley also results in a large discharge volume to Sandy Creek (Cook et al., 2006a).

There was no dataset available to identify both aquifer, level of fracturing and geomorphology. National geology mapping was used in conjunction with land surface elevation, however these datasets do not allow the level of fracturing of the aquifers to be incorporated into the analysis. Because of this, the normalisation of geology was done assuming they are fractured (and therefore more likely to contribute baseflow) when this may not be the case in reality.

Rule 4: Rivers and wetlands in the vicinity of springs are more likely to be groundwater fed.

Rationale: Springs emerge directly from aquifers and can be considered to be GDEs. Springs are also responsible for maintaining permanent or persistent flow in many rivers. Using a buffer of 25 m around springs and rivers, it can be assumed that where they intersect, the spring contributes to river flow. The Queensland wetland mapping also contains several Regional Ecosystem (RE) codes that indicate the ecosystem is reliant on a spring. These were included in the analysis.

Rule 5: Where groundwater levels are higher elevation than the base of a waterbody, groundwater discharge occurs to that waterbody

Rationale: Where shallow watertables exist (that is, watertables that are in contact with the base of surface waterbodies), it is more likely that groundwater discharge to the surface waterbody will occur. This discharge may occur permanently (for example in higher elevation areas), or intermittently when the watertable elevation is higher than the river level.

Rule 5 was implemented using specific depth to watertable contours where they were available, or the FLAG landscape dataset where watertable contours were not available. Use of the FLAG dataset requires some large assumptions to be made, such as that the watertable reflects the topography. For mapping of GDEs that rely on groundwater discharge to the surface, it is assumed that low-lying topography has a higher likelihood of connection between groundwater and surface water. Similarly, an elevated landscape is characterised by a larger unsaturated zone separating the watercourse and the watertable, meaning that the likelihood of groundwater discharge is lower.

The rule is not as effective where the FLAG dataset is used, compared to where depth to watertable contours are used. Because of this, rule 5 using the FLAG dataset is weighted very low. However,

the FLAG dataset is often the only piece of information available, and therefore often dictated the final result. That is, if a wetland is located in a topographic low, it will result in a high potential for groundwater interaction being assigned where there are no other datasets to contribute to (decrease) the GDE potential. Despite this impact, FLAG was used for wetlands (not rivers) because the large variations in elevation in WP4 mean the watertable is likely to reflect the topography relatively well in this area. FLAG was used for the analysis of wetlands and not rivers in WP4, since rivers will always be identified as low-lying in the FLAG dataset, whereas wetlands could be perched in higher elevations and would be less likely to be connected to groundwater in those landscapes. Also, since there was often little other data for wetlands in WP4, the use of FLAG meant that more features could be included in the GDE potential mapping, rather than only being shown in the IDE layer.

Rule 6: Waterbodies which are close to GDEs that rely on the subsurface presence of groundwater (i.e. vegetation GDEs) are more likely to be GDEs, since the watertable would generally be shallow in these areas.

Rationale: In general, where vegetation is identified as potentially using groundwater the watertable must be relatively shallow, and it is therefore more likely that groundwater discharge to waterbodies could occur in the area. The presence of a GDE that relies on subsurface presence of groundwater can therefore be used to identify potential groundwater discharge points, which result in GDEs that rely on the surface expression of groundwater.

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 37. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 37 GIS analysis rules to identify GDEs that rely on the surface expression of groundwater in WP4**

Rule	
1	Permanent water regime indicates groundwater connection
2	Waterbodies occurring in bioregions west of the ranges receive less rainfall and therefore are more likely to rely on groundwater
3	Non-permanent waterbodies may also receive groundwater contributions if they are in certain lithological and geomorphological units

Rule	
4	Rivers and wetlands in the vicinity of springs or GDEs that have been mapped in previous studies are groundwater fed
5	Where groundwater levels are the same or high elevation than the base of a waterbody, groundwater discharge occurs to that waterbody
6	Waterbodies which are close to subsurface GDEs are more likely to be GDEs, since the watertable would generally be shallow in these areas

9.2.2. Selection of data for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 38 shows the feature layers selected to map GDEs that rely on the surface expression of groundwater for WP4. These layers contain all the river, wetland and springs features that were analysed to establish whether a groundwater connection exists. These are either the datasets that the rules in section 9.2.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 38 Feature layer datasets for analysis of GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs) in WP4**

State	Ecosystem	Dataset Name	Source or Custodian
NSW	Springs	ADMIN_HighPriority_GDEPoint_Jan2011	NSW Office of Water
	Springs	BM_Swamps_5B_region	Blue Mountains City Council
	Rivers	Major Watercourses	Geoscience Australia
	Rivers	GDE_Alstonville_stream40mBuffer	NSW Office of Water
	Rivers	ADMIN_HighPriority_GDELine_Jan2011	NSW Office of Water

State	Ecosystem	Dataset Name	Source or Custodian
	Wetlands	NSW Wetlands 2006	NSW Office of Environment & Heritage
QLD	Springs	HYD_SPRING_V3	DERM
	Rivers	Major Watercourses	DERM
	Wetlands	QLD_WETLAND_ SYSTEM_100K_A, V2	DERM

Use of the NSW Hydrolines dataset was considered as the feature layer for river mapping, however the dataset contains errors which would need to be addressed, and also does not contain any useful attributes for the analysis (for example, perenniality). The accuracy of the dataset could not be determined since there was no metadata available. For these reasons, the National major watercourse mapping was maintained as the feature layer for rivers for NSW and Queensland. The feature layer datasets listed provide full coverage of WP4 and therefore mapping of GDEs that rely on the surface expression of groundwater can be completed for the whole work package area.

9.2.3. Selection of GIS analysis datasets for implementation of rules

Table 39 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the surface expression of groundwater in WP4. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 39, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

Table 39 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the surface expression of groundwater

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	Permanent water regime indicates groundwater connection	Watercourse mapping with permanency of flow attributes	National watercourse mapping	Whole WP	Where a permanent water regime occurs, it is more likely that groundwater maintains the water regime during low rainfall periods (3). A seasonal water regime indicates it is possible that groundwater maintains the presence of water after rainfall has ceased (2), and an intermittent or episodic water regime suggests rainfall dependence rather than groundwater use (1). Permanence attributes such as 'non-permanent' give no information about how long the presence of water remains after rainfall ceases, and so give no information about potential groundwater contributions (0).
		Wetlands mapping with permanency attributes	QLD_WETLAND_SYSTEM_100_K (Qld)	QLD Could not analyse rule for NSW wetlands	
		Landsat open water intersect	WP4 Landsat (NSW)	NSW	Remote sensing data was not used for Qld since a more comprehensive Landsat analysis for Qld was used to develop the WTRREGIME_ attribute. This was used instead. For NSW, remote sensing of open water was used as an indicator of permanent presence of water. Where Landsat or MODIS open water intersected a wetlands/river polygon, the polygon was considered more likely to contain open water, and for this to contain groundwater (3). Where no intersect is recorded, the rule gives no indication whether the wetland/river interacts with groundwater or not (0), i.e. just because it doesn't intersect with open water doesn't mean the wetlands/river won't be interacting with groundwater.
		MODIS open water intersect	WP4 MODIS (NSW)	NSW	
2	Waterbodies occurring in bioregions west of the ranges receive less rainfall and	Mapping that delineates the east/ western ranges	IBRA Bioregions (sub-regions)	Whole WP	Bioregions which delineate areas on the east of the ranges receive higher annual rainfall, and persistent waterbodies are therefore less likely to be filled by groundwater discharge (1). On the west of the ranges rainfall is lower, and persistent waterbodies are more likely to be sustained by groundwater (3).

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
	therefore are more likely to rely on groundwater				
3	Non-permanent waterbodies may also receive groundwater contributions if they are in certain lithological and geomorphological units	Watercourse mapping with permanency of flow attributes	National watercourse mapping	Whole WP	Certain geological formations suggest a greater likelihood of groundwater discharge to rivers and wetlands (3), while others are less likely to contribute baseflow to surface water bodies (1).
		Wetlands mapping with permanency attributes	QLD_WETLAND_SYSTEM_100_K	Qld	
		Aquifer mapping	None available	NA	
		Geology mapping	National geology	Whole WP	
4	Rivers and wetlands in the vicinity of springs or known GDEs are groundwater fed	Springs mapping	HYD_SPRING_V3 Spring REs ADMIN_HighPriority_GDEPoint_Jan2011 BM_Swamps_5B_region	Qld Qld NSW Blue Mtns	The springs datasets and the previously mapped GDE datasets are intersected with the vegetation polygons. Where the spring/majority of the previously mapped GDE falls within the vegetation polygon, a positive result is recorded for the intersect. Where a positive result for the intersect is recorded, vegetation is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or not (0), i.e. just because it doesn't intersect with a spring/previously mapped GDE, doesn't mean the vegetation won't be using groundwater. Due to the large size of many vegetation polygons, and the likelihood that groundwater discharging from a spring/previously identified GDE may in reality only be influencing a small part of that vegetation polygon, this rule is weighted quite low.
		Mapping of previously identified GDEs	GAB_watercourse_springs	Qld GAB	
5	Where groundwater levels are the same or	Depth to watertable mapping	Pioneer Depth to watertable map Burnett Basin depth to watertable map	Parts of NSW & Qld	Groundwater interaction is considered more likely where watertable depth is <5m (3), possible for watertables between 5 & 10m (2), and

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
	high elevation than the base of a waterbody, groundwater discharge occurs to that waterbody		Callide catchment depth to watertable map NSW gwslices 6 depth to WT map		unlikely for watertables >10m (1).
		Land surface elevation contours	FLAG (Qld & NSW, where depth to WT map doesn't cover)	WP where no DTWT data exists	FLAG data are broad scale, and requires significant assumptions to be made regarding depth to watertable. Flag is only used where there is no DTWT. This rule is weighted very low. Landscapes which indicate a shallow DTWT, more likely to support GDEs (3); landscapes which indicate medium DTWT, possibly support GDEs (2); landscapes which indicate deeper DTWT, unlikely to support GDEs (1).
6	Waterbodies which are close to subsurface GDEs are more likely to be GDEs, since the watertable would generally be shallow in these areas	Mapping of vegetation GDEs	WP4 mapping of GDEs that rely on the subsurface presence of groundwater	All WP apart from an area in west of NSW	Where a 'high potential' subsurface GDE intersects with a wetland/river, this was assumed to increase the potential for a wetlands/river GDE to exist (3).

9.2.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 39) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater interaction:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 39.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

9.2.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

9.2.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 40 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 40 are only comparable for each feature dataset, and so should only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Depth to watertable weighted so that deep watertables always result in a low or moderate GDE potential, depending on the other data; and shallow watertables always result in a high or moderate GDE potential, depending on other data.
- Springs and known GDEs weighted so that intersecting vegetation polygons have high GDE potential.

Table 40 Weighting for each GIS Analysis rule/dataset for GDEs that rely on surface expression of groundwater in WP4

Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6
	Persistent water regime/ presence of open water	In lower rainfall bioregion	Geological formation contributing baseflow	Presence of spring or Known GDE	Shallow watertable/ landscape elevation	Presence of a sub-surface GDE
nsw_wetlands (NSW)	0/2*	1	5	10	10/1	4
qld_wetlands (QLD)	5/0#	1	5	10	10/1	4
National watercourses (NSW, Qld)	5/2	1	5	18	10/0	4

* based on remote sensing data only (wetlands data has no attribute indicating water regime)

remote sensing of open water not used since water regime attribute in wetlands mapping has had false positives removed

9.2.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This includes non-natural landscapes such as reservoirs, dams and irrigated land. It also excludes features that are artefacts of mapping, and do not represent actual features in the landscape.

The definition queries applied to each dataset to exclude ecosystems that cannot be GDEs that rely on the surface expression of groundwater are listed below.

For the **Qld_wetlands_100K, v2** feature layer dataset definition queries were applied to the field 'WTRREGIME' to exclude polygons attributed as:

- TI (tidal)
- Blanks (' '; and '-')

To the field 'WETCLASS' to exclude polygons attributed as:

- Estuarine
- Marine
- Blanks (' '; and '-')

To the field 'HYDROMOD' to exclude polygons attributed as:

- H2M1
- H2M6
- H2M7
- H2M8
- H3C1
- H3C2
- H3C3

To the field 'HAB_L' to exclude polygons attributed as:

- Blanks (' '; and '-')
- Marine
- Estuarine – water

To the field 'POLY#' to exclude polygons attributed as:

- 1 (removes a single vertical straight line down the middle of the dataset)

For the **nsw_wetlands** feature layer dataset definition queries were applied to the field 'SUBGROUP' to exclude polygons attributed as:

- 'estuarine wetland'
- 'Non-wetland'
- 'reservoir'

For the **national_watercourses (Vic, NSW, Qld)** feature layer dataset definition queries were applied to the field ‘PERENNIAL’ to exclude polygons attributed as:

- Blanks (‘ ‘)

9.3. Attribution of GDE identified in previous studies (from literature)

GDEs were identified in the literature review in Task 2. These were matched to polygons in the vegetation, river, and wetland feature layers where possible. The majority of these GDEs could be matched to existing polygons, which were attributed as either 'GDE identified in previous study: fieldwork'; or 'GDE identified in previous study: desktop'. The Tier 3 attributes recorded in the literature review have also been entered into the GDE Atlas attribute table for the GDEs identified in previous studies.

9.4. Transfer of attributes from existing spatial datasets to GDE polygons

Tier one attributes were populated in the GDE Atlas attribute table using national datasets where available. Jurisdiction's spatial datasets also contained information which could be used in the GDE Atlas attribute table, to either:

- Identify GDEs that had been mapped in a spatial layer in previous studies, and/or
- To populate other attributes in the GDE Atlas attribute table for GDEs that were derived in Task 5.

9.4.1. Datasets used to map GDEs identified in previous studies

In work package 4, the spatial datasets used to attribute GDE polygons as either 'GDE identified in previous study: fieldwork'; or 'GDE identified in previous study: desktop' are shown in Table 41. These datasets were either used to attribute polygons within the feature layer datasets, or entered in their entirety as feature layer datasets. Either way, the information from these datasets was incorporated into the GDE Atlas to show where GDEs were identified in previous studies.

- **Table 41 Spatial datasets used to map GDEs identified in previous studies (both desktop and fieldwork studies)**

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
NSW			
GDE_Alstonville_springs40mBuffer	Springs	All	GDE_Alstonville_springs40mBuffer
ADMIN_HighPriority_GDEPoint_Jan2011	Springs	All	ADMIN_HighPriority_GDEPoint_Jan2011
BM_Swamps_5B_region (Blue Mtns)	Springs	SUBCOMMNAME = hanging swamp	BM_Swamps_5B_region (Blue Mtns)
00_mdb_SW-GW_v06_lcc (CSIRO GW/SW interaction mapping	Baseflow	CLASS = gaining	Major Watercourses
GDE_Alstonville_stream40mBuffer	Baseflow	All	GDE_Alstonville_stream40mBuffer

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
ADMIN_HighPriority_GDELine_Jan2011	Baseflow	All	Major Watercourses
Alstonville_veg_200mBuffer	Vegetation	All	Unensw10_12_08join_GDE94
Nsw_gw_management_areas	Vegetation	GMA_TYPE = coastal sand GMUs[C]	
QLD			
Spring REs	vegetation & wetlands	Selected REs[B]	QLD_WETLAND_SYSTEM_100K RE06b
HYD_SPRING_v3	Springs	Unvisited springs[A]	HYD_SPRING_v3
00_mdb_SW-GW_v06_lcc (CSIRO GW/SW interaction mapping	Baseflow	CLASS = gaining	Major Watercourses
RE06B	Vegetation	LANDZONE = 2 (on mainland)	RE06B
GDEs IDENTIFIED IN PREVIOUS STUDY: FIELDWORK			
QLD			
HYD_SPRING_v3	Springs	Visited springs[A]	HYD_SPRING_v3
Qld pattern fens	Wetlands	All	Qld pattern fens

A – Visited and unvisited springs were distinguished using the POINT_ID attribute, as advised by DERM.

B – Spring REs were identified by DERM.

C – Includes GMA_TYPE: Coastal sands, Coastal Alluvial Coastal Floodplain.

9.4.2. Datasets used to populate attributes in the GDE Atlas attribute table

Information from jurisdiction's spatial data was incorporated into the GDE Atlas by transferring the relevant attributes into the GDE Atlas attribute table. A summary of the data used to populate each attribute is shown in Appendix A.

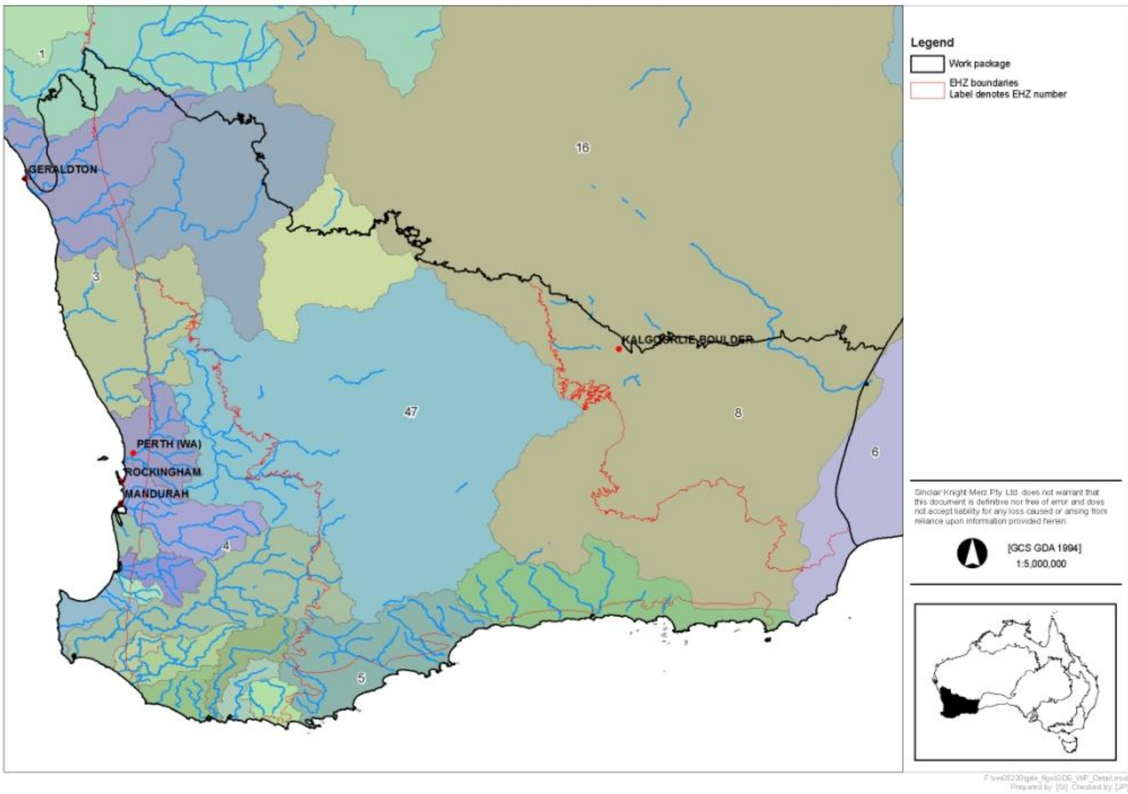
9.5. Data gaps and recommendations

The vegetation feature layers available for work package 4 did not cover some small areas in the south of the work package, which resulted in small gaps in the mapping of GDEs that rely on the subsurface presence of groundwater for those areas.

A state-wide depth to watertable contour map would significantly improve the Queensland GDE maps. Depth to watertable mapping is a key GIS analysis dataset and was only available for three small areas in Queensland (Pioneer catchment, Burnett Basin and Isaac Connors catchment).

10. Application of Methodology in south west Western Australia (WP5)

The WP5 area is shown in Figure 18 and incorporates 5 EHZs. Mapping of potential GDEs was completed for the majority of the area, however the wetlands mapping available for the GDE Atlas did not cover the entire WP5 area, with mapping absent in the north, east and southern areas. Because of this lack of wetland feature layer datasets, mapping of GDEs that rely on the surface expression of groundwater could not be completed for wetlands for the whole work package area. However, mapping of rivers covers the entire work package area, and this allowed GDEs that rely on the surface expression of groundwater to be mapped across the whole work package.



- **Figure 18 Work package 5 area showing river basins and EHZs**

10.1. Identification and Mapping of GDEs that rely on the SUBSURFACE presence of groundwater

10.1.1. Literature review and GIS analysis rules

The GIS analysis rules described in this section were based on the conceptual understanding gained during the literature review. The rules were applied across the whole work package 5 area.

Rule 1: Vegetation which demonstrates an ET that is higher than rainfall is more likely to be using groundwater.

Rationale: Vegetation water use studies (e.g. Morris et al., 1998; Prathapar and Myer, 1992) have shown that vegetation uses any available water source, such that ET is greater where water sources in addition to rainfall and water stored within the unsaturated zone exist (e.g. irrigation or groundwater). Therefore, riparian vegetation on unregulated streams in areas of shallow watertables (non-irrigated) that maintain high ET during dry periods will most likely be using groundwater.

The remote sensing layer and the ID layer (described in section 3) show the likelihood that a certain ecosystem is using a water source in addition to rainfall. Where the probability is higher, it is more certain that an additional water source is being accessed. As such, probabilities of above 8 are considered to strongly indicate that a second water source is present, and probably that larger volumes of water are being utilised. It is therefore assumed that probabilities of 8 and above suggest that this second water source is more likely to be groundwater.

Rule 1 must be used in conjunction with other information sources and existing ecosystem spatial datasets (e.g. maps of vegetation extent and type) to determine whether the additional water source is groundwater. This is the intention of the subsequent GIS rules. It is also recommended that the layer is always used in conjunction with localised expert knowledge.

Rule 2: Native vegetation in a shallow water table setting is likely to be using groundwater.

Rationale: PPK (2001) and Rutherford et al. (2005) found that in the Northern Perth Basin, remnant vegetation in a shallow watertable setting (0-5 m) is likely to be highly dependent on groundwater. This typically comprises vegetation associated with coastal wetland and watercourse fringes, swales and lower slopes of dunes or sand over limestone hills, valley bottoms and sandplains.

At a groundwater depth of 5-10 m some key (over storey and sub-storey dominant) vegetation components are likely to be dependent on groundwater as a summer water source. This typically includes vegetation on the upper fringes of wetlands and watercourses, mid-slopes of low dunes or sand over limestone/sandstone/shale hills, valley slopes and sandplains. A significant proportion of the vegetation however, predominantly sub-storey and understorey species, are likely to be dependent on soil moisture within the unsaturated soil profile only.

On the upper-slopes of dunes or sand over limestone/sandstone/shale hills, valley slopes and sandplains, where the groundwater is typically 10 - 20 m deep, some key (over storey and sub-storey dominant) vegetation components are likely to use groundwater as a summer water source. Most of the vegetation at this groundwater depth however, including over storey, sub-storey and understorey species, is likely to be dependent on soil moisture within the unsaturated soil profile

only. At a groundwater depth greater than 20 m, vegetation was considered to not be using groundwater.

Rule 3: Vegetation type is an indicator of groundwater use.

Rationale: The presence of a suite of vegetation species that are known to use groundwater can identify the broader ecosystem as groundwater dependent. According to Froend et al. (2004) within the categories of 0-3 m, 3-6 m and 6-10 m, *Banksia* are phreatophytic and derive some of their water from groundwater throughout the dry-wet cycle. Between these categories the degree to which groundwater is utilised by *Banksia* is dependent on the proximity of groundwater, availability of moisture in shallower horizons of the soil profile, root system distribution and maximum root depth. The highest proportion (>50%) of groundwater is used by vegetation in the 0-3 and 3-6 m depth categories. Vegetation in the 6-10 m category also use groundwater, however, they use proportionately more water from the upper layers of the soil profile as they have a larger volume of subsurface soil moisture store beyond the influence of direct evaporation (Zencich et al., 2002).

Rule 4: Groundwater discharge related to the presence of faults.

Rationale: Subsurface geological structures (faults) can act as conduits for groundwater flow, creating springs at the land surface. Rutherford et al. (2005) found that, in the Leederville-Parmelia, Yarragadee, Cattamarra, Eneabba and Lesueur aquifers in the Northern Perth Basin, there is a variety of potential GDEs related to the presence of faults. An example of this within WP5 is the diamond of the desert spring where the Carynginia Shale provides an impermeable barrier to flow, causing upward discharge from the Lesueur Sandstone along the Beagle Fault and into the superficial formations Rutherford et al. (2005).

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 42. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 42 GIS analysis rules to identify GDEs that rely on the subsurface presence of groundwater in WP5**

Rule	
1	Vegetation which demonstrates an ET that is higher than rainfall is more likely to be using groundwater
2	Native vegetation in a shallow water table setting is likely to be using groundwater

Rule	
3	Vegetation type is an indicator of groundwater use
4	Groundwater discharge related to the presence of faults

10.1.2. Selection of data for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 43 shows the features layers selected to map GDEs that rely on the subsurface presence of groundwater for WP5. These layers contain all the vegetation features that were analysed to establish whether a groundwater connection exists. The feature layers are either the datasets that the rules in section 10.1.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 43 Feature layer datasets for analysis of GDEs that rely on the subsurface presence of groundwater (vegetation) in WP5**

State	Ecosystem	Dataset Name	Source or Custodian
WA	Vegetation	RFA vegetation complexes	DEC
	Vegetation	Pre-European vegetation clipped to State remnant vegetation coverage	DEC / WAAA

The vegetation feature layer datasets listed provide full coverage of WP5 and therefore mapping of GDEs that rely on the subsurface presence of groundwater could be completed for the whole work package area.

The 1:250,000 scale pre-European vegetation GIS dataset was used for one of the vegetation feature layers. This layer provides a comprehensive database of the vegetation of the state, based on the work of J S Beard. Although the species identification in this mapping is quite broad in its classifications, it is the best available vegetation mapping for the areas not covered by the RFA complexes mapping. The pre-European vegetation layer was clipped to the State remnant

vegetation layer to provide an indicator of current natural vegetation extent. During this process, small isolated GDEs may have been clipped out of the Pre-European vegetation feature layer and will therefore not be mapped in the GDE layers. These small isolated GDEs will however, be included in the gridded remote sensing layer and the ID layer (see section 3). This layer has complete coverage of Australia. It is a gridded dataset consisting of $30m^2$ pixels, each with an ID likelihood rating of between 1 and 10. High likelihood (>5) pixels represent landscapes that are more likely than not to be using and accumulating an additional source of water. Low likelihood (<6) pixels indicate landscapes that are more unlikely to be accessing and using an additional water source (i.e. there is a less than 50% chance that the pixel accesses an additional water source. Hence it is more likely to solely be using rainfall than it is to be using groundwater).

10.1.3. Selection of GIS analysis datasets for implementation of rules

Table 44 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the subsurface presence of groundwater in WP5. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 44, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

▪ Table 44 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the subsurface presence of groundwater

#	Rule	Datasets required for analysis	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	Vegetation which demonstrates an ET that is higher than rainfall is more likely to be using groundwater	WP5 remote sensing (RS) layer	WP5 remote sensing (RS) layer	Entire WP area	The probability from the RS layer is assigned to each vegetation polygon by majority value. That is, the probability of the greatest number of pixels that intersect with the polygon becomes the probability of the whole polygon. Probabilities of 6 & 7 give no indication of groundwater use (0); probabilities of 8, 9 & 10 suggest groundwater use is more likely (3).
2	Native vegetation in a shallow water table setting is likely to be using groundwater	Depth to watertable	Derived from Groundwater Contours, Historical Maximum	Perth metro area, from Yanchep to Serpentine	Groundwater use is considered likely where watertable depth is <10m (3), possible for watertables between 10 & 20m (2), and unlikely for watertables >20m (1).
		Landscape type information	Land systems mapping	Entire WP area	In the absence of watertable elevation mapping, shallow watertables can be assumed to exist in low-lying elevations. Depressions / flats (3), slopes (2) and hills (1).
		Aquifers indicating shallow watertables/ discharge	DWAID aquifers	Entire WP area	Aquifers can be used to indicate likely shallow groundwater / discharge areas. Unconfined – sedimentary aquifer, paleodrainage (3), Unconfined – fractured rock aquifer (2), Confined aquifers (0). Normalisation was done by reviewers.
		Previous GDE mapping	Mid West potential GDEs and associated values polygons	Mid west region	Dataset represents parks and reserves with remnant native vegetation over shallow (<20 m) groundwater. This datasets is intersected with the vegetation polygons. Where a positive result for the intersect is recorded, vegetation is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or

					not (0), i.e. just because it doesn't intersect with a previously mapped GDE, doesn't mean the vegetation won't be using groundwater.
3	Vegetation type is an indicator of groundwater use	Vegetation mapping with attributes to identify species likely to be using groundwater and/or in likely landscapes	RFA Vegetation Complexes Pre European vegetation	Entire WP area	Attributes describing vegetation types were normalised as either likely to use groundwater (3); possibly use groundwater (2), unlikely to use groundwater (1), or not sure (0). Normalisation was done from literature and by reviewers and jurisdictions.
4	Groundwater discharge related to the presence of faults	Exposed faults	1:500 000 Interpreted bedrock geology of Western Australia 1:2 500 000 Geological Map of Western Australia 1998	Entire WP area	These datasets are intersected with the vegetation polygons. Where a positive result for the intersect is recorded, vegetation is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or not (0), i.e. just because it doesn't intersect with a fault, doesn't mean the vegetation won't be using groundwater.

10.1.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 44) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater use:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 44.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

10.1.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

10.1.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 45 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not

comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 45 are only comparable for each feature dataset, and so may only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Depth to watertable was weighted so that deep watertables always result in a low or moderate GDE potential, depending on the other data; and shallow watertables always result in a high or moderate GDE potential.
- Vegetation was weighted so that likely groundwater using vegetation always results in a high or moderate GDE potential, depending on other data and where there is no depth to watertable data; and unlikely groundwater using vegetation always results in a low or moderate GDE potential, depending on other data and where there is no depth to watertable data.

Table 45 Weighting for each GIS Analysis rule/dataset for GDEs that rely on subsurface presence of groundwater in WP5

Feature Layer Dataset	Rule 1	Rule 2				Rule 3	Rule 4
	High ET	Depth to watertable	Land systems	DWAID	Mid West potential GDEs polygons	Vegetation species	Presence of a fault
RFA Vegetation Complexes	8	NA	4	6	2	10	2
Pre European vegetation	8	10	4	6	2	6	2

10.1.5.2. Definition query

Definition queries were generally applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This included non-natural landscapes such as settlements, pasture, and plantations, as well as natural landscapes that do not use groundwater, such as grasslands and bare earth.

All vegetation polygons that had an ID likelihood of 5 and less were removed at this stage, as these ecosystems were not likely to be accessing a source of water in addition to rainfall. By removing vegetation polygons with ID likelihood values below the <6 threshold, three vegetation polygons

that exist in an area where vegetation is likely to be groundwater dependent were also removed. After consultation, these three polygons were included in the final GDE layer as ‘GDEs derived in a previous study’.

No additional definition queries were required for the feature layer datasets **DEC pre European** and **RFA vegetation complexes.**

10.2. Identification and Mapping of GDEs that rely on the SURFACE expression of groundwater

10.2.1. Literature review and GIS analysis rules

The GIS analysis rules described in this section were based on the conceptual understanding gained during the literature review. The rules were applied across the whole work package 5 area.

Rule 1: A wetland in a shallow watertable setting (<5 m) is likely to be in connection with groundwater.

Rationale: According to Froend and Loomes (2004), the groundwater dependence of many wetland ecosystems can largely be inferred from their position in the landscape, their response to altered water regimes, and the occurrence of vegetation species associated with shallow groundwater. Unlike terrestrial vegetation, wetland species are often shallow rooted, having adapted to shallower water tables (Muir, 1983; Groom, et al., 2000).

According to Wilson and Valentine (2009), the majority of permanently inundated wetlands, or lakes, are shallow expressions of the groundwater table, which fill following winter rainfall and dry during summer as groundwater levels fall, rainfall decreases and surface evaporation increases. Sumplands, holding water only during winter and spring, and damplands, seasonally waterlogged areas, can form as expressions of underlying groundwater. Floodplains hold water when streams such as Ellen Brook, Gingin Brook or Quin Brook overflow in winter or spring, and palusplains can become saturated from seasonally elevated groundwater levels. Sumplands and palusplains can also form from rainfall perching over more impermeable soils (like diatomaceous earths which have increased water holding capacities).

Rule 2: A wetland with known groundwater dependent vegetation species is most likely to be in connection with groundwater.

Rationale: The presence of a suite of known wetland vegetation species can identify an ecosystem as groundwater dependent. According to Froend et al. (2004) if *Melaleuca preissiana*, *Eucayptus rudis* and/or *Banksia littoralis* occurred within an area of 0-3 m groundwater depth, the site was regarded as a wetland.

Rule 3: Rivers intersecting springs are groundwater fed.

Rationale: Springs emerge directly from aquifers and are considered to be GDEs. Springs are also responsible for maintaining permanent or persistent flow in many rivers and riverine pools. An example of spring discharge maintaining perennial flow is Poison Gully and Milyeannup Brook in the Blackwood River Area. Poison Gully and Milyeannup Brook are perennial tributaries of the Blackwood River, where the Yarragadee Formation outcrops or subcrops. The spring sources of Poison Gully and Milyeannup Brook correspond with the groundwater-levels in the Yarragadee

Formation, and hence demonstrate that these two tributaries, and their associated wetlands, are directly maintained by groundwater from that formation (URS, 2004).

Rule 4: Underlying geology indicates potential for groundwater discharge to surface.

Rationale: Timms (2009) studied a number of the small lakes on the Esperance sandplain, 100 km north and north-east of Esperance. Most of the lakes are roundish to elongated, very shallow and saline and all lie in swales of old dunes, most of which are aligned in a general east-west direction. They tend to fill in winter-spring and dry in summer-autumn, although in the north inundation is less reliable as rainfall is lower. The lakes in the north of the Esperence sandplain also tend to be of higher salinity than those in the south. Timms (2009) found that although some lakes are subject to occasional large overland flows, most are groundwater “windows” and as such, the acidity/alkalinity of the lakes is controlled by groundwater pH.

According to the South West groundwater areas allocation plan (DOW, 2009) in the South West groundwater area there are rivers that are strongly connected to, and are dependent on, groundwater. An example of this interconnection between groundwater and surface water is the Yarragadee Aquifer discharging to the Blackwood River and its tributaries Milyeannup Brook and Poison Gully. The groundwater discharge maintains perennial flow and important environmental values in the tributaries and permanent pools in the river. Another example is the Leederville Aquifer discharging into the lower Blackwood River between Nannup and Milyeannup Brook and downstream of Layman Brook. The baseflow to the river helps to improve water quality and maintains permanent pools throughout the summer months. St John and Rosa Brooks and upper Margaret River are dependent on discharge from the Leederville Aquifer. Many rivers on the coastal plains, such as the Scott and Capel rivers, are also supported by groundwater (DOW, 2009).

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 46. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 46 GIS analysis rules to identify GDEs that rely on the surface expression of groundwater in WP5**

Rule	
1	A wetland in a shallow watertable setting (<5 m) is likely to be in connection with groundwater
2	A wetland with known groundwater dependent vegetation species is most likely to be in connection with groundwater
3	Rivers intersecting springs are groundwater fed

Rule	
4	Underlying geology indicates potential for groundwater discharge to surface

10.2.2. Selection of data for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 47 shows the feature layers selected to map GDEs that rely on the surface expression of groundwater for WP5. These layers contain all the river, wetland and springs features that were analysed to establish whether a groundwater connection exists. These are either the datasets that the rules in section 10.2.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 47 Feature layer datasets for analysis of GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs) in WP5**

State	Ecosystem	Dataset Name	Source or Custodian
WA	Wetland	Geomorphic Wetlands Swan Coastal Plain (Classification)	DEC
	Wetland	Geomorphic Wetlands Augusta to Walpole	DEC
	Wetland	Geomorphic wetlands Cervantes South	DEC
	Wetland	Geomorphic Wetlands Darkin (Area D)	DEC
	Wetland	Geomorphic wetlands Cervantes Eneabba	DEC
	Wetland	Wheatbelt Wetlands	DEC
	Wetland	Important wetlands	DEC
	Wetland	South Eastern Coast Wetlands	DoW
	River	Hydrography linear hierarchy	DoW
	Spring	MW Potential GDEs Associated Values Points (modified)	DoW

The geomorphic wetland layers were supplied by DEC, however there were a number of additional wetland layers that had not been published / endorsed at the time of production. It is a recommendation that future updates to the GDE Atlas include any additional geomorphic wetland datasets that have been endorsed since the last update. The wetlands mapping available for the GDE Atlas did not cover the entire WP5 area, with mapping absent in the north, east and southern areas. Because of this lack of wetland feature layer datasets, mapping of GDEs that rely on the surface expression of groundwater could not be completed for wetlands for the whole work package area. However, mapping of rivers covers the entire work package area, and this allowed GDEs that rely on the surface expression of groundwater to be mapped across the whole work package.

10.2.3. Selection of GIS analysis datasets for implementation of rules

Table 48 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the surface expression of groundwater in WP5. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 48, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

Table 48 GIS analysis datasets used to implement analysis rules for GDEs that rely on the surface expression of groundwater

#	Rule	Datasets required for analysis	Dataset name (& where used)	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	A wetland/river in a shallow water table setting is likely to be in connection with groundwater	Depth to watertable	Derived from Groundwater Contours, Historical Maximum	Perth metro area, from Yanchep to Serpentine	Groundwater use is considered likely where watertable depth is <5m (3), possible for watertables between 5 & 10m (2), and unlikely for watertables >10m (1).
		Landscape type information	Land systems mapping	Entire WP area	In the absence of watertable elevation mapping, shallow watertables can be assumed to exist in low-lying elevations. Depressions / flats (3), slopes (2) and hills (1).
2	A wetland/river with known groundwater dependent vegetation species is most likely to be in connection with groundwater	Subsurface GDEs	Subsurface GDE mapping	Whole WP	Where a 'high potential' subsurface GDE intersects with a wetland/river, this was assumed to increase the potential for a wetlands/river GDE to exist (3).
		WP5 remote sensing (RS) layer	WP5 remote sensing (RS) layer	Entire WP area	The probability from the RS layer is assigned to each wetland polygon by majority value. That is, the probability of the greatest number of pixels that intersect with the polygon becomes the probability of the whole polygon. Probabilities of 6 & 7 give no indication of groundwater use (0); probabilities of 8, 9 & 10 suggest groundwater use is more likely (3).
		Previous GDE mapping	Mid West potential GDEs and associated values polygons	Mid west region	Dataset represents parks and reserves with remnant native vegetation over shallow (<20 m) groundwater. This datasets is intersected with the wetland polygons. Where a positive result for the intersect is recorded, wetland vegetation is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or not (0), i.e. just because it doesn't intersect with a previously mapped GDE, doesn't mean the wetland vegetation won't be using groundwater.

3	wetland/river intersecting springs are groundwater fed	Previous GDE mapping	Mid West potential GDEs and associated values polypoints (Included only those points that have the words "pool", "spring", "springs", "soak", "soakage", "waterhole", "hole", "swamp", "rockhole" and "lagoon" in the "Name" field)	Mid west region	The Mid West potential GDEs (polypoints) dataset was intersected with the wetland/rivers. Where a positive result for the intersect is recorded, the wetland/river is more likely to receive groundwater discharge (3). Where no intersect is recorded, the rule gives no indication whether the river receives groundwater discharge or not (0).
		Watercourse mapping with permanency of flow attribute	Major Watercourses	Entire WP area	Where a perennial flow regime occurs, it is more likely that baseflow maintains the flow during low rainfall periods (3). A ‘non-perennial’ attribute gives no information about potential groundwater contributions (0).
		Landsat open water	WP5 Landsat	Entire WP area	Remote sensing of open water was used as an indicator of permanent presence of water, and hence baseflow contribution. Where Landsat intersected a buffered river, the polygon was considered more likely to contain open water, and for this to contain groundwater (3). Where no intersect is recorded, the rule gives no indication whether the wetland/river interacts with groundwater or not (0), i.e. just because it doesn’t intersect with a open water doesn’t mean the river won’t be interacting with groundwater.
4	Underlying geology indicating groundwater discharge to surface	Aquifers indicating likely groundwater discharge	DWIAD aquifers	Entire WP area	Aquifers can be used to indicate likely groundwater discharge. Unconfined – sedimentary aquifer, paleodrainage (3), Unconfined – fractured rock aquifer (2), Confined aquifers (0).

10.2.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 48) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater interaction:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 48.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

10.2.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

10.2.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 49 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative

differences between weightings controlling the GDE potential result. Weightings are not comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 49 are only comparable for each feature dataset, and so should only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Depth to watertable was weighted so that deep watertables always result in a low or moderate GDE potential; and shallow watertables always result in a high or moderate GDE potential
- Springs and known GDEs were weighted so that intersecting vegetation polygons have high GDE potential

Table 49 Weighting for each GIS Analysis rule/dataset for GDEs that rely on surface expression of groundwater in WP5

Feature Layer Dataset	Rule 1		Rule 2			Rule 3			Rule 4
	Depth to watertable	Land systems	Mid West potential GDEs polygons	High ET	Subsurface GDE confidence	Mid West potential GDEs polypoints (modified)	Permanent flow regime	Open Water (remote sensing)	Aquifers
Hydrography linear hierarchy	NA	2	NA	NA	6	10	2	8	5
Geomorphic wetlands - Swan Coastal Plain	10	5	2	10	5	10	NA	NA	NA
Geomorphic wetlands - Augusta to Walpole	NA	5	NA	10	5	NA	NA	NA	NA
Geomorphic wetlands - Cervantes South	NA	5	2	10	NA	10	NA	NA	NA
Geomorphic wetlands - Darkan	NA	5	NA	10	5	NA	NA	NA	NA
Geomorphic wetlands – Cervantes Eneabba	NA	5	2	10	5	10	NA	NA	NA

Feature Layer Dataset	Rule 1		Rule 2			Rule 3			Rule 4
Basin Wetlands of the Wheatbelt and other prioritized areas	NA	5	2	10	5	NA	NA	NA	8
Directory of important wetlands	NA	5	2	10	5	NA	NA	NA	8
South Eastern Coast Wetlands	NA	5	NA	10	NA	NA	NA	NA	NA

10.2.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This includes non-natural landscapes such as reservoirs, dams and irrigated land. It also excludes features that are artefacts of mapping, and do not represent actual features in the landscape.

The definition queries applied to each dataset to exclude ecosystems that cannot be GDEs that rely on the surface expression of groundwater are listed below.

For the **DEC_Important_Wetlands** feature layer dataset all wetlands which were either marine and coastal, or human-made (i.e. types 'A' or 'C' in the 'WET_TYPE' field) were excluded from analysis using a definition query.

For the **Geomorphic wetlands - Swan Coastal Plain** feature layer dataset a definition query was applied to exclude polygons that are unlikely to be GDEs are:

In the field 'CLASSIFCTN':

- Artificial channel
- Artificial lake
- No longer a wetland
- Estuary-Peripheral
- Estuary-Waterbody (except for Peel Inlet, Harvey Estuary and Leschenault Inlet, based on review comments from Ray Froend)

In the field 'EVALUATION':

- Multiple Use
- Not Applicable

For the **Geomorphic wetlands – Augusta Walpole** feature layer dataset a definition query was applied to exclude polygons that are unlikely to be GDEs are in the field ‘CLASS’:

- Estuary (shoreline and peripheral)
- Estuary (waterbody)

For the feature layer datasets **Geomorphic wetlands – Cervantes South, Geomorphic wetlands – Darkin**, **Geomorphic wetlands – Cervantes Eneabba**, **South Eastern Coast wetlands** and **Wheatbelt wetlands** no definition queries were required.

10.3. Attribution of GDE identified in previous studies (from literature)

GDEs were identified in the literature review in Task 2. These were matched to polygons in the vegetation, river, and wetland feature layers where possible. The majority of these GDEs could be matched to existing polygons, which were attributed as either ‘GDE identified in previous study: fieldwork’; or ‘GDE identified in previous study: desktop’. The Tier 3 attributes recorded in the literature review have also been entered into the GDE Atlas attribute table for the GDEs identified in previous studies.

10.4. Transfer of attributes from existing spatial datasets to GDE polygons

Tier one attributes were populated in the GDE Atlas attribute table using national datasets where available. Jurisdiction’s spatial datasets also contained information which could be used in the GDE Atlas attribute table, to either:

- Identify GDEs that had been mapped in a spatial layer in previous studies, and/or
- To populate other attributes in the GDE Atlas attribute table for GDEs that were derived in Task 5.

10.4.1. Datasets used to map GDEs identified in previous studies

In other work packages, existing spatial datasets that identified GDEs were used to attribute GDE polygons as either GDE identified in previous study: fieldwork; or GDE identified in previous study: desktop. These datasets were either used to attribute polygons within the feature layer datasets, or entered in their entirety as feature layer datasets.

There were no datasets for WP5 that were included as ‘GDEs derived in previous study: fieldwork, or desktop’. The dataset ‘Mid West potential GDEs and Associated Values (polypoints, polygons, polylines)’ was not used to attribute ecosystems as ‘GDEs derived in previous study’, as this dataset was based on place names data (rather than systematic identification of physical features in the landscape).

10.4.2. Datasets used to populate attributes in the GDE Atlas attribute table

Information from jurisdiction’s spatial data was incorporated into the GDE Atlas by transferring the relevant attributes into the GDE Atlas attribute table. A summary of the data used to populate each attribute is shown in Appendix A.

10.5. Data gaps and recommendations

The wetlands feature layers available for the GDE Atlas did not cover the entire WP5 area, with mapping absent in the north, east and southern areas. Because of this lack of wetland feature layer datasets, mapping of GDEs that rely on the surface expression of groundwater could not be completed for wetlands for the whole area. A number of additional wetland layers had not been published / endorsed at the time of production. It is a recommendation that future updates to the GDE Atlas include any additional geomorphic wetland datasets that have been endorsed since the last update.

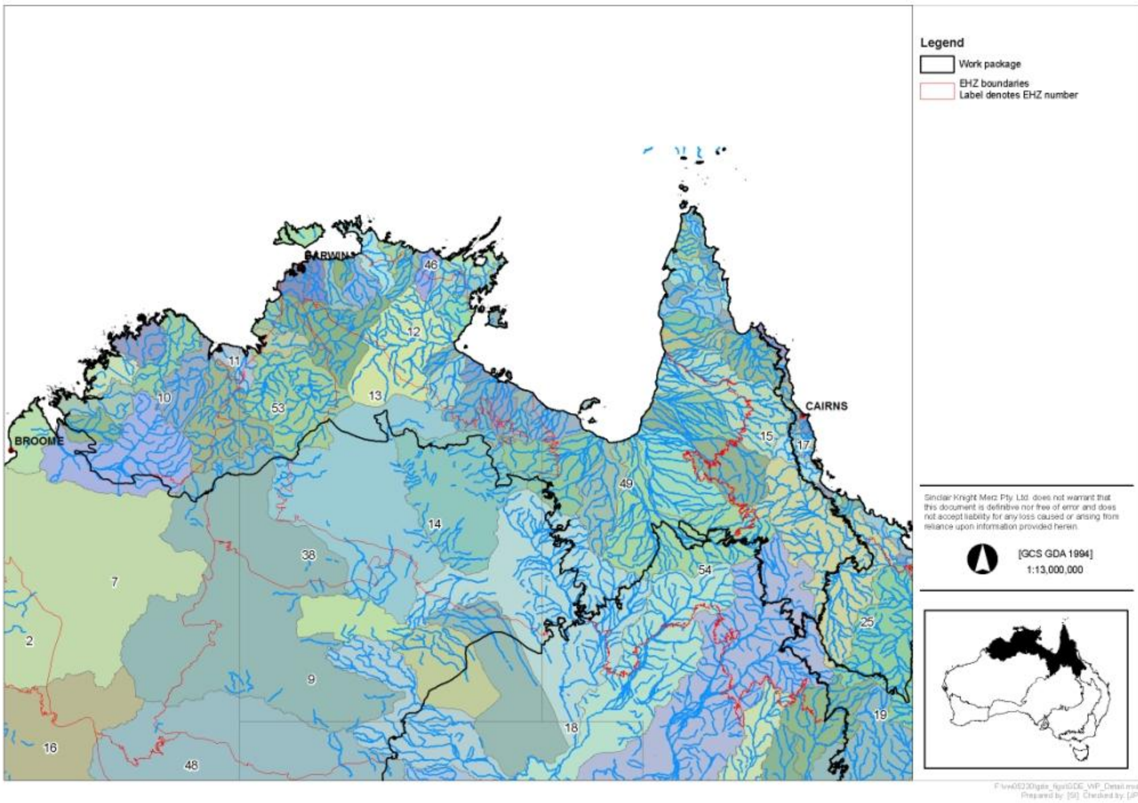
However, mapping of rivers currently covers the entire work package area, and this allowed GDEs that rely on the surface expression of groundwater to be mapped across the whole work package.

A state-wide depth to watertable contour map would significantly improve the GDE maps. Depth to watertable mapping is a key GIS analysis dataset and was only available for the Perth metro area in the current GDE mapping.

Existing spatial datasets that showed the locations of wetlands or rivers that were known to use groundwater were not available for the current potential GDE mapping. There are therefore no GDEs classified as 'GDE derived in previous study' in the GDE maps. If any such datasets exist, it is recommended they are included in future updates of the Atlas.

11. Application of methodology in Northern Australia (WP6)

The WP6 area is shown in Figure 19 and incorporates 8 EHZs. The climate is classified as summer dominant, where rainfall occurs almost exclusively in summer and the winter is dry. Rivers and wetlands commonly demonstrate a seasonal water regime unless groundwater contributions are maintaining flow or inundation throughout the dry season. Soils are generally sandy but can hold significant moisture, which provides an important dry season water source for vegetation. The majority of the work package 6 area consists of eucalypt savannah ecosystems.



- **Figure 19 Work package 6 area showing river basins and EHZs**

Mapping of GDEs was completed for the entire work package area, however suitable vegetation mapping was sparse in the NT, and wetlands mapping in WA only captured wetlands listed on the Directory of Important Wetlands Australia (DIWA). Therefore although analysis occurred in these areas, not all of the ecosystems that actually exist in the areas were analysed, since they were not mapped in existing spatial datasets.

More detailed vegetation mapping exists for some locations in the NT, mainly in the form of multiple landunit and landsystems maps. A recommendation for future work is to combine these

maps into a vegetation layer with greater coverage which could then be used for mapping in the Atlas.

11.1. Identification and Mapping of GDEs that rely on the SUBSURFACE presence of groundwater

11.1.1. Literature review and GIS analysis rules

The GIS analysis rules were developed based on the concepts and understandings gained from reviewing literature for the region. Much of the literature reviewed related to the Daly Basin and the Darwin area, however the concepts were applied to the whole work package.

The fundamental concept controlling vegetation water use is that vegetation will utilise the water source that requires the least energy to access, meaning that if groundwater is shallow it would be the preferred water source, however where the watertable is deeper, water stored within the unsaturated zone constitutes the least energy option. Four to five metres of soil has been found to provide sufficient stored water to maintain ecosystems throughout the dry season, and groundwater is deeper than this across much of the Top End (L. Hutley, pers. comm., 18/10/2011). Sandy soils predominate in the tropics and they are often thought of as indicating that groundwater use is more likely, since they have a low soil water holding capacity. However soils in the tropics are replenished annually during the wet season and release the water to vegetation easily during the dry season. This makes water stored in the unsaturated zone a preferential source across the large areas of northern Australia where the watertable is greater than approximately 5m deep.

To summarise, even in sandy soils, a watertable depth of greater than approximately 5 m means there is sufficient water stored in the unsaturated zone to maintain ecosystems throughout the dry season. This concept has been demonstrated by multiple studies (Hutley et al., 2011; O'Grady et al., 2002 & 2005, Cook et al., 1998a) that have shown plant physiology and ET are tightly coupled with rainfall. Along a steep rainfall gradient (the Northern Australian Tropical Transect, which runs 1000km south from Darwin) the physiology of Eucalypt savannah plant species and ET correlate strongly with rainfall and therefore with the presence of water stored in the unsaturated zone. This indicates that groundwater is not required to close the water balance. Rather, the ET and physiological characteristics of vegetation are determined by the availability of water stored in the unsaturated zone. It is concluded that groundwater is generally not used by most Eucalypt savannah ecosystems, and these cover the majority of the work package 6 land surface. GDEs are more likely to exist where groundwater is shallow, and as riparian or spring-fed ecosystems.

This concept characterises the Eucalypt savannah ecosystems of WA and the NT, however may not be as effective in Queensland where the monsoon becomes less dominant which results in a drier climate. In the east of the work package, vegetation that transpires throughout the dry season is

more likely to be relying on groundwater instead of water stored in the unsaturated zone (L. Hutley, pers. comm., 18/10/2011).

Rule 1: High probability IDEs are potential GDEs.

Rationale: the remote sensing layer shows the likelihood that a certain ecosystem is using a water source in addition to rainfall. Where the likelihood is higher, it is more certain that an additional water source is being accessed. As such, likelihoods of 6 and above are considered to indicate that a second water source is present. Similarly, IDE probability of <6 are excluded from analysis by a definition query (section 11.1.5.2), as these ecosystems are unlikely to be accessing an additional water source. Very high remote sensing probabilities (8 and above) are considered to suggest that significant use of an additional water source is occurring, and because of this, some of the additional water use may be provided by groundwater. As such, very high IDE probabilities are used to indicate a greater likelihood of groundwater use.

Rule 2: Vegetation around persistent water features (excluding estuaries and man made lakes) is likely to access groundwater, except where the water feature is located on coastal floodplains where Holocene marine muds are present, or on cracking clay soils.

Rationale: Since rainfall in the tropics is very distinctly seasonal and a dry period of several months occurs reliable each year, it is assumed that where surface water persists throughout the dry season, it must be maintained by groundwater inflows. For groundwater to discharge into a surface water body, the watertable must be relatively shallow, and is therefore likely to be within reach of vegetation roots. Using this logic, it is assumed that water bodies that are mapped as ‘permanent’ or ‘perennial’ indicate the presence of groundwater discharging into the water body, and hence, a shallow watertable.

An important exception to the logic which links permanent surface water to groundwater discharge, is the occurrence of waterholes and swamps on cracking clay soil plains, which are common in northern Australia. These are low-lying swamps which capture run off during the wet season and persist until the next wet season because they are located on very low permeability soils and because they are relatively deep (Hatton et al., 1998). The swamps can be up to 3 or 4m deep, which is sufficient to persist throughout the dry season until surface water inflow occurs in the next wet season. Flow between the surface water and the groundwater is limited in these systems due to the impermeable nature of the cracking clay soils. Therefore, the water source of vegetation surrounding and within these swamps (for example grasses, and tree species including Lophostemon suaveolens and Eucalyptus) is dominated by captured surface water, although there may be some groundwater seepage into the swamps as well. Vegetation which is identified as an IDE and which occurs near a persistent lake on the cracking clay soil plains can be considered to rely on surface water inflows to the lake and should therefore be mapped as having a low potential for groundwater interaction (P. Jolly, pers. comm.).

Cracking clay soils are mapped in the Pre-European vegetation mapping in WA, in the NT Landsystems mapping, and in the Queensland RE codes within the vegetation mapping. Hence, the influence of cracking clay soils on permanent waterbodies can be used to reduce the likelihood of groundwater use by vegetation for the whole work package area.

The presence of Holocene muds (which mostly occur in floodplains and estuaries at elevations of less than 5 m) also result in permanent waterbodies that cannot be attributed to groundwater inflows. The spatial extent of Holocene mud is represented by acid sulphate soil risk maps in NT and WA, as Holocene muds typically produce acid when exposed to the atmosphere. During the Holocene period, the eastern part of Australia was more uplifted, which largely precluded the deposit of find-grained marine muds. Consideration of Holocene marine muds has therefore not been considered for the Queensland part of the work package.

Rule 3: Vegetation around previously identified GDEs is likely to access groundwater.

Rationale: Where GDEs were identified in previous studies, it is likely that vegetation surrounding these GDEs is also likely to be using groundwater. These previous studies generally identified wetland, spring or river GDEs, and indicate that groundwater is probably at, or close to the surface. Since these previous studies show that groundwater is present, nearby vegetation could also be accessing it. Previously identified GDEs include the ‘end of dry flows’ mapping in the NT, GAB Watercourse springs in Queensland, and springs mapping for the whole area.

Rule 4: Where watertables are shallow (<5 m), vegetation uses groundwater.

Rationale: In general, where shallow watertables (<5 m) occur, vegetation is more likely to be accessing groundwater than in areas where groundwater levels are deep. This is partially because when the watertable is shallow it is within the rooting depth of vegetation, however it is also because with an unsaturated soil profile of more than approximately 5 m, vegetation accesses water in the soil profile in preference to groundwater (Cook et al., 1998a; Hutley et al., 2011).

Mapping of watertable depth is available for the NT as a series of points of depth to watertable data. A 300m buffer was applied to these points for the analysis. Where the points/buffers conflict, a conservative approach towards inclusion was taken, and the shallowest value was used for the analysis.

In the absence of watertable elevation mapping, the elevation of the land surface may be used to approximate groundwater depth. The assumption is that where the topography is low-lying, groundwater is closer to the surface, and in elevated landscapes groundwater is deeper. The spatial datasets available to model this are relatively unreliable for this purpose, as they were not created convey either watertable or land surface elevations, and they are mapped at a regional scale. The Rangelands data in WA and Landzone data in Queensland was used, however, these datasets pick out broad scale landforms, and not the topography which relates specifically to rivers or wetlands.

Because of this, the data was combined with the FLAG dataset created for this project, which informs on variations in elevation within each of the broad landforms.

Although shallow watertables are generally considered to occur mostly in low-lying landscapes, there are a few exceptions to this in northern Australia. The first is the presence of cracking clay soil plains, which occur in low-lying landscapes, but as described above, are highly impermeable and generally prevent throughflow of groundwater.

The other situation where low-lying elevations are not reflective of a shallow water table is on plateaus. In northern Australia these plateaus commonly consist of permeable sandstone overlying less permeable quartzite. Water is trapped in the sandstone and discharges to creeks which cut through the sandstone and flow from the edge of the plateau as waterfalls. Vegetation on top of the plateaus can access the groundwater trapped above the impermeable quartzite. Therefore in northern Australia, shallow watertables can be associated with both high elevations (plateaus) and low elevations (valleys) (P. Jolly, pers. comm.).

Rule 5: Vegetation type is an indicator of groundwater use.

Rationale: The most widespread vegetation ecosystem in northern Australia is the Eucalypt savannah woodlands, which dominate the northern third of the continent. The balance between trees and grasses in a Eucalypt savannah distinguishes this ecosystem from grasslands (with a near absence of trees) and closed forests (Hutley et al., 2011). Field studies have demonstrated that the dry season water requirements of Eucalypt savannah ecosystems can be entirely satisfied by water stored in the unsaturated zone (Cook et al., 1998a; Hutley et al., 2011).

Even in severe drought years it is unlikely that Eucalypt savannah ecosystems rely on groundwater, since in wet seasons with lower than average rainfall, water stored in the unsaturated zone was sufficient to maintain vegetation activity throughout the following dry season (Cook et al., 1998a). Reduced rainfall in the tropics primarily results in reduced runoff, not in reduced recharge. Therefore, even in the driest wet seasons on record, water stored in the unsaturated zone was replenished enough to support eucalyptus savannah through the following dry season. The same study (Cook et al., 1998a) also found that Paperbark swamp communities were unlikely to rely on groundwater for typical seasonal water requirements.

In the riparian zone of the Daly River, vegetation occurrence and water source was found to correlate with topography. Melaleuca species were predominantly located on river banks and were found to use a combination of river water and groundwater. Eucalyptus species occurred in the more elevated topography of the levee banks and used predominantly water stored in the unsatured zone. Certain species (*Melaleuca argentea* W.Fitzg and *Barringtonia acutangula* (L.) Gaertn.) use groundwater almost exclusively and are associated with river banks and lower terraces where the watertable is <5 m deep (O'Grady et al., 2003).

Monsoon Vine Forest (MVF) frequently occurs around springs and seepages and has been found to use groundwater for a large proportion of the water requirements. For example, Liddle et al. (2008) measured the groundwater use of MVF to be up to 50% of total water use at the end of the dry season. However Blanch et al. (2005) notes that MVF can also occur on well-drained soils where they may not be GDEs.

Rule 6: Soil depth and water holding capacity indicates potential for vegetation to rely on groundwater as opposed to water stored in the unsaturated zone.

Rationale: The wet/dry tropics is characterised by a deep weathered soil profile which is dominated by red, yellow and grey sandy loams. Several studies have demonstrated the reliance of eucalypt savannah ecosystems on water stored in the unsaturated zone, rather than groundwater (Cook et al., 1998a; Hutley et al., 2011). Hutley (2011) found a strong relationship between plant physiology and rainfall in sites along the North Australian Tropical Transect (NATT). Results showed that vegetation structure and function correlated strongly with rainfall, which suggests that it is mainly the variation in rainfall (and resulting availability of soil moisture) that results in differentiation between plants along the transect.

In addition to evidence provided by changes in plant physiology, several water balances have shown that there is little requirement for eucalypt savannah ecosystems to access groundwater. In the Daly Basin for example, a 5 m deep red earth can hold 970 mm of available moisture which is identical to measured ET in this catchment (Creswell et al., 2011). Heavy soils are shallower (typically 2 m) and store less available moisture (300 – 400 mm) (L. Hutley, pers. comm.).

The availability of sufficient water stored in the unsaturated zone is primarily due to the depth of the soil profile: that is, because the soils are generally deep across the Top End, and where the watertable is deep also (>5 m), the soils can hold sufficient moisture to maintain vegetation activity throughout the dry season. The soil water holding capacity of the red, yellow and grey sandy loams which are common across northern Australia is modest, however they release water readily. They therefore provide a low-energy source of water and as such, many ecosystems use water stored in the unsaturated zone in preference to groundwater. Where specific mapping of the water holding capacity (or available water capacity) of soils is available (as in Queensland), this is used to suggest whether vegetation is likely to access groundwater or not. Where soil water holding capacity information is not available, the soil type is used to assume likely available water capacity of the soils.

Rule 7: Vegetation occurring in estuaries and in coastal floodplains at less than 5 m elevation, or on cracking clay soils, is unlikely to be a GDE.

Rationale: On coastal floodplains (elevations less than approximately 5 mAHD) there is little vegetation. This is due to the marine origin of the sediments and the lack of subsequent uplift, which has meant that the floodplain sediments are still saline and are unlikely to support diverse

vegetation communities. The sediments are also low permeability, which restricts flow of fresh groundwater into the floodplain. Vegetation on these floodplains predominantly consists of grasses, with waterholes fringed by Melaleuca and estuaries fringed by mangroves, which are generally considered not to rely on groundwater. Some use of groundwater has been found for mangroves in the Darwin Harbour however, and without this, the species composition of the mangrove forest would be different (P. Brocklehurst, pers. comm., 11/11/2011). This groundwater contribution occurs largely at the edges of mangrove forests. Mangroves are therefore not excluded from the GDE mapping but since the available vegetation mapping is not detailed enough to distinguish the edges of mangrove forests from the centre, the entire polygon may be considered a GDE and may therefore be an over-representation.

Springs frequently occur on coastal floodplains. Where these are mapped, they will be incorporated into the GDE mapping and will override the confidence so the polygon will be mapped as a ‘GDE identified in previous study’.

Estuaries should be excluded from the GDE mapping. Vegetation that relies on groundwater occurs at the edge of these floodplains, at higher elevations (P. Jolly, pers. comm.). Additionally, rules for mapping estuaries would have to be specifically targeted to model estuarine functions, and because mapping of estuarine GDEs is not part of the current GDE Atlas scope, this has not occurred. It is therefore more accurate to remove estuaries from the mapping entirely.

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 50. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 50 GIS analysis rules for GDEs that rely on the subsurface presence of groundwater**

Rule	
1	High probability IDEs are potential GDEs
2	Vegetation around permanent water features (excluding estuaries and man made lakes) or previously identified GDEs are likely to access groundwater, except where the water feature is located on coastal floodplains where Holocene marine muds are present, or on cracking clay soil plains
3	Vegetation around previously identified GDEs is likely to access groundwater
4	Where watertables are shallow (<5 m), vegetation uses groundwater

Rule	
5	Vegetation type is an indicator of groundwater use
6	Soil depth and water holding capacity indicates potential for vegetation to rely on groundwater as opposed to water stored in the unsaturated zone
7	Vegetation occurring in estuaries and in coastal floodplains at less than 5m elevation, or on cracking clay soils, is unlikely to be a GDE.

11.1.2. Selection of data for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 51 shows the features layers selected to map GDEs that rely on the subsurface presence of groundwater for WP6. These layers contain all the vegetation features that were analysed to establish whether a groundwater connection exists. The feature layers are either the datasets that the rules in section 11.1.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 51 Feature layer datasets for analysis of GDEs that rely on the subsurface presence of groundwater (vegetation) in WP6**

State	Ecosystem	Dataset Name	Source or Custodian
NT	Vegetation	Greater_darwin_lc_52m	NRETAS
	Vegetation	NVIS2005_combo_part1_2_3	NRETAS
WA	Vegetation	DEC pre-european	DEC
QLD	Vegetation	QLD RE06b	DERM
	Vegetation	IQ_QLD_REGECOPRECL/ Rem veg	DERM
	Vegetation	CRC tropical veg (Qld)	Qld EPA

Two vegetation feature layers were used for the NT part of work package 6. The Greater Darwin vegetation map covers only a small area around Darwin. The NVIS2005_combo_1_2_3 map was created from other datasets and although it covers most of the NT portion of WP6, it only maps certain vegetation ecosystems (rainforest vegetation and Melaleuca) and is therefore incomplete. As such, although GIS analysis for GDEs that rely on subsurface presence of groundwater could occur for the whole work package, the data used does not incorporate all ecosystem polygons.

Although various landsystem and land unit maps existed which could have potentially been used as vegetation feature layers for the NT, they each covered a relatively small area (such as a single cattle station). Due to time constraints, the Atlas required maps with greater coverage (regional or state coverage) and could not incorporate the large number of maps with limited coverage.

A recommendation for future work is to create a vegetation feature layer from the various vegetation maps (Landunit and landsystems maps) that currently exist for the NT. If this does not result in a sufficiently extensive layer, NVIS vegetation mapping (www.environment.gov.au/erin/nvis) also covers the area. However, it contains large polygons which may need to be split into smaller polygons to enable meaningful GDE potential results to be derived.

11.1.3. Selection for GIS analysis datasets for implementation of rules

Table 52 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the subsurface presence of groundwater in WP6. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 52, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6. Because there was no appropriate vegetation feature layer for the NT, the analysis in Table 52 could not be carried out in the NT.

- **Table 52 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the subsurface presence of groundwater**

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	High likelihood IDEs (8, 9, 10) are potential GDEs	IDEs	WP6 IDEs, derived for project	Whole WP	The probability from the RS layer is assigned to each vegetation polygon by majority value. That is, the probability of the greatest number of pixels that intersect with the polygon becomes the probability of the whole polygon. Probabilities of 6 & 7 give no indication of groundwater use (0); probabilities of 8, 9 & 10 suggest groundwater use is more likely (3).
2	Vegetation around permanent water features (excluding estuaries) are likely to access groundwater, except where the water feature is located on coastal floodplains where Holocene marine muds are present, or on cracking clay soil plains	Watercourse mapping with permanency attributes	NT_Riv_Cks_250_p (NT) Geodata Lakes (NT) Major Watercourses (NT, QLD, WA)	NT NT Whole WP	Where a permanent water regime occurs, it is more likely that groundwater maintains the water regime during low rainfall periods. Where a vegetation polygon intersects a permanent waterbody, groundwater may be close to the surface, and hence, vegetation is more likely to be using it (3). Only permanent water bodies are normalised in this analysis. Permanence attributes such as 'non-permanent' give no information about how long the presence of water remains after rainfall ceases, and so give no information about potential groundwater contributions (0).
		MODIS open water	WP6 MODIS DATA (WA, NT, QLD)	Whole WP	Remote sensing data was not used for Qld since a more comprehensive Landsat analysis for Qld was used to develop the WTRREGIME_ attribute. This was used instead. For WA & NT remote sensing of open water was used as an indicator of permanent presence of water. Where Landsat or MODIS open water intersected a vegetation polygon, the polygon was considered more likely to contain open water, and for this to contain groundwater (3). Where no intersect is recorded, the rule gives no indication whether the wetland/river interacts with groundwater or not (0), i.e. just because it doesn't intersect with open water doesn't mean the wetlands/river won't
		Landsat open water	WP6 Landsat DATA (WA, NT, QLD)	Whole WP	

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
					be interacting with groundwater.
		Holocene muds mapping (Holocene mud exception does not apply in Qld)	ASSRM_ESTUARIES (WA) ACIDALL_G84_poly_polygon (NT)	WA NT	A permanent water regime or the presence of open water is only an indicator of potential groundwater use where there are no Holocene muds, or cracking clay soils. Where a vegetation polygon intersected with either cracking clay soils or Holocene muds, the permanency attribute was disregarded, and the vegetation was considered to be unlikely to rely on groundwater (1).
		Cracking Clay soil mapping	Pre-european (WA) NorthLS_250 (NT) Southern NT Landsystems (NT) Qld RE06b	WA NT NT Qld	
3	Vegetation around previously identified GDEs is also likely to use groundwater	Mapping of springs/ previously identified GDEs	Additional Potential Geodata Springs (NT) Springs_21_04_2009 (NT) Endofdryflows (NT) HYD_SPRINGS_V3 (Qld) GAB Watercourse Springs (Qld) Spring REs (Qld) NVIS2005_Combp_Part1_2_3 (NT)	NT NT NT Qld Qld Qld NT Could not analyse rule in WA	Identification of GDEs in previous mapping is considered to be a reliable data source and hence is used in the analysis. Where a spring or known GDE intersects a vegetation polygon, it is more likely that the vegetation is using groundwater (3). In the case of springs the vegetation may be using groundwater which has been discharged to the surface, and in the case of other GDEs (like Rivers) it is likely that groundwater will be shallow and therefore that vegetation can access the groundwater from beneath the watertable.
4	Where watertables are shallow (<5m), vegetation uses groundwater. Deep	Watertable elevation contours	Drill_SWL (NT) HYDSTRA_SWL_MIN (NT)	NT NT Could not analyse rule in Qld, WA	Groundwater interaction is considered likely where watertable depth is <10m (3), possible for watertables between 10 & 20m (2), and unlikely for watertables >20m (1).
		Landsurface elevation	DAFWA_landsystems_rangelands (WA)	WA Qld	Landscape datasets were used to approximate depth to watertable. In WA, certain Land Types within the rangelands dataset are indicative of

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
	watertables suggest vegetation relies on water stored in the unsaturated zone	contours	Qld RE06b FLAG, Derived for project (WA, NT, Qld)	Whole WP	shallow watertables. Where vegetation occurs on these landscapes (see normalisation tables), there is a higher potential for groundwater to be available. Other landscapes suggest that groundwater may not be available. Where no Rangelands data exists, the FLAG dataset is used to indicate topography, where low-lying elevations are more likely to have shallow groundwater (3), slopes are unlikely to have shallow groundwater (1) and plateaus could possibly have shallow groundwater (2). In Qld the Landzone attribute indicates broad scale potential for groundwater availability. This was combined with FLAG to give more suggestion of variation within the broad landzones.
5	Vegetation type is an indicator of likely groundwater use	Vegetation community/species mapping	greater_darwin_lc_52m (NT) NVIS2005_Combp_Part1_2_3 (NT) DEC pre european (WA) Qld_RE06b (QLD) CRC tropical veg (Qld)	NT NT WA Qld Qld	Attributes describing vegetation types were normalised as either likely to use groundwater (3); possibly use groundwater (2), unlikely to use groundwater (1), or not sure (0). Normalisation was done from literature and by reviewers and jurisdictions.
6	Soil depth and water holding capacity indicates potential for vegetation to rely on groundwater as opposed to water stored in the unsaturated	Soil water capacity mapping	gtrdw_25/Land Units Qld_Combinedsoils_2M	Could not analuse rule in WA (soil depth approximated by rule 3)	Where vegetation is growing in soils that hold sufficient water, there is no need for the vegetation to use groundwater, as it usually requires less energy to use the water stored in the unsaturated zone. Therefore, where the water holding capacity of soil is high, vegetation is unlikely to access groundwater (1), and where it is low, vegetation may require groundwater to maintain growth in dry periods (3).

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
	zone				
7	Vegetation occurring in estuaries and in coastal floodplains at less than 5m elevation, or on cracking clay soils, is unlikely to be a GDE.	Holocene muds mapping (WA, NT only)	ASSRM_ESTUARIES (WA) ACIDALL_G84_poly_polygon (NT)	WA NT Could not analyse rule in Qld	Vegetation occurring in impermeable soils such as Holocene mud or cracking clay is less likely to use groundwater since the flow of groundwater through these soils is limited (1).
		Cracking clay soils mapping	Pre-european veg mapping (WA) NorthLS_250 (NT) Southern NT Landsystems (NT) Qld RE06b (Qld)	WA NT NT Qld	

11.1.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 52) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater use:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 52.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

11.1.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

11.1.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 53 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not

comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 53 are only comparable for each feature dataset, and so may only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Springs always result in a vegetation polygon being assigned a high potential.
- Holocene muds or cracking clay soils always result in a low or moderate potential depending on other data.
- Shallow watertables always result in high or moderate potential, and deep water tables always result in low potential, depending on the other data.

Table 53 Weighting for each GIS Analysis rule/dataset for GDEs that rely on subsurface presence of groundwater in WP6

Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7
	High likelihood IDE	Vegetation around persistent water features	Presence of springs/ previously mapped GDEs	Depth to watertable/ land surface elevation*	Vegetation type	Soil water holding capacity	Veg in estuaries /coastal floodplains
greater_darwin_lc_52m (NT)	6	5	30	7/-	7	-	8
NVIS2005_Combp_Part1_2_3 (NT)	6	5	30	7/-	6	-	7
DEC pre european (WA)	5	7	-	-/2	5	-	12
Qld_RE06b (QLD)	8	8	22	-/2	8	4	8
CRC tropical veg (Qld)	8	8	28	-/1	10	4	8

* Used only where DTWT mapping is not available

11.1.5.2. Definition query

Definition queries were generally applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This included non-natural landscapes such as settlements, pasture, and plantations, as well as natural landscapes that do not use groundwater, such as grasslands and bare earth.

All vegetation polygons that had an ID likelihood of 5 and less were removed at this stage, as these ecosystems were not likely to be accessing a source of water in addition to rainfall. The additional definition queries applied to each dataset to exclude ecosystems that could not be subsurface GDEs are listed below.

For the **greater_darwin_lc_52m** feature layer dataset the definition queries were applied to the field ‘COMM’ to exclude polygons attributed as:

- Water
- Cleared land
- World

For the feature dataset **NVIS2005_Combo_part1_2_3** (which includes rainforest and melaleuca ecosystems only), no definition queries were applied.

For the **DEC pre-european** feature layer dataset the definition queries were applied to the field ‘SOURCE_DES’ to exclude polygons attributed as:

- Bare areas; drift sand
- Bare areas; freshwater lakes
- Bare areas; mud flats
- Bare areas; rock outcrops
- All polygons that were solely ‘grasslands’ (shrubs, low tree and sparse tree attributes were not excluded).

For the **RE06b** feature layer dataset the definition queries were applied to the field ‘DBVG2M’ to exclude polygons attributed as:

- 30 – 33
- 35
- Ocean
- Sand
- Water

And in the attribute ‘RE’ the attributes excluded were:

- Estuary
- Nil
- Non-rem
- Ocean
- Sand
- Water

11.2. Identification and mapping of GDEs that rely on the SURFACE expression of groundwater

11.2.1. Literature review and GIS analysis rules

The GIS analysis rules were developed based on the concepts and understandings gained from reviewing literature for the region. Much of the literature reviewed related to the Daly Basin and the Darwin area, however the concepts were applied to the whole work package.

The primary concept which is considered to identify GDEs that rely on the surface expression of groundwater in WP6 is the presence of surface water in the dry season, which indicates that groundwater discharge is occurring. However other factors such as depth of the waterbody, underlying geology, and marine influences can influence the efficacy of this concept. In addition to persistence of surface water, non-permanent waterbodies can also receive groundwater inputs since watertables may fluctuate significantly in the tropics, particularly where rainfall is intense. Depth to watertable is one of the strongest indicators of potential groundwater discharge, however spatial data which maps the depth to watertable is very limited. Underlying geology and the presence of GDEs that rely on the subsurface presence of groundwater (i.e. vegetation) are also acceptable indicators of where groundwater discharge to surface may occur.

Where an ecosystem fulfils several of these concepts, the potential for groundwater to be discharging to the surface is greater than if only a few of these concepts are satisfied. The specific rules and justification for each are outlined below.

Rule 1: Permanent water regime indicates groundwater connection.

Rationale: Rainfall in the area occurs almost exclusively during the 7 months between October and April, with the remaining 5 months being dry. The persistence of surface water throughout the dry season is therefore an indication that groundwater discharge may be occurring. The relationship between permanent flow and groundwater discharge is well documented (Zaar, 1999; Zaar, 2003b; Zaar, 2009; Moliere, 2007; Haig, 2003f; Matsuyama, 2003d; Fulton and Zaar, 2009; George, 2001; O’Grady et al., 2002; Hydrobiology, 2006). As such, permanent water features such as streams with low annual flow variability, springs, billabongs and waterholes that contain water throughout the year, are considered likely to be GDEs. In addition, perennial freshwater ecosystems in northern Australia host diverse aquatic ecosystems, for example in the Gregory and Nicholson Rivers (Hydrobiology, 2006), the Roper River (Knapton, 2009b; Blanch et al., 2005) and the Daly River (O'Grady, et al., 2001).

This assumption is true for permanent surface water systems that are less than 1m deep, since water bodies deeper than this may persist throughout the dry season due to the fact that their depth exceeds evaporation (evaporation is relatively low in the tropics due to high humidity). Surface water bodies that are less than 1m deep would be expected to dry out over the dry season if groundwater discharge was not occurring (P. Jolly, pers. comm.), as evaporation would exceed

water depth. Due to the absence of data on water body depth, it must be assumed that any permanent surface water feature is connected to groundwater for the purposes of this analysis. However, this rule more accurately predicts groundwater interaction for rivers than for wetlands, as perennial rivers rely on continuous groundwater contributions, rather than depth alone.

There are three exceptions where permanent water is not indicative of groundwater discharge. Firstly, estuaries have permanent water due to tidal influences and should therefore not be considered as GDEs (except where a strong groundwater influence has been documented – for example the Roper River (P. Jolly, pers. comm.)). The second is water storages, such as Lake Argyle, and Darwin River Dam. Where spatial data permits, these exceptions should be excluded from GDE mapping.

Thirdly, permanent swamps that occur in cracking clay plains are less likely to be GDEs. These swamps are low-lying and capture runoff during the wet season. The swamps persist until the next wet season because they are located on very low permeability soils. Therefore, they are effectively perched systems, and they rely on captured surface water rather than groundwater, although some groundwater inflow may still occur (P. Jolly, pers. comm.). This exception can generally be allowed for in the mapping, through the identification of certain Regional Ecosystem (RE) codes in the Queensland wetlands mapping that denote the presence of cracking clay plains, or the NT landsystems mapping. In WA there is no spatial data available to specifically identify cracking clay soils, and therefore this exception to the rule has not been allowed for in WA rivers and wetlands mapping.

Another scenario which reduces the likelihood of connection between groundwater and surface water is the presence of Holocene marine muds which occur near the coast. These muds also have a low permeability which restricts groundwater flow into waterways near the coast. Holocene muds also frequently result in acid sulphate soils, which are mapped in coastal areas. These acid sulphate soils spatial datasets are used to reduce the confidence in surface water features being GDEs in low-lying floodplains where the acid sulphate soils occur. This exception applies primarily to the NT and WA, as significant deposits of Holocene marine muds did not occur in Queensland since the landscape was more uplifted towards the east. Indeed, groundwater discharge to the coastal margins on the eastern side of the Gulf can result in diverse and highly productive wetlands (Hydrobiology, 2006).

Rule 1 is applied to permanent surface water features only (which are identified as rivers/wetlands mapped as ‘perennial’ or where MODIS or Landsat detects open water). Non-permanent waterbodies may also be GDEs, but these are identified using the concepts explained in rule 2 below. It should also be noted that losing stream reaches (streams where water moves from the stream into the aquifer) should not be considered as GDEs, although they may be permanently flowing. There is no spatial data to identify these reaches and as such, this concept could not be allowed for in the mapping.

Rule 2: Large fluctuations in watertable can result in groundwater discharge to non-permanent water bodies in the late wet season. Large fluctuations in watertable are expected to occur where rainfall is high (>1000 mm/yr), and intense (>60% of annual rainfall occurs in a 3 month period; and there are at least 10 days where >25 mm rainfall).

Rationale: Non-perennial rivers in the northern Australia may contain permanent groundwater-fed waterholes or pools which support aquatic ecosystems. Groundwater contributions to non-perennial streams may also extend the period of flow after rainfall has ceased. For groundwater to discharge seasonally into rivers, creeks and wetlands, the watertable must be relatively close to the surface, and must reach the surface seasonally. Therefore, where watertables fluctuate significantly, it can be assumed that groundwater discharge may occur at the times when watertables are highest.

The height of the watertable can vary significantly between seasons in the tropics. For example in the Daly Basin, the watertable in the Tindall Limestone varies seasonally from 2-25 m depth; in the Junduckin watertable varies from 8-25 m; and in the Oolloo it can vary from 2-26 m depth (Begg, 2001 after Chin, 1995). For permanent rivers this increases the volume of groundwater discharge, and for non-permanent rivers these large fluctuations can result in connection between groundwater and surface water when the watertable peaks.

Such large watertable fluctuations do not occur across the whole of northern Australia. Rather, it is in higher rainfall areas (say 1,000 mm/yr) that the watertable is likely to fluctuate significantly. Spatial datasets which indicate rainfall intensity are available from the Bureau of Meteorology, such as the percentage of total rainfall that occurs over a selected 3 month period (in this case the summer period of December to February was chosen) and the number of days when greater than 25 mm of rainfall occurs.

This concept applies only to non-permanent water bodies. Analysis of permanent water bodies is captured in Rule 1. Due to data limitations, this rule has not been used for wetlands in WA, as all wetlands are attributed as permanent and have therefore been incorporated in the analysis from Rule 1.

Rule 3: Rivers and wetlands are less likely to be GDEs where cracking clay plains or Holocene muds are present.

Rationale: Waterbodies which occur on the impermeable soils characterised by cracking clay plains and the Holocene muds are less likely to be connected to groundwater. The impermeable nature of the soils is a barrier to groundwater flow, such that even where groundwater is shallow, it may not be in connection with the overlying waterbody.

While Holocene muds occur largely on the coast, cracking clay plains are common throughout northern Australia. These soils also cause waterbodies to retain water throughout the dry season, even though there is no (or limited) groundwater connection. This is because there is relatively low evaporation in the tropics due to the high humidity, and as such, if a waterbody is greater than

approximately 1m deep, it may not dry up during the dry season despite not receiving groundwater contributions. This rule obviates the use of water persistence (Rule 1 and 2) to indicate groundwater connection. Rules 1 and 2 are therefore not used when mapping indicates the presence of cracking clay soils.

Rule 4: Rivers and wetlands in the vicinity of springs are groundwater fed.

Rationale: Springs are groundwater discharge points and can be considered to be GDEs. Springs are responsible for maintaining permanent or persistent flow in many rivers. Using a buffer of 25 m around springs and rivers, it can be assumed that where they intersect, the spring contributes to river flow.

Rule 5: Watertable depth indicating potential for connection between groundwater and surface water systems.

Rationale: The height of the watertable relative to the surface water body determines how long flow persists after rain ceases. This continuation of flow is the result of groundwater discharging into the watercourse until the watertable has declined to a lower elevation than the base of the watercourse.

Many streams in northern Australia are dominated by rainfall runoff and quick flow during the wet season. However where the watertable is close to the surface, groundwater can sustain flow after the wet season ends. Where the watertable is in close proximity to the surface it can be assumed that groundwater discharge to the surface is more likely.

Rivers such as the Daly and Katherine Rivers have permanent reaches and documented groundwater components. In the Daly River, the volume of groundwater inflow between the gauging station at Dorisvale and the Douglas River junction was estimated to be between 21% and 48% at the end of the dry season in 2000 and 2001 (Cook et al., 2003). Both the Daly and Katherine Rivers are deeply incised, suggesting that topography has an influence on groundwater connection, as low lying areas are in closer proximity to the watertable. Despite this link, the land surface elevation has not been used to approximate depth to watertable in the GDE analysis. This is because using land elevation requires a significant assumption to be invoked, namely, that the watertable elevation mimics that of the land surface. This is not always true, particularly in high conductivity aquifers. Also, land surface is usually lowest at drainage lines, so using the land elevation datasets means that waterbodies will result in a high confidence (unless there are other datasets to bring the confidence down) solely because they occur at low points in the landscape. This skews the results too much and has therefore been omitted from the mapping. An exception was made in WA however, where the rangelands dataset was used. This dataset picks out broad scale landforms, and not the topography which relates specifically to rivers or wetlands.

Rule 6: Underlying aquifer type indicates potential for groundwater discharge to surface.

Rationale: A relationship between permanency of flow and aquifer geology has been established in the Daly Basin. Permanent river reaches in the Daly are fed by carbonate aquifers (in particular the Tindall and Oolloo Limestone). Other formations such as the cretaceous sandstone and Junduckin Limestone contribute less to baseflow (Moliere, 2007). More broadly, it is assumed that where permanent rivers of the Daly Basin intersect a certain geological formation, that formation provides groundwater inputs to the river. Where non-permanent rivers intersect a certain geological formation, that formation may still provide groundwater inputs, however this discharge relies on the watertable being close to the base of the river.

In the Daly Basin, spring discharge is largely confined to the carbonate aquifers (Begg, 2001). In Queensland, it is reported that the fractured rock, river alluvium and limestone formations contribute baseflow to surface water features. The limestone in particular, contributes baseflow to the Gregory River, which is one of the only permanently flowing streams in arid/semi-arid Queensland (Hydrobiology, 2006).

The outcropping GAB aquifers also contribute baseflow to overlying rivers. The analysis therefore uses the presence of outcropping GAB aquifers as an indicator of potential baseflow to rivers. The GAB aquifers which are likely to contribute baseflow are listed in the GAB WRP (Queensland Gov, 2006). The aquifers are:

- Westbourne Formation
- Adori Sandstone
- Birkhead Formation
- Hutton Sandstone
- Evergreen Formation
- Boxvale Sandstone Member
- Precipice Sandstone
- Moolayember Formation
- Warang Sandstone
- Clematis Sandstone
- Rewan Formation
- Wallumbilla Formation
- Cadna-owie Formation
- Wyandra Sandstone Member
- Hooray Sandstone
- Ronlow Beds
- Toolebuc Formation
- Injune Creek Group
- Helby Beds
- Gilbert River Formation

- Garraway Beds
- Eulo Queen Group

Only the Moolayember Formation, Warang Sandstone, Wallumbilla Formation, Toolebuc Formation, Helby Beds, Garaway Sandstone, Ronlow Beds and Gilbert River Formation outcropped in WP6, according to the GA National Geology mapping.

Rule 6: The presence of GDEs that rely on the subsurface presence of groundwater indicates potential for nearby groundwater discharge.

Rationale: Lush vegetation can indicate the presence of a spring (Fulton and Zaar, 2009). Where vegetation is identified to be using groundwater, the watertable is likely to be shallow and as such, there is greater potential for groundwater to be discharging into nearby waterbodies. Therefore the presence of a GDE that relies on subsurface presence of groundwater can be used to identify potential groundwater discharge points, which result in GDEs that rely on the surface expression of groundwater.

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 54. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 54 GIS analysis rules to identify GDEs that rely on the surface expression of groundwater in WP6**

Rule	
1	Permanent water regime indicates groundwater connection, except where Holocene muds or cracking clay soils are present
2	Large fluctuations in watertable can result in groundwater discharge to non-permanent water bodies in the late wet season. Large fluctuations in watertable are expected to occur where rainfall is high (>1000 mm/yr), and intense (>60% of annual rainfall occurs in a 3 month period; and there are at least 10 days where >25 mm rainfall).
3	Rivers and wetlands are less likely to be GDEs where cracking clay plains or Holocene muds are present
4	Rivers and wetlands in the vicinity of springs are groundwater fed
5	Watertable depth indicating potential for groundwater discharge to surface.

Rule	
6	Underlying aquifer indicating groundwater discharge to surface
7	Subsurface GDEs indicating nearby groundwater discharge

11.2.2. Selection of data for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 55 shows the feature layers selected to map GDEs that rely on the surface expression of groundwater for WP6. These layers contain all the river, wetland and spring features that were analysed to establish whether a groundwater connection exists. These are either the datasets that the rules in section 11.2.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 55 Feature layer datasets for analysis of GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs) in WP6**

State	Ecosystem	Dataset Name	Source or Custodian
NT	Springs	Springs_21_4_ 2009	NRETAS
	Springs	Additional_Potential_Geodata_Springs	NRETAS
	Springs	Wadeye250_watersites	NRETAS
	Rivers	NT_Riv_Cks_ 250p	NRETAS
	Wetlands	Geodata Lakes	GA
	Wetlands	Geodata flats & swamps	GA
QLD	Springs	HYD_SPRING_V3	DERM
	Rivers	Major Watercourses	DERM
	Wetlands	QLD_WETLAND_ SYSTEM_100K_A	DERM

State	Ecosystem	Dataset Name	Source or Custodian
WA	Springs	No data available	NA
	Rivers	Hydrography_Linear _ Hierarchy	DOW
	Wetlands	DEC_Important_Wetlands	DEC

The feature layer datasets listed above fully cover the WP6 area, allowing mapping of GDEs that rely on the surface expression of groundwater to be mapped and analysed for the whole work package. The only additional feature dataset required was springs mapping for WA. The DEC_Important_Wetlands mapping only shows wetlands listed on the DIWA and as such, this is feature layers does not capture all wetlands in WA.

11.2.3. Selection of GIS analysis datasets for implementation of rules

Table 56 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the surface expression of groundwater in WP6. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 56, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

Table 56 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the surface expression of groundwater

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	Permanent water regime indicates groundwater connection	Watercourse mapping with permanency of flow attribute	NT_Riv_Cks_250_p National Major Watercourses	NT WA & Qld	Where a permanent water regime occurs, it is more likely that groundwater maintains the water regime during low rainfall periods (3). A seasonal water regime indicates it is possible that groundwater maintains the presence of water after rainfall has ceased (2), and an intermittent or episodic water regime suggests rainfall dependence rather than groundwater use (1). Permanence attributes such as 'non-permanent' give no information about how long the presence of water remains after rainfall ceases, and so give no information about potential groundwater contributions (0).
		Wetlands mapping with permanency attributes	QLD_WETLAND_SYSTEM_100_K DEC_Important_Wetlands Geodata Lakes	QLD WA NT Could not analyse rule for Geodata flats & swamps	
		Rockhole mapping with permanence attributes	HYD_SPRINGS_v3 (Rockholes)	Qld	Remote sensing data was not used for Qld since a more comprehensive Landsat analysis for Qld was used to develop the WTRREGIME_ attribute. This was used instead. For WA & NT, remote sensing of open water was used as an indicator of permanent presence of water. Where Landsat or MODIS open water intersected a wetlands/river polygon, the polygon was considered more likely to contain open water, and for this to contain groundwater (3). Where no intersect is recorded, the rule gives no indication whether the wetland/river interacts with groundwater or not (0), i.e. just because it doesn't intersect with open water doesn't mean the wetlands/river won't be interacting with groundwater.
		Landsat open water intersect	WP6 Landsat	WA, NT	
		MODIS open water intersect	WP6 MODIS	WA, NT	
2	Non-permanent rivers are likely to receive	Rainfall data	BoM dataset: Annual rainfall BoM dataset: % rainfall in Dec – Feb	Whole WP	The watertable is more likely to fluctuate significantly where rainfall is intense (>1000mm/yr), where there are more than 10 days of >25mm

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
	baseflow in areas where the watertable fluctuates significantly (where the rainfall is >1000mm/yr) and where rainfall is intense (>60% in 3 months; >10 days of >25 mm rainfall).		BoM dataset: number of days of rainfall >25 mm		rainfall, and where the most of the annual rainfall occurs in a single season. Watertables in these climates are more likely to fluctuate and result in groundwater discharge to non-permanent waterbodies in the late wet season (3). Where two of these climate criteria are satisfied, it is possible that groundwater discharge occurs in the late wet season (2), and where none or one of the criteria are satisfied, it is unlikely that the watertable fluctuates enough to result in groundwater discharge (1).
		Permanency of flow/water mapping	National Major watercourses NT_Riv_Cks_250_p DEC_Important_Wetlands Geodata Lakes QLD_WETLAND_SYSTEM_100K_A	Qld, WA NT WA NT Qld	This analysis is only applied to waterbodies mapped as non-permanent.
3	Rivers and wetlands are less likely to be GDEs where cracking clay plains or Holocene muds are present	Cracking clay plains mapping	NorthLS_250 Southern NT Landsystems QLD_WETLAND_SYSTEM_100K	NT NT Qld Could not use rule in WA	Where cracking clay plains or Holocene muds occur, waterbodies are unlikely to receive groundwater inputs due to the low permeability of the soils (1).
		Holocene muds mapping	ASSRM_ESTUARIES ACIDALL_G84_poly_polygon	WA NT Rule does not apply in Qld	
4	Rivers in the vicinity of springs are groundwater fed	Springs mapping	Springs_21_04_2009 Additional Potential Geodata Springs HYD_SPRING_V3 GAB Watercourse Springs	NT NT Qld Qld	Where a mapped spring intersects a river or wetland, the river or wetland is likely to be receiving groundwater inputs (3).

#	RULES	DATASETS NEEDED FOR ANALYSIS	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
			Spring REs	Qld Could not use rule in WA	
5	Watertable depth indicating potential for groundwater discharge to surface.	Watertable elevation contours	Drill_SWL_5 Drill_SWL HYDSRTA_SWL_MIN	NT NT NT Could not use rule in WA, Qld	Groundwater interaction is considered likely where watertable depth is <5m (3), possible for watertables between 5 & 10m (2), and unlikely for watertables >10m (1).
		Landsurface elevation data	DAFWA_landsystems_rangelands	WA	Certain land types are considered more indicative of shallow watertables (3), while others are considered more indicative of deeper watertables (1). This is a broad scale data which requires significant assumptions for use to indicate depth to watertable. Therefore, it is weighted low.
6	Underlying geology indicating groundwater discharge to surface	State/regional aquifer/geology mapping	NT_aquifers_r_01_08_2008 DWAID_Aquifers	NT WA	Certain geological formations are likely to contribute baseflow to rivers and wetlands (3) which flow over them. This may be through either springs or diffuse discharge. GAB aquifers, limestone and alluvium are the most likely to contribute baseflow in WP6.
		National geology/aquifer mapping	Basemap geology map	Qld	
7	Presence of GDEs that rely on the subsurface presence of groundwater indicating shallow watertables and possible groundwater discharge	Derived GDEs that rely on the subsurface presence of groundwater mapping	Derived GDEs that rely on the subsurface presence of groundwater	Whole WP	Where a 'high potential' subsurface GDE intersects with a wetland/river, this was assumed to increase the potential for a wetlands/river GDE to exist (3).

11.2.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 56) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater interaction:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 56 above.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

11.2.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

11.2.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 57 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative differences between weightings controlling the GDE potential result. Weightings are not comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 57 are only comparable for each feature dataset, and so should only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

For the surface GDE mapping, the weightings were developed so that:

- The presence of a spring intersecting a river, wetland, or waterhole always results in the feature being assigned a high potential.
- The presence of cracking clay soil or Holocene muds always results in a river, wetland, or waterhole being assigned a moderate or low potential.
- Shallow watertables result in a high potential, except where Holocene muds or cracking clay soils are present.
- Deep watertables always result in a low potential, except where a spring is present.
- The presence of certain aquifer types, GDEs that rely on the subsurface presence of groundwater, permanent water and/or fluctuating watertables are then used to adjust the result, or determine the result for features which have no depth to watertable, spring or cracking clay soil/Holocene muds.

- **Table 57 Weighting for each GIS Analysis rule/dataset for GDEs that rely on surface expression of groundwater in WP6**

Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7
	Persistence of water regime /open water#	Fluctuating watertables contributing to non-permanent water bodies	Presence of Holocene mud/ cracking clay soil	Presence of a spring	Depth to watertable	Geology indicating GW discharge	Presence of sub-surface GDE
Major watercourses (Qld)	5/1	2	NA	20	NA	4	2
QLD_WETLAND_100K (Qld)	5/NA	2	10	35	NA	4	2
HYD_SPRINGSv3 (rockholes) (Qld)	5/NA	1	NA	NA	NA	NA	2

Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7
Wadeye watersites (NT)	NA/1	NA	20	NA	8	8	2
NT_Riv_Cks_ (NT)	6/1	2	20	20	10	4	2
Geodata Lakes (NT)	7/1	1	12	16	12	5	2
Geodata Flats & Swamps (NT)	NA/5	2	14	12	12	5	2
DEC important wetlands (WA)	NA/5	NA	10	NA	1*	2	3
Hydrography Linear Hierarchy (WA)	6/1	2	18	NA	1*	3	3

remote sensing of open water not used since water regime attribute in wetlands mapping has had false positives removed
* Based on landscape data only, therefore weighted low as data is not as reliable or appropriate as depth to watertable contours.

11.2.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This includes non-natural landscapes such as reservoirs, dams and irrigated land. It also excludes features that are artefacts of mapping, and do not represent actual features in the landscape.

The definition queries applied to each dataset to exclude ecosystems that cannot be GDEs that rely on the surface expression of groundwater are listed below.

For the **Qld_wetlands_100K, v2** feature layer dataset definition queries were applied to the field ‘WTRREGIME’ to exclude polygons attributed as:

- TI (tidal)
- Blanks (‘ ‘; and ‘-‘)

To the field ‘WETCLASS’ to exclude polygons attributed as:

- Estuarine
- Marine
- Blanks (‘ ‘; and ‘-‘)

To the field 'HYDROMOD' to exclude polygons attributed as:

- H2M1
- H2M6
- H2M7
- H2M8
- H3C1
- H3C2
- H3C3

To the field 'HAB_L' to exclude polygons attributed as:

- Blanks (' '; and '-')
- Marine
- Estuarine – water

To the field 'POLY#' to exclude polygons attributed as:

- 1 (removes a single vertical straight line down the middle of the dataset)

For the **national_watercourses (Qld)** feature layer dataset definition queries were applied to the field 'PERENNIAL' to exclude polygons attributed as:

- Blanks (' ')

For the **Hydrology Linear Hierarchy dataset (WA rivers)** feature layer dataset definition queries were applied to the field 'HYD_NAME' to exclude polygons attributed as:

- Blanks (' ')=
- Attributes containing 'dam'
- Attributes containing 'estuary'
- Attributes containing 'channel'
- Attributes containing 'main supply'
- Attributes that were only numbers
- Lake Argyle
- Lake Kunnunarra

In the field 'TYPE_NAME':

- Estuarine

In the field 'HYD_TYPE':

- Drain

For the **DEC Important Wetlands dataset (WA wetlands)** feature layer dataset definition queries were applied to the field 'WET_TYPE' to exclude polygons attributed as:

- A (Marine and coastal zone wetlands)
- C (Human-made wetlands)

For the **NT_riv_cks_250_p (NT rivers)** feature layer dataset definition queries were applied to the field 'PERENNIAL' to exclude polygons attributed as:

- removed all features that were not classified as either 'perennial' or 'non-perennial'. This removed the polygons in between braided streams from the GDE mapping.

No definition queries were applied to the **Geodata swamps, flats and lakes datasets (NT wetlands), springs_21_04_2009 (NT springs), Wadeye_250watersites (NT waterholes), or Hyd_springs (Qld springs)** feature layer datasets.

11.3. Attribution of GDE identified in previous studies (from literature)

GDEs were identified in the literature review in Task 2. These were matched to polygons in the vegetation, river, and wetland feature layers where possible. The majority of these GDEs could be matched to existing polygons, which were attributed as either 'GDE identified in previous study: fieldwork'; or 'GDE identified in previous study: desktop'. The Tier 3 attributes recorded in the literature review have also been entered into the GDE Atlas attribute table for the GDEs identified in previous studies.

11.4. Transfer of attributes from existing spatial datasets to GDE polygons

Tier one attributes were populated in the GDE Atlas attribute table using national datasets where available. Jurisdiction's spatial datasets also contained information which could be used in the GDE Atlas attribute table, to either:

- Identify GDEs that had been mapped in a spatial layer in previous studies, and/or
- To populate other attributes in the GDE Atlas attribute table for GDEs that were derived in Task 5.

11.4.1. Datasets used to map GDEs identified in previous studies

In work package 6, the spatial datasets used to attribute GDE polygons as either GDE identified in previous study: fieldwork; or GDE identified in previous study: desktop are shown in Table 58. These datasets were either used to attribute polygons within the feature layer datasets, or entered in their entirety as feature layer datasets. Either way, the information from these datasets was incorporated into the GDE Atlas to show where GDEs were identified in previous studies.

- **Table 58 Spatial datasets used to map GDEs identified in previous studies (both desktop and fieldwork studies)**

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
NT			
Springs_21_4_2009	Springs	SOURCE = GA or topo maps	Springs_21_4_2009
Additional Potential Geodata Springs	Springs	All	Additional Potential Geodata Springs
QLD			
Spring REs	vegetation & wetlands	Selected REs[B]	QLD_WETLAND_SYSTEM_100K RE06b
HYD_SPRING_v3	Springs	Unvisited springs[A]	HYD_SPRING_v3

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
GAB Watercourse springs	Baseflow	All	National Major Watercourses
GDEs IDENTIFIED IN PREVIOUS STUDY: FIELDWORK			
NT			
endofdryflows	Baseflow	All	NT_Riv_Cks_ (NT)
Springs_21_4_2009	Springs	SOURCE = HYDTRA or Zaar	Springs_21_4_2009
QLD			
HYD_SPRING_v3	Springs	Visited springs[A]	HYD_SPRING_v3

A – Visited and unvisited springs were distinguished using the POINT_ID attribute, as advised by DERM.

B – Spring REs were identified by DERM.

11.4.2. Datasets used to populate attributes in the GDE Atlas attribute table

Information from jurisdiction's spatial data was incorporated into the GDE Atlas by transferring the relevant attributes into the GDE Atlas attribute table. A summary of the data used to populate each attribute is shown in Appendix A.

11.5. Data gaps and recommendations

The feature layer dataset used to map wetlands in WA only showed wetlands listed on the DIWA and as such, this is feature layer does not capture all wetlands in WA. It is recommended that a more complete wetlands feature dataset is developed for updates to the maps of GDEs that rely on the surface expression of groundwater. Springs mapping was also unavailable in the WA portion of work package 6, and should be developed for future updates of the GDE Atlas.

Two vegetation feature layers were used for the NT part of work package 6. The Greater Darwin vegetation map covered only a small area around Darwin. The NVIS2005_combo_1_2_3 map covered most of the NT portion of WP6, but only included certain vegetation ecosystems (rainforest vegetation and Melaleuca) and is therefore incomplete. As such, although GIS analysis for GDEs that rely on subsurface presence of groundwater occurred for the whole work package, the data used did not incorporate all ecosystem polygons. It is therefore possible that vegetation types other than rainforest and Melaleuca could be using groundwater but could not be identified in the Atlas.

Development of a vegetation feature dataset for NT that includes all vegetation ecosystems is recommended. A recommendation for future work is to create a vegetation feature layer from the various vegetation maps (Landunit and landsystems maps) that currently exist for the NT. If this

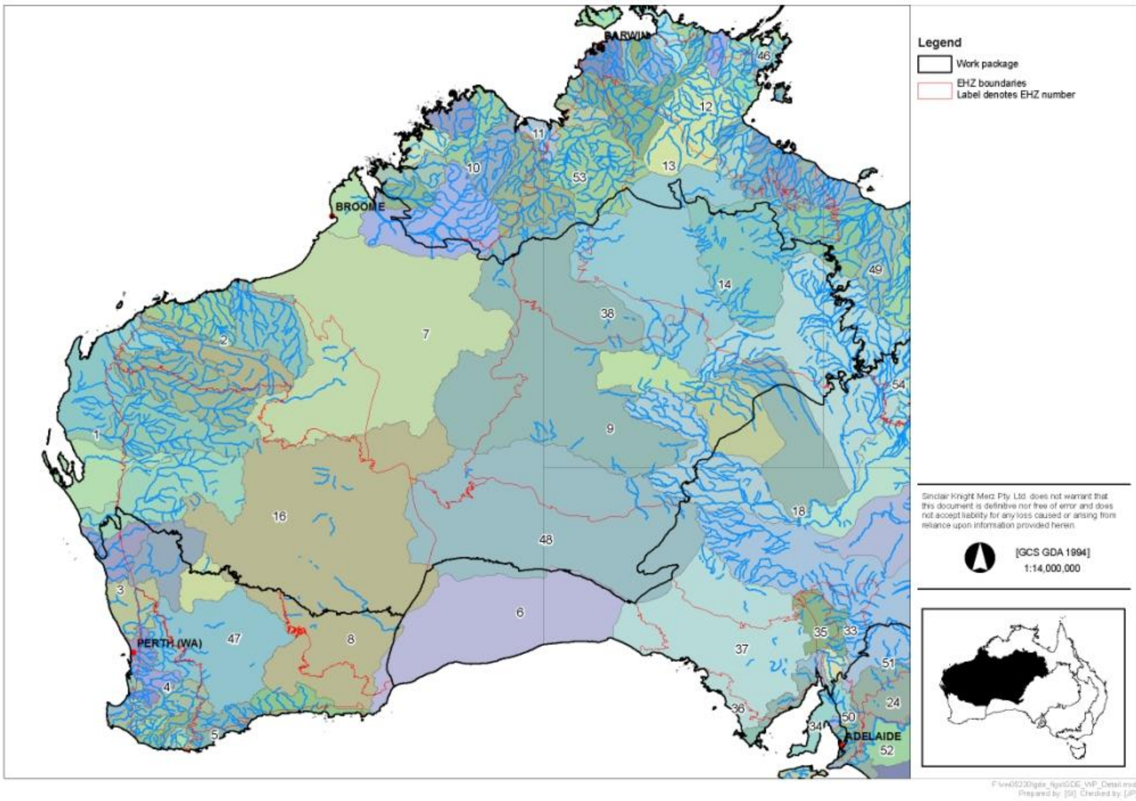
does not result in a sufficiently extensive layer, NVIS vegetation mapping (www.environment.gov.au/erin/nvis) also covers the area. However, it contains large polygons which may need to be split into smaller polygons to enable meaningful GDE potential results to be derived.

Inclusion of wetlands in NT in the map of GDEs that rely on the surface expression of groundwater relied upon the Geodata mapping of lakes, flats and swamps (Geoscience Australia) as feature layers. The analysis would benefit from improved attribution in these layers, as the only useable attribute in the current data was ‘perenniality’ for the Lakes layer. Adding ‘perenniality’ to flats and swamps, and other attributes describing the type of lake, flat or swamp would enable these datasets to fulfil more analysis rules and therefore increase the ‘lines of evidence’ for the GDE potential derived for each ecosystem.

Depth to watertable contour maps would significantly improve the GDE maps. Depth to watertable mapping is a key GIS analysis dataset and was largely unavailable for WP6. Point data was used to indicate depth to watertable in the NT and while it enabled reliable results for vegetation and wetland ecosystems, the limited spatial extent meant that it was not particularly useful for rivers. A contour map showing depth to watertable would enable the rule to be applied more consistently across the work package, however it would also mean that less reliable data which is the result of interpolation between bore locations would be included in the analysis.

12. Application of methodology in west central Australia and central western coast (WP7)

The work package 7 area is shown in Figure 20 and contains 8 EHZs. The climate of the area is classified as being semi-arid to arid. Rainfall on the northern perimeter of the work package falls predominantly in summer however for the majority of the work package, rainfall events occur episodically.



■ **Figure 20 Work package 7 area showing river basins and EHZs**

This work package spans the largest and least populated area of Australia, and there is limited availability of mapping datasets and literature for the area. The final GDE mapping has partial coverage of the work package, due to the lack of appropriate datasets to use in the analysis. Specifically, appropriate vegetation mapping to use as a feature layer was not available in the NT, meaning that mapping of GDEs that rely on the subsurface presence of groundwater could not be completed for the NT. More detailed vegetation mapping exists for some locations in the NT, mainly in the form of multiple landunit and landsystems maps. A recommendation for future work is to combine these maps into a vegetation layer with greater coverage which could then be used

for mapping in the Atlas. River, wetland and springs data was available for the whole area, enabling GDEs that rely on the surface expression of groundwater to be mapped.

12.1. Identification and Mapping of GDEs that rely on the SUBSURFACE presence of groundwater

12.1.1. Literature review and GIS Analysis Rules

Much of the literature available for review for WP7 related to the Pilbara - Hammersley region and the Ti-Tree Groundwater Basin. The work in the Ti-Tree Basin indicates that dryland and riparian vegetation GDEs may occur in some parts of the basin. Research is ongoing in the Ti-Tree Basin. In addition to reviewed literature, jurisdictional reviewers provided information on current knowledge of GDEs in WP7. The concepts developed from the literature review and jurisdictional feedback were applied to the whole work package.

Rule 1: Vegetation which demonstrates an ET that is higher than rainfall is more likely to be using groundwater

Rationale: Constant water use (measured in terms of ET from remote sensing) can indicate groundwater access during a period of low or no rainfall. Field studies undertaken by O'Grady et al. (2009) have shown that despite very little rainfall in the intervening period, *Corymbia opaca*, *Eucatyptus victrix* and *E. camaldulensis* maintained high leaf water potentials and tree water use from a period of high soil water availability (following summer rainfall) through a period of low soil water availability (following 7 months of very little rainfall during 2007). It was concluded at these sites that the presence of groundwater enabled constant water use by the plants.

Constant water use does not always relate to groundwater access. Hutley et al. (2001) found that vegetation classified as low open woodland in a deep watertable setting are likely to be regulating ET, so that growth is maintained through the dry period, without needing to access to groundwater. Hence, rule 1 must be used in conjunction with other information sources to determine whether the additional water source is groundwater. This is the intention of the subsequent GIS rules.

The remote sensing layer is intended to show the likelihood that a certain ecosystem is using a water source in addition to rainfall. Where the likelihood is higher, it is more certain that an additional water source is being accessed. As such, likelihoods of 6 and above are considered to indicate that a second water source may be present. Very high remote sensing probabilities (9 and 10) are considered to suggest that significant use of an additional water source is occurring, and because of this, some of the additional water use may be provided by groundwater. As such, very high IDE probabilities are used to indicate a greater likelihood of groundwater use.

It should be noted that there are some limitations to the remote sensing layer in WP7. The layer incorrectly classifies some arid landscapes as having a high probability due to the impact of highly

reflective surfaces. It is recommended that within arid regions the remote sensing layer is always used in conjunction with localised expert knowledge and any existing ecosystem spatial data sets such as maps of vegetation extent and type.

Rule 2: Riparian vegetation around permanent water features (e.g. pools and waterholes) may use groundwater. Exceptions to this rule include estuaries, man-made lakes and permanent water features that occur on cracking clay soils.

Rationale: A study undertaken by Braimbridge et al. (2010) for the Department of Water found that large areas of riparian and wetland vegetation on the Fortescue River and its tributaries was being sustained by discharge from the Millstream aquifer into permanent pools, and subsequent overflow into the Fortescue River and delta channels. In the absence of intermittent surface water flows, the watertable in the riverine and wetland alluvial sediments was being sustained by aquifer discharge.

In the NT, Boggy Hole and the riparian area along Running Waters (a spring creating flow for 5 km of the Finke River) are examples of groundwater discharge maintaining a permanent water regime, which may subsequently support riparian vegetation (A. Duguid, pers. comm.).

An important exception to the logic which links permanent surface water to groundwater discharge, is the occurrence of waterholes and swamps on cracking clay soil plains, which are common in northern Australia. These are low-lying swamps which capture run off during the wet season and persist until the next wet season because they are located on very low permeability soils and because they are relatively deep (Hatton et al., 1998). Extensive areas of cracking clay plains occur in WP7, particularly on the Barkly Tableland. Impermeable clay soils are thought to restrict groundwater interaction with the majority of the riverine waterholes and seasonal swamps and lakes in the area. Therefore, the riparian vegetation beside permanent waterbodies in cracking clay plains are not considered to be groundwater fed. They are more likely to rely on the storage of surface water after rain events (A. Duguid, pers. comm.).

Mapping of cracking clay soils was available for Queensland and the NT (although lack of a vegetation feature layer in the NT meant this rule could not be applied). The extents of cracking clay soils for SA were based on the Lake Eyre Basin drainage basin area, as cracking clay soils were thought to be common in northern SA.

Rule 3: Native vegetation in a shallow watertable setting (< 10 m) is likely to be using groundwater.

Rationale: In general, where shallow watertables (< 10 m) occur, vegetation is more likely to be accessing groundwater than in areas where groundwater levels are deep. The fundamental concept is that vegetation will utilise the water source that requires the least energy to access, meaning that if groundwater is shallow and below a certain salinity (A. Duguid, pers. comm.) it would be the preferred water source.

Springs with subsurface discharge can occur in the arid NT, “resulting in small patches of groundwater dependent vegetation and only sometimes exhibiting surface flow or pooling (e.g. when the watertable is raised by creek flow or direct recharge across the landscape from large rainfall events)” (pers. comm. A. Duguid).

In the absence of watertable elevation mapping, shallow watertables can be assumed to exist in some low-lying elevations across the work package area, or inferred from aquifer mapping (e.g. palaeochannels or alluvial systems). The assumption is that where the topography is low-lying, groundwater is closer to the surface, and in elevated areas groundwater is deeper.

Rule 4: Vegetation type is an indicator of groundwater use.

Rationale: Certain vegetation communities or species are often seen to be indicative of shallow watertables. In the NT, the very restricted Red Cabbage Palm (*Livistonia mariae)* is known to be groundwater dependent (A. Duguid, pers. comm.). Some riparian river red gum areas along generally dry river channels, and some extended para-riparian communities are believed to use groundwater part of the time. For example, the Arden Soak area on the Woodforde River and the extensive *Eucalyptus camaldulensis* and *E. coolabah* woodland south of Brumby Waterhole on the Finke River are thought to use groundwater intermittently (A. Duguid, pers. comm.).

E. camaldulensis is extremely wide spread along river systems. In some locations it is likely that water in the unsaturated zone is often sufficiently recharged by streamflow enough so that riparian river red gum vegetation does not require groundwater. In other locations, the groundwater is clearly shallow enough to be used (with the exception of those places where the groundwater is saline and presumably the trees are using water stored in the unsaturated zone). Likewise, some areas of riverine Melaleuca species may use groundwater. Very large inland tea-tree *Melaleuca glomerata* specimens can occur in creeks downstream of springs and *M. trichostachya* mainly occur in the arid NT where there is shallow groundwater associated with fractured rock aquifers (A. Duguid, pers. comm.).

Along the Fortescue River in WA, indicator species for groundwater discharge include (Braimbridge et al., 2010; Astron Environmental Service, 2008):

- *M. argentea* – high groundwater dependence – this species is an obligate phreatophyte. This species has a shallow planiform root system adapted to areas where surface water is present or groundwater is very shallow (maximum 2 to 3 m below ground level). The species has difficulties adjusting to short periods of dry conditions or reductions in water availability and exhibits signs of stress and even death if the watertable falls by more than 0.5 to 1m (Graham, 2001; Strategen, 2006).
- *E. camaldulensis* – medium to high groundwater dependence – this species is a facultative phreatophyte/vadophyte and groundwater dependent during periods of drought and some life stages. This species is generally found near rivers and major creek systems with a shallow

water table (2 to 5 m below ground level), however has been recorded where groundwater is up to 21 m below ground level (Landman, 2001). The bimorphic root system (surface lateral roots and a tap root) of this species enables it to access both groundwater and water held in the unsaturated, vadose zone above the watertable. Although *E. camaldulensis* is reported to be capable of sinking new tap roots in response to groundwater decline, drawdown of >10 m over a prolonged period may cause irreversible stress (Woodward-Clyde, 1997). Deaths of *E. camaldulensis were* recorded in the Millstream delta when the depth to groundwater increased beyond 5 m.

- *E. victrix* – medium groundwater dependence – this species is a facultative phreatophyte / vadophyte and tends to be found in drier areas than *E. camaldulensis* and *M. argentea* (Muir Environmental, 1995b). Although tolerant of long periods of drought and less susceptible to watertable drawdown, this species appears sensitive to prolonged inundation (Strategen, 2006). In WA it generally grows along rivers and major creeks, often with *E. camaldulensis* and *M. argentea*, and is found scattered as the dominant stratum on floodplains. In the arid NT, *E. victrix* particularly occurs in swamps and floodplains and is less typically observed along creeks. It also appears to thrive with prolonged inundation in swamps in the NT (A. Duguid, pers. comm.).

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 59. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 59 GIS analysis rules for GDEs that rely on the subsurface presence of groundwater**

Rule	
1	Vegetation which demonstrates an ET that is higher than rainfall is more likely to be using groundwater
2	Riparian vegetation around permanent water features (e.g. springs, pools and water holes) may use groundwater
3	Native vegetation in a shallow water table setting (< 10 m) is likely to be using groundwater
4	Vegetation type is an indicator of groundwater use

12.1.2. Data selection for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 60 shows the feature layers selected to map GDEs that rely on the surface expression of groundwater for WP7. These layers contain all the vegetation features that were analysed to establish whether a groundwater connection exists. The feature layers are either the datasets that the rules in section 12.1.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 60 Feature layer datasets for analysis of GDEs that rely on the subsurface presence of groundwater (vegetation) in WP7**

State	Ecosystem	Dataset Name	Source or Custodian
SA	Vegetation	SA VEG DATA	DOW
WA	Vegetation	Rangeland land systems mapping	Vegetation
	Vegetation	Subsystems north	Vegetation
	Vegetation	Pre European vegetation	Vegetation
NT	Vegetation	Livistona_mariae_distribution-generalised_to_drainage_lines_2012	NRETAS
QLD	Vegetation	re06b_NW_Qld	DERM
	Vegetation	re06b_SW_Qld	DERM
	Vegetation	IQ_QLD_REGECOPRECL_DCDB_A clipped to 'r' from Vegetation Management Act Remnant Vegetation Cover Version 6	DERM

For the Northern Territory (NT), extensive vegetation mapping exists at 1:1 million scale and at much finer scales for some areas, mostly in the form of land unit mapping. The 1:1 million data was too coarse for the analysis method used in the Atlas, and the various finer scale datasets could not be combined into a useable layer for the analysis. Hence, there was minimal vegetation

mapping available for use as a feature layer in the NT portion of WP7. This prevented mapping of GDEs that rely on the subsurface presence of groundwater for the NT. The only vegetation feature layer dataset available was the *Livistona mariae* data, which mapped ‘GDEs identified in a previous study, fieldwork’, and so was not analysed to derive a GDE potential value.

For WA, the rangelands and subsystems mapping was used in preference to the pre-European vegetation mapping since they contained smaller mapped polygons and therefore distinguished one ecosystem from another more accurately. Gaps in the Queensland RE06b data were filled using the pre-clearing data combined with the extents of remnant vegetation. Overall, the feature datasets allowed complete coverage of mapping for GDEs that rely on the subsurface presence of groundwater for WA and Queensland.

12.1.3. Data selection for GIS analysis datasets

Table 61 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the subsurface presence of groundwater in WP7. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 61, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6. Because there was no appropriate vegetation feature layer for the NT, the analysis in Table 61 could not be carried out in the NT.

Table 61 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the subsurface presence of groundwater

#	Rule	Datasets required for analysis	Dataset name	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	Vegetation which demonstrates ET that is higher than rainfall is more likely to be using groundwater	WP7 remote sensing (RS) layer	WP7 RS layer	All of QLD in WP area. All of SA in WP area. All of WA in WP area. Rule could not be used in NT due to lack of useable vegetation datasets.	The probability from the RS layer is assigned to each vegetation polygon by majority value. That is, the probability of the greatest number of pixels that intersect with the polygon becomes the probability of the whole polygon. Probabilities of 6, 7 & 8 give no indication of groundwater use (0); probabilities of 9 & 10 suggest groundwater use is more likely (3).
2	Riparian vegetation around permanent water features (e.g. pools and water holes) uses groundwater.	Watercourse mapping with permanency attributes	Watercourse250K_GDE_Classification_v1 (SA) Major Watercourses	SA WA & QLD Rule could not be used in NT due to lack of useable vegetation datasets.	Where a perennial flow regime occurs, it is more likely that groundwater maintains the flow during low rainfall periods (3). A 'non-perennial' attribute gives no information about potential groundwater contributions (0).
		Wetland mapping with permanency attributes	QLD_WETLAND_SYSTEM_100K_A	QLD	Where a permanent water regime occurs, it is more likely that groundwater maintains the water regime during low rainfall periods (3). A seasonal water regime indicates it is possible that groundwater maintains the presence of water after rainfall has ceased (2), and an intermittent or episodic water regime suggests rainfall dependence rather than groundwater use (1). Permanence attributes such as 'non-permanent' give no information about how long the presence of water remains after rainfall ceases, and so give no information about potential groundwater contributions (0).

		Cracking clay soils mapping	RE06b – Specific RE codes	QLD	Where cracking clay soils exist, the presence of permanent or persistent water cannot be considered to indicate groundwater discharge. Vegetation surrounding the permanent waterbodies is therefore less likely to be interacting with groundwater (1).
		Springs and groundwater-fed waterholes	Gazetteer_AquaticEcosystems Pilbara Pools_dataset	SA WA Rule could not be used in NT due to lack of useable vegetation datasets.	The springs datasets and the previously mapped GDE datasets are intersected with the vegetation polygons. Where a positive result for the intersect is recorded, vegetation is more likely to be using groundwater (3). Where no intersect is recorded, the rule gives no indication whether the vegetation is using groundwater or not (0), i.e. just because it doesn't intersect with a spring/previously mapped GDE, doesn't mean the vegetation won't be using groundwater.
3	Native vegetation in a shallow water table setting (< 10 m) is likely to be using groundwater	Depth to watertable	GWater_Shallow_SWL	SA	Groundwater use is considered likely where watertable depth is <10m (3), possible for watertables between 10 & 20m (2), and unlikely for watertables >20m (1).
		Landscape type information	Rangeland land systems mapping Subsystems north	WA	In the absence of watertable elevation mapping, shallow watertables can be assumed to exist in low-lying elevations. Depressions / flats (3), slopes (2) and hills (1).
		Geology indicating shallow watertables/ discharge	hydrogeology_statewide	WA	Surface geology can be used to indicate likely shallow groundwater / discharge areas. Surficial Sediments - Shallow Aquifers & Dolomite (3), Rocks of Low Permeability, Fractured and Weathered Rocks - Local Aquifers (2), Sedimentary Rocks - Extensive And Deep Aquifers (1). Normalisation was done by reviewers.
		soil water holding	Qld_Combinedsoils_2M	QLD	Qld: 'low' SWHC is where AWC (field capacity) – AWC (wilting

		capacity (SWHC)			point) = <9mm (3); 'high' SWHC capacity is where AWC (field capacity) – AWC (wilting point) = >9mm (1).
4	Vegetation type is an indicator of groundwater use	Vegetation mapping with attributes to identify species likely to be using groundwater and/or in likely landscapes	PRE_EUROPEAN re06b_NW_Qld re06b_SW_Qld IQ_QLD_REGECOPRECL_DCDB_A	WA QLD	Attributes describing vegetation types were normalised as either likely to use groundwater (3); possibly use groundwater (2), unlikely to use groundwater (1), or not sure (0). Normalisation was done from literature and by reviewers and jurisdictions.

12.1.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 61) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater use:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 61.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

12.1.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

12.1.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 62 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative

differences between weightings controlling the GDE potential result. Weightings are not comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 62 are only comparable for each feature dataset, and so may only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Springs always result in a vegetation polygon being assigned a high or moderate potential.
- The presence of cracking clay soils always results in a low or moderate GDE potential.
- A high ET:P ratio always results in a high or moderate GDE potential.

Table 62 Weighting for each GIS Analysis rule/dataset for GDEs that rely on subsurface presence of groundwater in WP7

Feature Layer Dataset	Rule 1	Rule 2				Rule 3				Rule 4
		Permanence								
	High ET:P	River	Wetland	Spring	Cracking clay plains	Depth to watertable	Land systems	Soil water holding capacity	Geology	Vegetation species
SA VEG DATA (SA)	7	NA	NA	10	10	8	NA	NA	NA	6
Rangeland land systems mapping (WA)	8	2	NA	10	NA	NA	6	NA	6	6
Subsystems north (WA)	10	NA	NA	NA	NA	NA	7	NA	7	7
Pre European vegetation (WA)	8	2	NA	10	NA	NA	6	NA	6	6
re06b_NW_Qld (QLD)	10	NA	4	NA	10	NA	NA	5	NA	6
re06b_SW_Qld (QLD)	10	NA	4	NA	10	NA	NA	5	NA	6
IQ_QLD_REGECOPRECL_DCDB_A (QLD)	10	NA	4	NA	10	NA	NA	5	NA	6

12.1.5.2. Definition query

Definition queries were generally applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This included non-natural landscapes such as settlements, pasture, and plantations, as well as natural landscapes that do not use groundwater, such as grasslands and bare earth.

All vegetation polygons that had an ID likelihood of 5 and less were removed at this stage, as these ecosystems were not likely to be accessing a source of water in addition to rainfall. By removing vegetation polygons with ID likelihood values below the <6 threshold, three vegetation polygons that exist in an area where vegetation is likely to be groundwater dependent were also removed. After consultation, these three polygons were included in the final GDE layer as ‘GDEs derived in a previous study’.

For the QLD vegetation feature layer datasets (**re06b_NW_Qld, re06b_SW_Qld and IQ_QLD_REGECOPRECL_DCDB_A)** definition queries were applied to exclude polygons that are unlikely to be GDEs are:

- In the field ‘DBVG2M’:
  - 30
  - 31
  - 33
- And in the field ‘RE’:
  - Non-rem

For the feature layer dataset **Rangeland land systems mapping** (used in WA) the definition queries applied to the vegetation mapping to exclude polygons that are unlikely to be GDEs are in the field ‘DESCRIPTIO’:

- Bare coastal mudflats with mangroves on seaward fringes, samphire flats, sandy islands, coastal dunes and beaches
- Claypan

For the feature layer dataset **Subsystems north** (used in WA) the definition queries applied to the vegetation mapping to exclude polygons that are unlikely to be GDEs are in the field ‘MU_SUM_DESC’:

- Mine site. Disturbed soil
- Rock outcrop. Bare rock
- Rock outcrop

For the feature layer dataset **DEC pre European** (used in WA) the definition queries applied to the vegetation mapping to exclude polygons that are unlikely to be GDEs are in the field ‘SOURCE_DES’:

- 'Bare areas; claypans'
- Grasslands

For the feature layer dataset **SA_VEG_DATA** (used in SA) the definition queries applied to the vegetation mapping to exclude grasslands in the field ‘DOMSPECIES’.

12.2. Identification and Mapping of GDEs that rely on the SURFACE expression of groundwater

12.2.1. Literature review and GIS analysis rules

The primary concept which identifies GDEs that rely on the surface expression of groundwater in WP7 is that, if surface water is present after a prolonged dry period, it is likely to be maintained through groundwater discharge. The validity of this assumption however is reliant on factors such as depth of the waterbody, underlying geology, and marine influences. Non-permanent waterbodies can also receive groundwater inputs. Depth to watertable and waterbody persistence together provide one of the strongest indicators of potential groundwater discharge, however spatial data for this concept is very limited. Underlying geology (e.g. palaeochannels or alluvial systems) and land system mapping are also acceptable indicators of where groundwater discharge to surface may occur.

Rule 1: A permanent flow/inundation regime indicates potential groundwater discharge.

Rationale: In semi-arid to arid environments, persistence of water in waterholes, rivers or pools can be an indicator of groundwater discharge due to relatively high evaporation rates and limited surface water inputs and precipitation. There are few natural features in WP7 with permanent water.

Waterholes can be persistent or permanent when they are deep (to outlast declines from evaporation between rain events), shaded (to reduce evaporation) or are replenished by groundwater inputs. Some permanent pools are associated with spring discharge. In other pools the aquifer discharge is insufficient to create surface flow and analysis of water chemistry profiles are needed to confirm that groundwater discharge is occurring. Most of the permanent riverine waterholes in the arid and semi-arid NT are in rocky range country where bedrock forms the base of the waterhole. Some exceptions to this exist, such as the mid-Finke River waterholes in sandy alluvium, and waterholes in the Georgina River in the Lake Nash areas which are underlain by heavy clay soils (A. Duguid, pers. comm.).

In the absence of groundwater connection, waterholes in the arid NT generally have to be at least 3-4 metres deep to persist through dry periods (Silcock, 2009). Due to the absence of data on water body depth, this concept could not be used in the analysis.

It has generally been assumed that any permanent surface water feature is connected to groundwater for the purposes of this analysis, however there are three exceptions where permanent water does not indicate groundwater connection. Firstly, estuaries have a permanent water regime due to tidal influences and should therefore not be considered as GDEs (except where a strong groundwater influence has been documented). For example, the Eighty Mile Beach system (north of the De Grey) is a saline, coastal wetland that is believed to be groundwater-fed (R. Loomes,

pers. comm.). The second exception is water storages – where spatial data permits, these exceptions should be excluded from GDE mapping.

The third exception to this rule is the cracking clay soils (as discussed in section 12.1.1). Cracking clay soils are highly impermeable and can capture and store run off in low-lying swamp areas for extended periods of time. If sufficiently deep, the swamp can persist until the next rainfall event without groundwater contributions, as the impermeable nature of the underlying cracking clays prevent leakage through the base of the waterbody. Extensive areas of cracking clay plains occur in WP7, particularly on the Barkly Tableland, and permanent waterbodies occurring in these soils have a limited potential for interaction with the groundwater system.

Rule 2: Rivers or waterholes intersecting springs are groundwater fed.

Rationale: Springs emerge directly from aquifers and are GDEs. Springs are also responsible for maintaining permanent or persistent flow in many rivers and riverine pools in the arid zone.

The Millstream wetland system in the Pilbara region comprises approximately 20 km of the Fortescue River and tributaries. It includes four major permanent river pools (Deep Reach, Crossing, Livistona and Palm pools) interconnected by permanent flowing channels, spring-fed pools on tributaries, and large areas of riparian and wetland vegetation. The wetlands are hydraulically connected to the Millstream aquifer, which maintains permanent and semi-permanent riverine pools and flowing streams in between intermittent surface water events (Braimbridge et al., 2010). Based on the estimated size of the surface features, a buffer of 25 m was placed around springs and rivers and 200 m around permanent riverine pools (due to their larger size). It can be assumed that where a river intersects a spring, the spring is contributing to river flow.

In the arid and semi-arid NT, the only perennial stream sections are spring-fed. Most of these are less than 500m long, although one is known to be 5-6 km. The majority of springs in arid NT discharge from fractured rock aquifers associated with elevated rocky ranges, but there are also some in calcrete aquifers including on the edges of salt lakes (A. Duguid, pers. comm.).

Rule 3: Shallow watertable (<5 m) indicates potential for connection between groundwater and surface water systems.

Rationale: The height of the watertable relative to the surface water body determines how long flow persists after rain ceases. This continuation of flow is the result of groundwater discharging to surface until the watertable has declined to a lower elevation than the base of the watercourse. Therefore, where the watertable is in close proximity to the surface it can be assumed that groundwater discharge to the surface is more likely.

In the Millstream Delta in the Pilbara region of Western Australia, the groundwater contribution to surface water flows varies with aquifer level. Depending on the level of the watertable in the Millstream aquifer, delta channels may be either losing or gaining streams.

In the absence of watertable elevation mapping the elevation of the land surface may be used to approximate groundwater depth. This assumes that the watertable is a more subdued imitation of the land surface, such that in low-lying areas the watertable is close to the surface, and in elevate landscapes the watertable is deeper.

Following periods of exceptionally high rainfall some rivers and creeks are known to run for many months (e.g. Todd River in 1974 and 2010, Finke River in 2000-2001 and 2010-11, Trephina Creek and Ross River in 2010-11, Georgina River at Junction with Rankin River in 2011) (A. Duguid, pers. comm.). These infrequent occurrences have not been well studied and have therefore not been included in the Atlas as ‘GDEs identified in previous study’.

Rule 4: Underlying geology indicates potential for groundwater discharge to surface.

Rationale: A relationship has been established between palaeodrainages and disconnected chains of salt lakes in the south west of WA (Timms, 2009). These chains of salt lakes are connected to shallow valley floor aquifers that are highly saline. This rule was applied in WP5 (south west of WA) and is also applicable in WP7 (Mike Braimbridge, pers. comm.).

In the NT there are some well known ‘chains’ of salt lakes formed by groundwater discharge, however no consistent mapping is available to distinguish which lakes are saline GDEs. One of the issues is that features broadly referred to as salt lakes include those with a well documented regional groundwater discharge (e.g. Lake Lewis and some of the Karinga Creek system). Others are included for which there is no data and for which the present day salinity may not reflect a current discharge process (e.g. Plenty Lakes and possibly lakes in the Poeppel Corner area) (A. Duguid, pers. comm.). Salt lakes (apart from Lake Lewis) have not been included in the GDE maps for the NT area of WP7, as the relevant datasets were unavailable. NRETAS have advised this mapping would be available for future updates to the GDE Atlas.

The rules used to identify GDEs that rely on the subsurface presence of groundwater are summarised in Table 63. None of these rules was used in isolation. Where all rules indicated groundwater use, the potential for the ecosystem to be a GDE was high. Where there were conflicting indications of groundwater use, the GDE potential was lower.

- **Table 63 GIS analysis rules to identify GDEs that rely on the surface expression of groundwater in WP7**

Rule	
1	A permanent flow/inundation regime indicates a potential groundwater discharge
2	Rivers or wetlands intersecting springs are groundwater fed

Rule	
3	Shallow watertable (<5 m) indicates potential for connection between groundwater and surface water systems
4	Underlying geology indicates potential for groundwater discharge to surface

12.2.2. Data selection for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 64 shows the feature layers selected to map GDEs that rely on the surface expression of groundwater for WP7. These layers contain all the river, wetland and spring features that were analysed to establish whether a groundwater connection exists. These are either the datasets that the rules in section 12.2.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 64 Feature layer datasets for analysis of GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs) in WP7**

State	Ecosystem	Dataset Name	Source or Custodian
SA	Wetlands	Wetlands_GDE_Classification_v1	DOW
	River	Watercourse250K_GDE_Classification_v1	DOW
	Springs and waterholes	Gazetteer_AquaticEcosystems	DOW
WA	Wetlands	Important wetlands	DEC
	River	Hydrography_linear_hierachy	DoW
	Pools	Pilbara pools	DoW
NT	Springs and groundwater-fed waterholes	revised arid NT data to SKM 5Mar2012	NRETAS
	Wetlands	GD3_Stirling_Swamp	NRETAS

State	Ecosystem	Dataset Name	Source or Custodian
	Wetlands	Snt_allwb_g94	NRETAS
	Wetlands	Ground_sites_g94	NRETAS
	Rivers	NT Riv Cks 250p	NRETAS
QLD	Wetlands	QLD_WETLAND_SYSTEM_100K_A	DERM
	Rivers	National Major Watercourses	Geoscience Australia

NRETAS have recently identified an additional dataset that maps salt lakes which can be provided as polygons for mapped lakes (Geodata 3) in the following 3 categories (A. Duguid, pers. comm.):

1. known contemporary groundwater connection/discharge
2. probably contemporary groundwater connection/discharge
3. playas with some soil salinity but no knowledge of groundwater

It is a recommendation that future updates to the GDE Atlas include this dataset as well as any additional datasets that have been identified since the last update.

12.2.3. Data selection for GIS analysis datasets

Table 65 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the surface expression of groundwater in WP7. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The right-hand column briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 65, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

Table 65 GIS analysis datasets used to implement the analysis rules for GDEs that rely on the surface expression of groundwater

No.	Rule	Datasets required for analysis	Dataset name (& where used)	Coverage of dataset/rule	Implementation of rule (and normalised value)
1	A permanent flow / inundation regime indicates groundwater connection	Watercourse mapping with permanency of flow attribute	Watercourse250K_GDE_Classification_v1 (SA) Major Watercourses NT_Riv_Cks_ 250p	SA WA & QLD NT (GULF OF CARPENTARIA)	Where a perennial flow regime occurs, it is more likely that groundwater maintains the flow during low rainfall periods (3). A 'non-perennial' attribute gives no information about potential groundwater contributions (0).
		Wetland mapping with permanency attributes	Wetlands_GDE_Classification_v1 QLD_WETLAND_SYSTEM_100K_A	SA QLD	Where a permanent water regime occurs, it is more likely that groundwater maintains the water regime during low rainfall periods (3). A seasonal water regime indicates it is possible that groundwater maintains the presence of water after rainfall has ceased (2), and an intermittent or episodic water regime suggests rainfall dependence rather than groundwater use (1). Permanence attributes such as 'non-permanent' give no information about how long the presence of water remains after rainfall ceases, and so give no information about potential groundwater contributions (0).
		Landsat open water	WP7 Landsat	SA, WA & QLD Not NT (due to incorrect classification of some arid landscapes)	Remote sensing of open water was used as an indicator of permanent presence of water. Where Landsat intersected a wetlands/river polygon, the polygon was considered more likely to contain open water, and for this to contain groundwater (3). Where no intersect is recorded, the rule gives no indication whether the wetland/river interacts with groundwater or not (0), i.e. just because it doesn't intersect with open water doesn't mean the wetlands/river won't be interacting with groundwater. Wetland mapping in WP7 is not comprehensive, Therefore in some instances, the Landsat data will correctly indicate open water but no wetland polygon will be available to define boundaries.

No.	Rule	Datasets required for analysis	Dataset name (& where used)	Coverage of dataset/rule	Implementation of rule (and normalised value)
2	Rivers or wetlands intersecting springs are groundwater fed	Springs and groundwater-fed waterholes	Gazetteer_AquaticEcosystems Pilbara Pools_dataset revised arid NT data to SKM 5Mar2012	SA WA NT	The springs datasets and the previously mapped GDE datasets are intersected with the river/wetland polygons. Where the spring falls within the river/wetland polygon, a positive result is recorded for the intersect. Where a positive result for the intersect is recorded, the river/wetland is more likely to be interacting with groundwater (3). Where no intersect is recorded, the rule gives no indication whether the river/wetland is interacting with groundwater or not (0), i.e. just because it doesn't intersect with a spring, doesn't mean the river/wetland won't be interacting with groundwater.
3	Shallow watertable indicating potential for connection between groundwater and surface water systems	Depth to watertable	GWater_Shallow_SWL HYDSTRA_SWL_MIN Drill_SWL	SA NT NT	Groundwater use is considered likely where watertable depth is <5m (3), possible for watertables between 5 & 10m (2), and unlikely for watertables >10m (1). It should be noted in the NT that the SWL data is point data from bores that was buffered by 3km.
		Landscape type information	Rangeland land systems mapping Subsystems north	WA	In the absence of watertable elevation mapping, shallow watertables can be assumed to exist in low-lying elevations. Depressions / flats (3), slopes (2) and hills (1).
4	Underlying geology	Geology indicating shallow watertables/	hydrogeology_statewide	WA	Geology can be used to indicate likely shallow groundwater / discharge areas. Surficial Sediments - Shallow Aquifers, Dolomite, paleodrainage (3), Rocks of Low

No.	Rule	Datasets required for analysis	Dataset name (& where used)	Coverage of dataset/rule	Implementation of rule (and normalised value)
	indicating groundwater discharge to surface	discharge	DWIAD aquifers		Permeability, Fractured and Weathered Rocks - Local Aquifers (2), Sedimentary Rocks - Extensive And Deep Aquifers (1). Normalisation was done by reviewers.

12.2.4. Normalisation of GIS analysis attributes

The attributes in the GIS analysis datasets used (listed above in Table 65) and contained in the permutations table for each feature layer, were normalised so that they could be incorporated into a spreadsheet which calculates GDE potential. Normalisation involved assigning a rating of 0, 1, 2, or 3, which was intended to indicate the likelihood of groundwater interaction:

- 3 = likely to result in groundwater interaction;
- 2 = may result in groundwater interaction;
- 1 = unlikely to result in groundwater interaction;
- 0 (or a 'blank') = attribute gives no information on groundwater interaction.

A description of how these normalisations were assigned to the GIS analysis attributes is described in the right-hand column of Table 65.

Where there was no information to inform the normalisation, the attribute was left as a blank. Where the majority of the attributes in a GIS analysis datasets could not be normalised, the GDE potential result is based on very few datasets and is therefore relatively unreliable.

12.2.5. Calculation of GDE Potential

Calculation of GDE potential was undertaken using the GIS analysis rules, GIS analysis datasets and the normalised values discussed above. The potential for an ecosystem to be a GDE was calculated by combining the normalised values for each of the rules. That is, the normalised values (1, 2, 3 or 0) assigned to attributes within the GIS analysis datasets were combined to obtain a single value which indicates the overall potential of the ecosystem to be GDE.

The calculation used to combine the normalised datasets is:

$$\frac{(\text{Rule 1} \times \text{weighting}) + (\text{Rule 2} \times \text{weighting}) + (\text{Rule 3} \times \text{weighting}) + (\text{Rule 4} \times \text{weighting})\ldots}{\text{Sum of total weightings (where the normalised value was either 1, 2, or 3)}}$$

12.2.5.1. Weighting of individual GIS analysis rules

The next stage of the GDE potential calculation involved assigning a relative weighting to individual rules (and the GIS analysis datasets used to implement the rules) to reflect their ability to identify GDEs.

Table 66 shows the weighting that was given to each GIS analysis rule to identify the GDE potential for each ecosystem polygon. The weightings applied are relative, with the relative

differences between weightings controlling the GDE potential result. Weightings are not comparable between feature datasets, since the use of different datasets in different areas means that the same rule may be weighted differently where (for example) one dataset was more suitable than another.

The weightings for rules in Table 66 are only comparable for each feature dataset, and so should only be compared along the rows (i.e. left to right) rather than between different rows (i.e. vertically).

The weightings below were developed so that:

- Springs was weighted so that intersecting vegetation polygons have high or moderate GDE potential.
- The presence of cracking clay soils resulted in a low or moderate GDE potential.

Table 66 Weighting for each GIS Analysis rule/dataset for GDEs that rely on surface expression of groundwater in WP7

Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7
	Open Water (remote sensing)	Permanent water	Cracking clay soils	Presence of a spring	Depth to watertable	Geology	Land system
Watercourse250K GDE Classification v1 (SA)	8	NA	10	10	5	NA	NA
Wetlands GDE Classification v1 (SA)	8	NA	10	10	5	NA	NA
Gazetteer_AquaticEcosystems (SA)	8	NA	10	NA	6	NA	NA
Hydrography linear hierarchy (WA)	8	3	10	10	NA	6	5
Important wetlands (WA)	8	NA	NA	10	NA	6	5
GD3_Stirling_Swamp (NT)	NA	NA	NA	NA	NA	NA	NA
Snt_allwb_g94 (NT)	NA	NA	10	10	5	NA	NA

Feature Layer Dataset	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7
Ground_sites_g94 (NT)	NA	NA	10	10	5	NA	NA
NT Riv Cks 250p (NT)	NA	3	10	10	5	NA	NA
QLD WETLAND SYSTEM 100K A (QLD)	8	5	10	NA	NA	NA	NA
National Major Watercourses (QLD)	8	NA	10	NA	NA	NA	NA

12.2.5.2. Definition query

Definition queries were applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This includes non-natural landscapes such as reservoirs, dams and irrigated land. It also excludes features that are artefacts of mapping, and do not represent actual features in the landscape.

The definition queries applied to each dataset to exclude ecosystems that cannot be GDEs that rely on the surface expression of groundwater are listed below.

For the feature layer dataset **NT_Riv_Cks_ 250p** (used in NT), **GA watercourse lines** feature layer dataset (used in QLD), **Hydrography_linear_hierachy** (used in WA) and **Watercourse250K_GDE_Classification_v1** (used in SA) a definition query was applied to the ‘PERENNIAL’ field to remove all features that were **not** classified as either ‘perennial’ or ‘non-perennial’. This removed the polygons in between braided streams from the GDE mapping (i.e. "PERENNIAL" <> ' ').

The definition queries applied to the **QLD_WETLAND_SYSTEM_100K** dataset to exclude polygons that are unlikely to be GDEs are:

- In the field ‘HAB_L’
  - Artificial/ highly modified wetlands (dams, ring tanks, irrigation channels, drains, canals)
- In the field ‘WETCLASS’
  - ' '
  - ‘-‘
- In the field ‘WTRREGIME’
  - ' '
- In the field ‘HYDROMOD_L’

- 'Modified - levee bank
- 'Modified - dams or weirs'
- Artificial wetlands - dams, ringtanks
- Artificial wetlands - levees on floodplain

For the **DEC_Important_Wetlands** feature layer dataset (used in WA) all wetlands which were either marine and coastal, or human-made (i.e. types ‘A’ or ‘C’ in the ‘WET_TYPE’ field) were excluded from analysis using a definition query.

For the feature layer dataset **Snt_allwb_g94** (used in NT) a definition query was applied to the ‘FEAT_CODE’ field to remove reservoirs (i.e. "FEAT_CODE" <> 'reservoir').

For the feature layer datasets **GD3_Stirling_Swamp** and **Ground_sites_g94** (used in NT) and **Wetlands_GDE_Classification_v1** and **Gazetteer_AquaticEcosystems** (used in SA) no definition queries were required.

12.3. Attribution of GDE identified in previous studies (from literature)

GDEs were identified in the literature review in Task 2. These were matched to polygons in the vegetation, river, and wetland feature layers where possible. The majority of these GDEs could be matched to existing polygons, which were attributed as either 'GDE identified in previous study: fieldwork'; or 'GDE identified in previous study: desktop'. The Tier 3 attributes recorded in the literature review have also been entered into the GDE Atlas attribute table for the GDEs identified in previous studies.

12.4. Transfer of attributes from existing spatial datasets to GDE polygons

Tier one attributes were populated in the GDE Atlas attribute table using national datasets where available. Jurisdiction's spatial datasets also contained information which could be used in the GDE Atlas attribute table, to either:

- Identify GDEs that had been mapped in a spatial layer in previous studies, and/or
- To populate other attributes in the GDE Atlas attribute table for GDEs that were derived in Task 5.

12.4.1. Dataset used to map GDEs identified in previous studies

In work package 7, the spatial datasets used to attribute GDE polygons as either 'GDE identified in previous study: fieldwork'; or 'GDE identified in previous study: desktop' are shown in Table 67. These datasets were either used to attribute polygons within the feature layer datasets, or entered in their entirety as feature layer datasets. Either way, the information from these datasets was incorporated into the GDE Atlas to show where GDEs were identified in previous studies.

Table 67 Spatial datasets used to map GDEs identified in previous studies (both desktop and fieldwork studies)

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
SA			
Gazeteer_AquaticEcosystems	Springs	DIST_ADM_2 = SPRG	Gazeteer_AquaticEcosystems
WA			
Pilbara Pools_Dataset	Pools	Pools that appear in 3 or more image dates	Pilbara Pools_Dataset
NT			
Revised arid NT data to SKM 5Mar2012	Springs & groundwater-fed waterholes	Discharge Known ≠ y	Revised arid NT data to SKM 5Mar2012

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs IDENTIFIED IN PREVIOUS STUDY: DESKTOP			
Livistona_mariae_distribution-generalised_to_drainage_lines_2012	Riparian vegetation	All	Livistona_mariae_distribution-generalised_to_drainage_lines_2012
QLD			
Spring REs	Springs	Selected RE codes[A]	QLD_WETLAND_SYSTEM_100K
GDEs IDENTIFIED IN PREVIOUS STUDY: FIELDWORK			
NT			
Revised arid NT data to SKM 5Mar2012	Springs & groundwater-fed waterholes	Discharge Known = y	Revised arid NT data to SKM 5Mar2012

A – Spring REs were identified by DERM.

12.4.2. Datasets used to populate attributes in the GDE Atlas attribute table

Information from jurisdiction's spatial data was incorporated into the GDE Atlas by transferring the relevant attributes into the GDE Atlas attribute table. A summary of the data used to populate each attribute is shown in Appendix A.

12.5. Data gaps and recommendations

The most significant data gap in work package 7 is the lack of an appropriate vegetation feature dataset for the NT, which has prevented mapping of GDEs that rely on the subsurface presence of groundwater. Extensive vegetation mapping exists at 1:1 million scale in the NT and at much finer scales for some areas, mostly in the form of land unit mapping. It is recommended that a vegetation feature layer is created from the various vegetation maps that currently exist prior to the first update of the GDE Atlas. If this does not result in a sufficiently extensive layer, NVIS vegetation mapping (www.environment.gov.au/erin/nvis) also covers the area. However, it contains large polygons which may need to be split into smaller polygons to enable meaningful GDE potential results to be derived.

A feature layer delineating wetlands in WA was not available for mapping of GDEs that rely on the surface expression of groundwater. Future mapping should determine whether any wetlands mapping exists for the area and if not, Geodata (Geodata 250K, Feature Class: Lakes, Swamps, Flats) may be considered as a substitute.

Depth to watertable contour maps would significantly improve the GDE maps. Depth to watertable mapping is a key GIS analysis dataset and was largely unavailable for WP7. Point data was used to indicate depth to watertable in the NT and while it enabled reliable results for vegetation and wetland ecosystems, the limited spatial extent meant that it was not particularly useful for rivers. A contour map showing depth to watertable would enable the rule to be applied more consistently across the work package, however it would also mean that less reliable data which is the result of interpolation between bore locations would be included in the analysis.

NRETAS have recently identified an additional dataset which maps salt lakes and could be provided as polygons for mapped lakes (Geodata 3) in the following 3 categories (A. Duguid, pers. comm.):

1. known contemporary groundwater connection/discharge
2. probably contemporary groundwater connection/discharge
3. playas with some soil salinity but no knowledge of groundwater

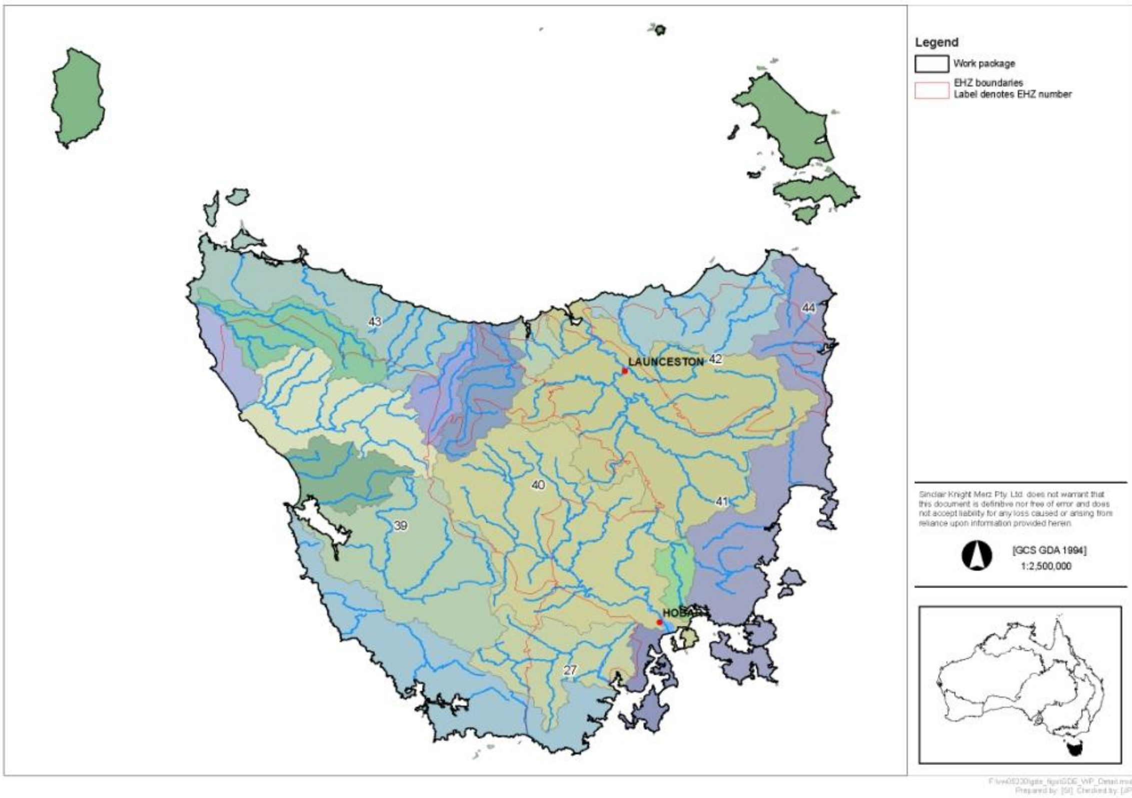
NRETAS have undertaken waterbody mapping for the NT portion of the Lake Eyre Basin using Landsat satellite data (Barnetson and Duguid, 2008; Barnetson and Duguid, 2010), which delineates many otherwise unmapped wetlands. However it includes many false positives due to shaded parts of the landscape, therefore it was not used in analysis for the GDE Atlas.

Springs mapping with greater coverage of WA would also improve the mapping of GDEs that rely on the surface expression of groundwater. It is recommended that future updates to the GDE Atlas include these datasets.

13. Application of Methodology in Tasmania (WP8)

The WP8 area is shown in Figure 21 and incorporates the 7 EHZs in Tasmania.

Mapping of potential GDEs was completed for the entire area. Vegetation mapping was available for the whole of Tasmania, which enabled complete coverage of mapping for GDEs that rely on the subsurface presence of groundwater. Rivers, wetlands and some localised springs datasets were also available for all of Tasmania, allowing GDEs that rely on the surface expression of groundwater to be mapped for the whole state.



- **Figure 21 Work package 8 area showing river basins and EHZs**

The development of the GDE layers in WP8 occurred prior to the seven remaining work packages and before the methodology to determine GDE potential was finalised. The mapping occurred before the development of permutations tables, and consensus through the Steering Committee on the 5 classification of GDEs. The rules were developed by SKM and a subconsultant and discussed with department staff in a 3 day workshop.

The process in WP8 is consistent with all work packages as it involved the development of rule sets that involved the integration of spatial data sets within a GIS environment. However, unlike all other work packages, the rules sets pre-determined the potential for an ecosystem to be a GDE, whereas the permutation tables (used in other work packages) determined the GDE potential based upon the combinations of rule sets and the weightings applied to each rule. Therefore, with the exception of the vegetation datasets, the approach in WP8 did not involve normalising GIS analysis attributes (section 4.6.1), weighting each rule (section 4.6.2), or assigning a range of scores (section 4.6.4) that determined GDE potential, but rather the GDE potential is a direct product of the rule sets developed.

The concepts and rules developed were applied to GDEs that rely on the subsurface presence of groundwater, and GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs and vegetation) across the whole work package. Combinations of wetland types, vegetation communities (as mapped by the World Heritage Area (WHA) mapping, and TasVeg vegetation layers), slope class and geology were used to define areas where the seasonal or permanent expression of groundwater at the land surface is likely.

The mapped vegetation community from TasVeg or WHA was used as the basic mapping unit and several rules were established to categorise the vegetation community as being groundwater dependent. In some cases, the vegetation community alone was used to derive potential GDE. However, additional criteria were typically required; for example, the vegetation community had to be coincident with a flat slope or break of slope to be recognised as a GDE. A number of the rules were site or region (EHZ) specific. The WHA mapping layer was used in preference to the TasVeg layer where they were coincident.

Rules for GDEs were also provided by Maj-Britt di Falco (UTAS) and used as corroborative evidence for the GDEs identified using the existing rules developed by the SKM team.

The rule sets provided have subtle differences depending on the particular scale geological mapping used. The work package has complete 1:250k coverage, however where 1:25k mapping existed it was used in preference (i.e. where the WHA mapping was present). The dataset used is indicated by the abbreviations of 25k or 250k. The resultant rules set are outlined in the following sections.

13.1. Identification of GDEs that rely on the SURFACE expression of groundwater (rivers, wetlands, springs)

13.1.1. GIS anlaysis rules

Rule 1: Low lying and break of slope (less than 5^{o}) landscapes are likely to have shallow water tables and are therefore more likely to support GDEs.

Rationale: In the absence of depth to watertable information expert consultation within workshops (DPIPWE, UTAS and Elizabeth Corbett) conclude that within the vast majority of WP8 low lying and break of slope landscapes have shallow water tables.

Rule 2: Slope of less than 5^{o} is an indicator of groundwater discharge and GDEs are therefore more likely to occur in these areas.

Rationale: Field based surveys in the development of the WHA and TasVeg vegetation layers determined that button grass exist within groundwater discharge zones when on a slope less than 5^{o}. This rule only applies to mapped Button grasses, which are a wetland species.

Rule 3: Geology is an indicator of shallow groundwater discharge.

Rationale: The landform ‘periglacial slope deposits’ overlying Precambrian and Cambrian Quartz rocks are generally associated with localised groundwater flow systems and localised groundwater discharge. Other identified geological units that are likely to result in groundwater discharge include:

- 25k geological mapping = Qpt and Qpg
- 250k geological mapping = Qpt and Qpg only when overlying Precambrian and Cambrian Quartz rocks

Rule 4: Vegetation type is an indicator of groundwater discharge within wetlands.

Rationale: Expert advice determined that a range of vegetation types within the Tas VEG and WHA vegetation layers are indicators of the presence of groundwater discharge within wetlands, and are more akin to the surface expression of groundwater as they are generally fully inundated with groundwater. Each vegetation polygon was assessed against a series of criteria and the potential then assigned (Table 68 and Table 69), the criteria were:

- Vegetation type
- Bio –Region
- Slope
- Geology
- Geography and altitude for WHA vegetation layer

The combination of the criteria determined the potential that any given polygon within the TasVeg and WHA feature data sets has on interacting with groundwater. The potential was low, medium or high (Table 68 and Table 69).

▪ **Table 68 Classification criteria of TasVeg classes as GDEs that rely on the surface expression of groundwater**

TasVeg code	Vegetation Type	Vegetation Community	Bio Region**	Slope	Geology	Geography	Comments	Potential for groundwater interaction*
AHF	Saltmarsh and wetland	Freshwater aquatic herbland	all	flat	peat, alluvium			high
AHL	Saltmarsh and wetland	Lacustrine herbland	CH,K,all	flatish	peat			high
AHS	Saltmarsh and wetland	Saline aquatic herbland	NS,SR,W, K	flat	alluvium			high if inland
ARS	Saltmarsh and wetland	Saline sedgeland/rushland	NS, K, W	flat	variable			high if inland
ASF	Saltmarsh and wetland	Freshwater aquatic sedgeland and rushland	CH, SR, all	flat	variable	coastal to s.a.	ASF in Derwent River above Bridgewater, and at Moulting Lagoon (148.219;42.036) removed as derived GDE due to steady or periodic seawater incursions (rather than groundwater discharge).	high
ASS	Saltmarsh and wetland	Succulent saline herbland	K, others?	flat	alluvium	coastal		low
AUS	Saltmarsh and wetland	Saltmarsh (undifferentiated)		flat	various	usually coastal		High
AWU	Saltmarsh and wetland	Wetland (undifferentiated)	all	flat	usually peat	coastal to s.a.	Pipers River mouth (147.153;41.024), West Arm Tamar River (146.772;41.164), Windermere Tamar River (147.044;41.315), Cape	high

							Barren Island (148.155;40.446) and Thirsty Lagoon Cape Barren Island (148.446;40.386) removed as derived GDE due to steady or periodic seawater incursions (rather than groundwater discharge).	
FSM	Agricultural, urban and exotic vegetation	Spartina marshland	NS,K	unable to use slope				high
HCM	Highland treeless vegetation	Cushion moorland	CH, SR, W	gentle	various	above 650m		Variable
HHW	Highland treeless vegetation	Western alpine heathland	CH, SR, W	gentle	siliceous seds	above 800m		variable
HSE	Highland treeless vegetation	Eastern alpine sedgeland	SR	flat	dolerite	above 650m		variable
HSW	Highland treeless vegetation	Western alpine sedgeland/herbland	CH,SR,W	flat	siliceous seds	above650m		med
MAP	Moorland, sedge land, rush land and peat land	Alkaline pans	W	flat	Calc. seds	intermediat e	AKS Alkaline Pans mis-mapped at 145.966;42.793 and 145.957;42.697 - removed as GDE.	high
MRR	Moorland, sedge land, rush land and peat land	Restionaceae rushland	CH, SR,NS,W	flat	various	low to highland		med

MSW	Moorland, sedge land, rush land and peat land	Western lowland sedgeland	W	flat	siliceous seds.	lowland	Vegetation classes exceeding altitudes of 400m were excluded, except for mid-altitude occurrences of these moorlands near the Sentinel Range and Crossing River. The following locations (longitudes and latitudes) indicate where BR and MSW polygons remain classed as GDEs: 146.211 42.828, 146.2 42.842, 146.199 42.853, 146.209 42.854, 146.232 42.841, 146.256 42.891, 146.355 42.896, 146.36 42.908, 146.351 42.916, 146.341 42.948. Polygons within the boundary 145.929;43.021 (NW corner) and 146.234;43.191 are also included.	med
NAF	Non-eucalypt forest and woodland	Acacia melanoxylon swamp forest	K,W	flat	various	lowland		med
NLM	Non-eucalypt forest and woodland	Leptospermum lanigerum - Melaleuca squarrosa swamp forest L	SR,NS,K, W	flat	various	lowland	Swamps within the boundary of 145.387;42.259 (NW corner) and 145.523;42.282 (SE corner) classed as sub-surface GDEs.	med

NME	Non-eucalypt forest and woodland	Melaleuca ericifolia swamp forest	NS,K,W	flat	various	lowland		high
SMR	Scrub, heathland and coastal complexes	Melaleuca squarrosa scrub	NS, W, K	flat	siliceous	coast to 400m		med
SSK	Scrub, heathland and coastal complexes	Scrub complex on King Island	K	flat to gentle	sand sheet	low	Only SSK over wetland areas are GDEs	med

- **Table 69 Classification criteria of WHA classes as a GDE reliant on the surface expression of groundwater**

WHA code	TasVeg code	Vegetation Type	Vegetation community	Slope	Geology	Geography	Altitude	Potential for groundwater interaction
ALK	MAP	Moorland and wetlands	alkaline pans	flat	calcareous seds.	intermediate	300-700m	high
ATG	HSE	Moorland and wetlands	Alpine and subalpine sedgeland	flat	various; peat soils	above 650m	>650m	med
AW	HSW	Western Graminoid moorland	Western Graminoid moorland	flat to gentle	quartzite	above 650m	>650m	med
AWG	GPH	Wet grassland	Wet grassland	flat to moderate	deep alluvium	above 900m	>900m	high
BR	MSW	Moorland and Wetlands	Rowitta sedgy buttongrass moorland	flat	peat/siliceous gravels	lowland to intermed.	0-700m	high
MSF	NLM	*Melaleuca* swamp forest	Melaleuca swamp forest	flat	alluvium +/- peat	lowland	0-450m	high
SME	SMM	Short *Melaleuca* swamp	Short *Melaleuca* swamp	flat	peat on various	coastal to intermed.	0-700m	high
WET	AWU	Wetland	Wetland	flat	various	various		high

*Confidence as assigned by Corbett and Corbett (pers. comm.)

**Bio region / EHZ codes defined as CH: Central Highlands, K: King Island, SR: Southern Ranges, W: West, NS: Northern Slopes, SE: South East, BL: Ben Lomond, F: Flinders

Rule 5: Geology is an indicator of groundwater connection to wetlands groundwater discharge (only applies to Bruny Island).

Rationale: Wetland types (salt, marsh and wetland) that exist on Quaternary geology are likely to be connected to the watertable.

Rule 6: Elevation is an indicator of groundwater connection wetlands (only applies to Bruny Island and Napier region).

Rationale: Wetland that are less than 10 mAHD are considered to be connected to the watertable, when on quaternary geology (25k).

Rule 7: Elevation is an indicator of groundwater connection wetlands (only applies to Strahan region).

Rationale: Wetlands less than 20 metres elevation are considered to be connected to the water table, when on Qpso or Qpsw geology (25k) or Geology 250K= Qps

Rule 8: Wetland class is an indicator of groundwater connection.

Rationale: The CFEV waterbodies layer was used as the feature layer. The waterbodies layer includes a number of artificial wetlands and these were removed from the analysis using WB_ARTIF field in the CFEV Waterbodies layer. In addition to this, a lookup table was provided by DPIPWE that identified potential GDEs using the WB_PCLASS field (Table 70) in the CFEV waterbodies layer.

- **Table 70 Lookup table applied to CFEV waterbodies layer to derive potential GDEs (Ian Houshold, DPIPWE, pers. comm.)**

WB_PCLASS	GDE (Y/N)	Confidence (H/L)	WB_PCLASS	GDE (Y/N)	Confidence (H/L)
Wb1	Y	L	Wb11	N	N/A
Wb2	Y	L	Wb12	Y	H
Wb3	Y	L	Wb13	Y	H
Wb4	Y	L	Wb14	N	N/A
Wb5	N	N/A	Wb15	N	N/A
Wb6	N	N/A	Wb16	N	N/A
Wb7	Y	L	Wb17	N	N/A
Wb8	Y	L	Wb18	Y	H
Wb9	Y	H	Wb19	Y	H
Wb10	N	N/A			

Rule 9: Geology and slope is an indicator of groundwater connection with stream.

Rationale: All streams in Tasmania were assumed (through workshops) to be connected to the groundwater, however, some are likely to be connected losing. River stretches are considered to connected the groundwater but losing (not a GDE) where they occurred on a slope classed "flat" and geology units Qh or Qps. All other river stretches are considered GDEs.

Rule 10: Geological contacts within steeply incised basalt valleys within the Northwest incised basalt plateau regions are an indicator of spring occurrences.

Rational: locations of known springs were provided by CFEV (2008) and DPIPWE for the Smithton area. A ruleset was also applied to approximate the occurrence of springs that frequently occur at base of Tertiary basalt in deeply incised valleys where it contacts basement (Ian Houshold, pers. comm.). Potential springs were defined at the edge of Basalt (where Tb intersects other geologies) on steep slopes and where drainage lines occur.

- **Table 71 GIS analysis rules to identify GDEs that rely on the surface expression of groundwater in WP8**

Rule	
1	Low lying and break of slope (less than 5^{o}) landscapes are likely to have shallow water tables
2	Slope on specific geology types is an indication of shallow water tables.
3	Geology is an indicator of shallow groundwater discharge
4	Vegetation type is an indicator of groundwater discharge
5	Geology is an indicator of groundwater connection to wetlands groundwater discharge (only applies to Bruny Island)
6	Elevation is an indicator of groundwater connection wetlands (only applies to Bruny Island and Napier region)
7	Elevation is an indicator of groundwater connection wetlands (only applies to Straun region)
8	Wetland class is an indicator of groundwater connection
9	Streams an indicator of groundwater discharge

Rule	
10	Geological contacts within steeply incised basalt valleys within the Northwest incised basalt plateau regions are an indicator of spring occurrences

13.1.2. Data selection for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 72 shows the feature layers selected to map GDEs that rely on the surface expression of groundwater for WP8. These layers contain all the river, wetland and spring features that were analysed to establish whether a groundwater connection exists. These are either the datasets that the rules in section 13.1.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 72 Feature layer datasets for analysis of GDEs that rely on the surface expression of groundwater in WP8**

State	Ecosystem	Dataset Name	Source or Custodian
Tas	Karst	CFEV2008	DPIPWE
	Wetlands	CFEV2008	DPIPWE
	Waterbodies	CFEV2008	DPIPWE
	Vegetation	TasVeg	DPIPWE
	Vegetation	WHA	DPIPWE
	Springs	CFEV2008	DPIPWE
	Springs	Smithton Mound Springs	DPIPWE
	Streams	CFEV2008	DPIPWE
	Vegetation	TasVeg	DPIPWE
	Vegetation	WHA	DPIPWE

State	Ecosystem	Dataset Name	Source or Custodian
	Burrowing Crayfish	Allanaspides_gda94.shp Type2_Ombrastacoides_gda94.shp Sinermis_gda94.shp Efossor_gda94.shp Egranulatus_gda94.shp Emartigener_gda94.shp Espinicaudatus_gda94.shp Eyabbimunna_gda94.shp	DPIPWE

13.2. Identification of GDEs that rely on the SUBSURFACE presence of groundwater

13.2.1. GIS anlaysis rules

The rules to identify GDEs that rely on the subsurface presence of groundwater were devised as series of specific GIS intersects with a pre-determined GDE potential. Each vegetation polygon in the two vegetation layers (TasVeg and WHA) was assessed against a series of criteria and the GDE potential then assigned (Table 73 and Table 74), the criteria were:

- Vegetation type
- Bio –Region
- Slope
- Geology
- Geography

The combination of the criteria determined the potential that any given polygon within the TasVeg and WHA feature data sets has on interacting with groundwater. The potential was low, medium or high (Table 73 and Table 74).

Table 73 GIS rules for the assessment of GDEs that rely on the subsurface presence of groundwater (TasVeg)

TasVeg code	Vegetation Type	Vegetation Community	Bio Region**	Slope	Geology	Geography	Comments	Potential for groundwater interaction*
DAC	Dry eucalypt forest and woodland	Eucalyptus amygdalina coastal forest and woodland	CH, NS, SR, K	flat to mod	various	below 400m		various
DKW	Dry eucalypt forest and woodland	King Island eucalypt woodland	K	gentle	various	lowland		med-low
DOV	Dry eucalypt forest and woodland	Eucalyptus ovata forest and woodland	SR, NS, K, W	flat to gentle	various	below 500m		low
DPE	Dry eucalypt forest and woodland	Eucalyptus perriniana forest and woodland	SE	flat to gentle	sediments	500 to 560m		med
GSL	Grassland and sedgeland	Lowland grassy sedgeland	CH, SR, NS, K	flat to mod.	various	below 600m		med
MBE	Moorland, sedge land, rush land and peat land	Eastern buttongrass moorland	CH,SR,W	gentle	various	below 1000m	GDEs only apply for gentle slopes (less than 10 degrees).	low
MBP	Moorland, sedge land, rush land and peat land	Pure buttongrass moorland	CH,SR,W	flat	alluvium	intermediate		med

MBS	Moorland, sedge land, rush land and peat land	Buttongrass moorland with emergent shrubs	SR,W	flat to steep	siliceous seds.	below 1050m		med
MSP	Moorland, sedge land, rush land and peat land	Sphagnum peatland	CH,, SR	flat to gentle	dolerite	highland		high
RFE	Rainforest and related scrub	Rainforest fernland	CH,SR,K,W	mod to steep	various	below 800m		med
RHP	Rainforest and related scrub	Lagarostrobos franklinii rainforest and scrub	SR,W	mainly flat	alluvium	intermediate		med
RMU	Rainforest and related scrub	Nothofagus rainforest undifferentiated	all	flat	various	below 100m		high
RMU	Rainforest and related scrub	Nothofagus rainforest undifferentiated	all	flat	various	above 100m		high
RPW	Rainforest and related scrub	Athrotaxis cupressoides open woodland	CH,SR	flat to mod	various	above 900m		med
SHL	Scrub, heathland and coastal complexes	Lowland sedgy heathland	SR, NS, K, W	flat				low

SHW	Scrub, heathland and coastal complexes	Wet heathland	CH, SR, NS, K, BL, SE, F	flat to mod.	various	below 650m	SHW at Hazards Neck (148.291;42.181) and Passage Beach (148.285;42.253) re-classed and as ASF to be a surface GDE.	med
SLW	Scrub, heathland and coastal complexes	Leptospermum scrub	all	flat or gullies	various	below 800m		med
SRI	Scrub, heathland and coastal complexes	Riparian scrub	all	flat to mod	alluvium or rock	below 600m		med
WVI	Wet eucalypt forest and woodland	Eucalyptus viminalis wet forest	SR, NS, W	mod - unable to use slope	various	below 600m		med

- **Table 74 GIS rules for the assessment of GDEs that rely on the subsurface presence of groundwater (WHA)**

WHA code	TasVeg code	Vegetation Type	Vegetation community	Slope	Geology	Geography	Altitude	Potential for groundwater interaction
ABM	HHE	Boronia moorland	Boronia moorland	undulating	quartzite	subalpine	>900m	med
AGC	HSW	Graminoid and cushion moorland	Graminoid and cushion moorland	gentle	various	above 700m	>700m	med
AMM	NAF,NAR	Acacia melanoxylon	Acacia melanoxylon	flat to steep	various	lowland to intermed	0-700m	med
ASS	HSE	Scoparia heath	Scoparia heath	flat to gentle	dolerite	above 900m	>900m	med

BEA	MBE	Eastern buttongrass	Eastern buttongrass	flat to gentle	various; peat soils	lowland to subalpine	0-900m	med
BMM	SMM	Subalpine Melaleuca moorland	Subalpine Melaleuca moorland	flat to gentle	siliceous seds.	above 700m	>700m	med
BPB	MBP	Pure buttongrass	Pure buttongrass	flat	alluvium	intermediate	300-700m	med
CA	HCM	Cushion moorland (>50% cushions)	Cushion moorland (50%+ cushions)	gentle	various	subalpine	>900m	med
CP	SBR	Coastal broadleaf	Coastal broadleaf	flat to moderate	sand sheet and other	coastal	0-700m	med
ET	DTO	Eucalyptus aff. Tenuiramis shrubbery	E. aff. tenuiramis shrubbery	gentle	quartzite	lowland	0-450m	med
EV	DOW	Eucalyptus ovata (E. nitida) wet and riverine forests	E. ovata (E. nitida) wet forest and riverine shrubberies	flat	alluvium	<200m	<200m	med
FEN	RFE	Ferns	Ferns	gullies - unable to use slope	various	below 900m	<900m	med
HPW	RHP	Huon pine in rainforest and riverine shrubberies	Huon Pine in rainforest and riverine shrubberies	flat to mod- unable to use slope	alluvium or quartzite	below 350m	<350m	med
HWT	SLW	Tall wet heath	Tall wet heath	gentle to steep	various	below~ 900m	<900m	med
MB	MBS	Melaleuca on buttongrass	Melaleuca on buttongrass	flat to gentle	peat on siliceous seds	lowland to intermed	0-700m	med
MM	NLM	Melaleuca fringe forest	Melaleuca fringe forest	flat to gentle	alluvium	lowland	0-450m	high

MXn	SMM	Norold Range Melaleuca moorland	Norold Range Melaleuca moorland	mod.	quartzite	subalpine	>900m	med
RFT	RMU	Rainforest	rainforest with leatherwood, Celerytop pine.	flat to steep	various	-	>900m	high
RVF	SRI	Riverine flora	Riverine flora	flat to mod.	various	lowland	0-450m	med
SFB	HSE	Sedgy fern bog	Sedgey fern bog	flat to mod.	peat on various	above 600m	>600m	med
SLE	MRR	Sedgy moorland	Sedgy moorland	flat	various	below 900m	<900m	high
SPH	RPW	Pencil pines on alpine heath or woodland	Pencil Pines in alpine heath or woodland	flat to gentle	dolerite, quartzite	above 900m	>900m	med
SSS	MSP	Sphagnum	Sphagnum	flat to gentle	mostly dolerite	above 600m	>600m	med
TR	WNR	Towtera rainforest	Towtera rainforest	undulating	sandunes and swales	coastal	2km buffer	med
TTM	MBS	Tea tree moorland	Tea tree moorland	gentle	peat on quartzite	subalpine	>900m	med

13.2.2. Data selection for Feature Layers

Feature layers are the spatial layers that contain the linework which delineates ecosystems in the GDE Atlas. They contribute all the possible linework for the Atlas. Therefore, if a GDE was to be mapped in the Atlas, it had to be represented by a polygon in the feature layer datasets. If an area was not covered by a feature layer dataset, no GDE mapping was possible for that area.

Table 75 shows the feature layers selected to map GDEs that rely on the subsurface presence of groundwater for WP8. These layers contain all the vegetation features that were analysed to establish whether a groundwater connection exists. These are either the datasets that the rules in section 13.2.1 are applied to, or they show locations of GDEs identified in previous studies.

The particular datasets used as feature layers were selected based on their coverage (i.e. coverage of a very small area was unworkable) and their attributes (preferred data sets had attributes that were useful in the analysis).

- **Table 75 Feature layer datasets for analysis of GDEs that rely on the subsurface presence of groundwater (vegetation) in WP8**

State	Ecosystem	Dataset Name	Source or Custodian
Tas	Vegetation	TasVeg	DPIPWE
	Vegetation	WHA	DPIPWE
	Burrowing Crayfish	Allanaspides_gda94.shp Type2_Ombrastacoides_gda94.shp Sinermis_gda94.shp Efossor_gda94.shp Egranulatus_gda94.shp Emartigener_gda94.shp Espinicaudatus_gda94.shp Eyabbimunna_gda94.shp	DPIPWE
	Karst	CFEV2008	DPIPWE
	Springs	Northwest incised basalt plateau predicted springs	NA

13.2.3. Data selection for GIS analysis datasets to implement rules for GDEs that rely on the surface expression of groundwater, and for GDEs that rely on the subsurface presence of groundwater

Table 76 shows the GIS analysis datasets used to analyse each rule for GDEs that rely on the subsurface presence of groundwater, and GDEs that rely on the surface expression of groundwater in WP8. The datasets listed contained attributes that enable each rule to be implemented, by assigning the attributes to the coincident polygons in the feature layers. The column second from the right briefly explains how the datasets were used for each rule, including the general approach to normalising the attributes of the GIS analysis dataset. The spatial extent of the dataset limits where the rule can be applied, hence abrupt spatial variations or anomalies in the GDE maps may be related to the coverage of GIS analysis datasets.

Using the datasets listed in Table 76, GIS analysis was carried out to join the GIS analysis attributes to the ecosystem features within each feature layer. This process resulted in a permutation table for each feature layer, which could then be analysed using the normalisation and GDE potential calculation processes described in the following sections. More information on the permutation table is included in the description of the general methodology in section 4.5 to 4.6.

- **Table 76 GIS analysis datasets used to implement the rules for GDEs that rely on the surface expression, and subsurface presence of groundwater**

Datasets needed for analysis	Dataset name	Coverage of dataset/rule	Implementation of rule	GDE type mapped using analysis dataset
Vegetation mapping layers for vegetation community, DEM to provide slope and altitude, geology for regolith	TASVEG, WHA	All state wide except for WHA vegetation map, which only covers the World Heritage regions.	Combinations of vegetation community (as mapped by the WHA and TasVeg vegetation layers), slope class and geology were provided by expert consultation (Corbett and Corbett) to define areas where the seasonal or permanent expression of groundwater at the land surface is likely, or where vegetation relies on the subsurface presence of groundwater.	GDEs that rely on the surface expression of groundwater GDEs that rely on the subsurface presence of groundwater
CFEV waterbodies	CFEV waterbodies	All of Tasmania	Rules were provided by DPIPWE to identify GDEs based on the WB_PClass attribute	GDEs that rely on the surface expression of groundwater GDEs that rely on the subsurface presence of groundwater

CFEV wetlands	CFEV wetlands	All of Tasmania	Rules were provided by expert input to differentiate confidence scores. Rules were related to specific locations.	GDEs that rely on the surface expression of groundwater GDEs that rely on the subsurface presence of groundwater
CFEV rivers for line work, CSIRO connectivity layer for attributing previously determined connectivity class (gaining, losing, variably gaining/losing), layer of flow persistence, DEM and surface geology	CFEV rivers, CSIRO sustainable yields report stream connectivity layer (CSIRO 2009), , tasdemstreamsv293, DEM, geol250_poly_GDA94.shp	All of Tasmania	All streams in Tasmania were assumed to be connected to groundwater. Rules were applied to attribute the connectivity class. The CSIRO connectivity layer took precedence. In remaining areas a ruleset was established to attribute the likely connectivity class according to flow persistence (tasdemstreamsv293.shp), geology and slope.	GDEs that rely on the surface expression of groundwater
CFEV rivers, surface geology, DEM	CFEV rivers, geol250_poly_GDA94.shp, DEM	Northern Tasmania	A ruleset was also applied to approximate the occurrence of springs that frequently occur at base of Tertiary basalt in deeply incised valleys where it contacts basement (Ian Houshold, pers. comm.). Potential springs were defined at the edge of Basalt (where Tb intersects other geologies) on steep slopes and where drainage lines occur.	GDEs that rely on the surface expression of groundwater

13.3. Definition Query

Definition queries were applied to each feature layer dataset in order to exclude ecosystems that cannot be GDEs. This includes non-natural landscapes such as reservoirs, dams and irrigated land. It also excludes features that are artefacts of mapping, and do not represent actual features in the landscape.

The definition queries applied to each dataset to exclude ecosystems that cannot be surface GDEs are listed below.

For the wetlands feature layer dataset (**CFEV Wetlands)** definition queries were applied to the attribute field ‘WB_PClass’ to exclude polygons that were attributed as ‘WB_ARTIF’, which removed all artificial wetlands.

Definition queries were generally applied to each feature layer dataset to exclude ecosystems that cannot be GDEs. This included non-natural landscapes such as settlements, pasture, and plantations, as well as natural landscapes that do not use groundwater, such as rainforest, grasslands and bare earth.

For the vegetation feature layer dataset (**TasVeg)** definition queries were applied to the attribute field ‘Category’ and ‘Community’ to exclude polygons that were attributed as:

Tasveg_Category	Tasveg_Community	Tasveg_Category	Tasveg_Community
Dry eucalypt forest and woodland	Eucalyptus amygdalina forest and woodland on dolerite	Rainforest and related scrub	Nothofagus gunnii rainforest and scrub
Dry eucalypt forest and woodland	Eucalyptus amygdalina forest and woodland on sandstone	Rainforest and related scrub	Athrotaxis selaginoides - Nothofagus gunnii short rainforest
Dry eucalypt forest and woodland	Eucalyptus amygdalina inland forest and woodland on Cainozoic deposits	Rainforest and related scrub	Athrotaxis selaginoides rainforest
Dry eucalypt forest and woodland	Eucalyptus coccifera forest and woodland	Rainforest and related scrub	Athrotaxis selaginoides subalpine scrub
Dry eucalypt forest and woodland	Eucalyptus dalrympleana - Eucalyptus pauciflora forest and woodland	Rainforest and related scrub	Highland rainforest scrub with dead Athrotaxis selaginoides
Dry eucalypt forest and woodland	Eucalyptus globulus dry forest and woodland	Rainforest and related scrub	Leptospermum with rainforest scrub
Dry eucalypt forest and woodland	Eucalyptus nitida dry forest and woodland	Rainforest and related scrub	Nothofagus - Leptospermum short rainforest
Dry eucalypt forest and woodland	Eucalyptus obliqua dry forest	Rainforest and related scrub	Nothofagus rainforest undifferentiated
Dry eucalypt forest and woodland	Eucalyptus ovata heathy woodland	Rainforest and related scrub	Athrotaxis cupressoides - Nothofagus gunnii short rainforest
Dry eucalypt forest and woodland	Eucalyptus pauciflora forest and woodland on dolerite	Rainforest and related scrub	Athrotaxis cupressoides rainforest
Dry eucalypt forest and woodland	Eucalyptus pauciflora forest and woodland not on dolerite	Rainforest and related scrub	Highland low rainforest and scrub
Dry eucalypt forest and woodland	Eucalyptus rodwayi forest and woodland	Scrub, heathland and coastal complexes	Acacia longifolia coastal scrub
Dry eucalypt forest and woodland	Eucalyptus amygdalina - Eucalyptus obliqua damp sclerophyll forest	Scrub, heathland and coastal complexes	Banksia marginata wet scrub
Dry eucalypt forest and woodland	Eucalyptus tenuiramis forest and woodland on dolerite	Scrub, heathland and coastal complexes	Broad-leaf scrub
Dry eucalypt forest and woodland	Eucalyptus tenuiramis forest and woodland on sediments	Scrub, heathland and coastal complexes	Coastal scrub on alkaline sands

Dry eucalypt forest and woodland	Eucalyptus viminalis - Eucalyptus globulus coastal forest and woodland	Scrub, heathland and coastal complexes	Coastal heathland
Dry eucalypt forest and woodland	Eucalyptus viminalis grassy forest and woodland	Scrub, heathland and coastal complexes	Coastal complex on King Island
Dry eucalypt forest and woodland	Eucalyptus viminalis shrubby/heathy woodland	Scrub, heathland and coastal complexes	Dry scrub
Agricultural, urban and exotic vegetation	Marram grassland	Scrub, heathland and coastal complexes	Heathland on granite
Agricultural, urban and exotic vegetation	Pteridium esculentum fernland	Scrub, heathland and coastal complexes	Subalpine heathland
Native grassland	Lowland grassland complex	Scrub, heathland and coastal complexes	Inland heathland (undifferentiated)
Native grassland	Coastal grass and herbfield	Scrub, heathland and coastal complexes	Melaleuca squamea heathland
Native grassland	Highland Poa grassland	Scrub, heathland and coastal complexes	Queenstown regrowth mosaic
Native grassland	Lowland Poa labillardierei grassland	Scrub, heathland and coastal complexes	Seabird rookery complex
Native grassland	Lowland Themeda triandra grassland	Scrub, heathland and coastal complexes	Coastal scrub
Highland treeless vegetation	Alpine coniferous heathland	Scrub, heathland and coastal complexes	Western subalpine scrub
Highland treeless vegetation	Eastern alpine heathland	Scrub, heathland and coastal complexes	Western wet scrub
Moorland, sedge land, rush land and peat land	Sparse buttongrass moorland on slopes	Wet eucalypt forest and woodland	Eucalyptus brookeriana wet forest
Moorland, sedge land, rush land and peat land	Buttongrass moorland (undifferentiated)	Wet eucalypt forest and woodland	Eucalyptus dalrympleana forest
Moorland, sedge land, rush land and peat land	Subalpine Diplarrena latifolia rushland	Wet eucalypt forest and woodland	Eucalyptus delegatensis forest with broad-leaf shrubs
Moorland, sedge land, rush land and peat land	Highland grassy sedgeland	Wet eucalypt forest and woodland	Eucalyptus delegatensis forest over Leptospermum
Non-eucalypt forest and woodland	Acacia dealbata forest	Wet eucalypt forest and woodland	Eucalyptus delegatensis forest over rainforest
Non-eucalypt forest and woodland	Allocasuarina littoralis forest	Wet eucalypt forest and woodland	Eucalyptus delegatensis wet forest (undifferentiated)
Non-eucalypt forest and woodland	Acacia melanoxylon forest on rises	Wet eucalypt forest and woodland	Eucalyptus globulus King Island forest
Non-eucalypt forest and woodland	Allocasuarina verticillata forest	Wet eucalypt forest and woodland	Eucalyptus globulus wet forest
Non-eucalypt forest	Bursaria - Acacia woodland and	Wet eucalypt forest	Eucalyptus nitida forest over

and woodland	scrub	and woodland	Leptospermum
Non-eucalypt forest and woodland	Banksia serrata woodland	Wet eucalypt forest and woodland	Eucalyptus nitida forest over rainforest
Non-eucalypt forest and woodland	Leptospermum scoparium - Acacia mucronata forest	Wet eucalypt forest and woodland	Eucalyptus nitida wet forest (undifferentiated)
Non-eucalypt forest and woodland	Leptospermum forest	Wet eucalypt forest and woodland	Eucalyptus obliqua forest with broad-leaf shrubs
Non-eucalypt forest and woodland	Subalpine Leptospermum nitidum woodland	Wet eucalypt forest and woodland	Eucalyptus obliqua forest over Leptospermum
Non-eucalypt forest and woodland	Notelaea - Pomaderris - Beyeria forest	Wet eucalypt forest and woodland	Eucalyptus obliqua forest over rainforest
Rainforest and related scrub	Coastal rainforest	Wet eucalypt forest and woodland	Eucalyptus obliqua wet forest (undifferentiated)
		Wet eucalypt forest and woodland	Eucalyptus subcrenulata forest and woodland

For the vegetation feature layer dataset **(WHA)** definition queries were applied to the attribute field 'Veg_Community' to exclude polygons that were attributed as:

WHA_Veg_Community	**WHA_Veg_Community**
Grassy alpine heath	Kingbilly alpine rainforest
Shrubby eastern alpine heath	Kingbilly Pine in rainforest
Acacia dealbata	Kingbilly with Pencil Pine and fagus
Boronia heath	Short tea tree scrub
Coniferous heath	Tea tree forest
alpine E. coccifera woodland	E. coccifera mixed forest
Deciduous Beech	E. delegatensis mixed forest
Western subalpine scrub	E.nitida mixed forest
Fire-dependent grassland and grassy herbfields	E. obliqua mixed forest
Baeckea heath	Shrubby muttonbird rookery
alpine E. subcrenulata woodland	E. subcrenulata mixed forest
Shrubby western alpine heath	Pandani
Banksia moorland	Pencil Pine/ fagus shrubbery
Banksia scrub	Tall broadleaf shrubbery
Sparse buttongrass on slopes	Pencil Pine forest
Southwest buttongrass	Pencil Pines in rainforest
Coastal bracken/herbfield	Western implicate rainforest with Kingbilly Pine
Cyathodes juniperina dwarf forest	Dwarf alpine rainforest and shrubberies
Coastal E. obliqua woodland	Rainforest scrub
Coastal rainforest	Rainforest
Beachback shrubberies	Fire damaged rainforest

Tall coastal shrubberies	Kingbilly western scrub
Diselma shrubbery	Wet forest shrubbery
E. nitida dry scrub	Subalpine E. coccifera woodland
dry heathy E. obliqua	heathy E. delegatensis
E nitida coastal forest	single myrtles
E. coccifera/tall tea tree woodland	subalpine E. subcrenulata forest
E. coccifera/tall tea tree woodland	E. vernicosa subalpine shrubberies
E. vernicosa Norold Range	Towterer E. nitida/Celery Top forest
Coastal grass	Tea tree forest
E. coccifera mixed highland forest	Tea tree rainforest
Diplarrena grassy heath	Coastal heath
Tall dry scrub	*E. delegatensis* wet forest
Grassland	E. nitida wet forest
Heath	E. nitida wet scrub
Coastal shrubberies	E. obliqua wet forest

13.4. Attribution of GDEs identified in previous studies (from literature)

GDEs were identified in the literature review in Task 2. These were matched to polygons in the vegetation, river and wetland feature layers where possible. The majority of these GDEs could be matched to existing polygons, which were attributed as either ‘GDE identified in previous study: fieldwork’; or ‘GDE identified in previous study: desktop’. The Tier 3 attributes recorded in the literature review have also been entered into the GDE Atlas attribute table for the GDEs identified in previous studies.

13.5. Transfer of attributes from existing spatial datasets to GDE polygons

The CFEV river layer was used as the feature layer and it was attributed to distinguish reaches that were likely to be gaining, losing or variably gaining/losing in order to identify stream reaches where groundwater contributions are most likely. The following process was applied to attribute the layer:

Datasets used:

- 1. CSIRO Tas SY GW_SW_Code.shp coverages (Parsons, et al., 2008)
- 2. tas_demstreamsv293.shp (Stein’s dataset provided by DPIPWE)
- 3. Slope analysis
- 4. 1:250k geology

Rulesets:

- Apply buffer of 25m either side of stream layer to convert lines to polygon features
- Use dataset #1 to map gaining, losing and variable gaining-losing streams. This dataset will override all other analysis

Elsewhere,

- Assign gaining streams where metagroup* from dataset #2 = J, I or H, and slope = steep, moderate, gentle
- Assign losing streams where metagroup from dataset #2 = H, G or D, slope = flat, and geology = Qh or Qps
- Assign remaining streams as variable gaining/losing
- *Stein’s metagroups: I = stable winter basleflow, J = stable baseflow, H = unpredictable baseflow, G = predictable winter intermittent, D = unpredictable intermittent flow.
- Map attributes from connectivity analysis to CFEV rivers linework.

The connectivity ruleset defers to the existing connectivity maps provided by CSIRO Sustainable Yields project (Parsons, et al., 2008). The secondary rules using Stein’s layer identified most

reaches in Tasmania as being either gaining or variably gaining/losing, which is consistent with the previous studies (e.g. Parsons, et al., 2008).

Several assumptions and limitations are inherent in the connectivity in Steins layer and should not be used outside the context of the GDE Atlas. Stein's layer was generated using a gridded product such that the linework is inaccurate at the local scale. These accuracies are likely to be reflected in the final attributes when they were mapped to the CFEV rivers linework.

13.5.1. Datasets used to map GDEs identified in previous studies

In work package 8, the spatial datasets used to attribute GDE polygons as either GDE identified in previous study: fieldwork; or GDE identified in previous study: desktop are shown in Table 77. These datasets were either used to attribute polygons within the feature layer datasets, or entered in their entirety as feature layer datasets. Either way, the information from these datasets was incorporated into the GDE Atlas to show where GDEs were identified in previous studies.

- **Table 77 Spatial datasets used to map GDEs identified in previous studies (both desktop and fieldwork studies)**

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
GDEs identified in previus studies, desktop			
Karst_for_atlas.shp (subset of CFEV2008)	Subterranean	All	Karst_for_atlas.shp (subset of CFEV2008)
Smithton_Majorsprings_GDEAtlas.shp	Spring	All	Smithton_Majorsprings_GDEAtlas.shp
GDEs identified in previus studies, fieldwork			
Smithton_Moundsprings_GDEAtlas.shp	Spring	All	Smithton_Moundsprings_GDEAtlas.shp
Allanaspides_gda94.shp	Burrowing crayfish	All	Allanaspides_gda94.shp
Type2_Ombrastacoides_gda94.shp	Burrowing crayfish	All	Type2_Ombrastacoides_gda94.shp
Sinermis_gda94.shp	Burrowing crayfish	All	Sinermis_gda94.shp
Efossor_gda94.shp	Burrowing crayfish	All	Efossor_gda94.shp
Egranulatus_gda94.shp	Burrowing crayfish	All	Egranulatus_gda94.shp
Emartigener_gda94.shp	Burrowing crayfish	All	Emartigener_gda94.shp
Espinicaudatus_gda94.shp	Burrowing crayfish	All	Espinicaudatus_gda94.shp

Spatial Dataset	GDE Type	Which features (if not all)	Feature layer these are attributed to
Eyabbimunna_gda94.shp	Burrowing crayfish	All	Eyabbimunna_gda94.shp
CFEV Springs	Spring	All	CFEV Springs

13.5.2. Datasets used to populate attributes in the GDE Atlas attribute table

Information from jurisdiction's spatial data was incorporated into the GDE Atlas by transferring the relevant attributes into the GDE Atlas attribute table. A summary of the data used to populate each attribute is shown in Appendix F.

14. Maps derived for the GDE Atlas

The application of the methodology described in sections 6 to 13, resulted in the completion of IDE and GDE maps. Along with the remote sensing products developed in Task 4 (described in section 3) these maps are included in the GDE Atlas and are described in this section. The purpose of this section is to present the final maps and establish a link between the methodology and maps described in this report, to the maps as they are presented on the GDE Atlas website[14].

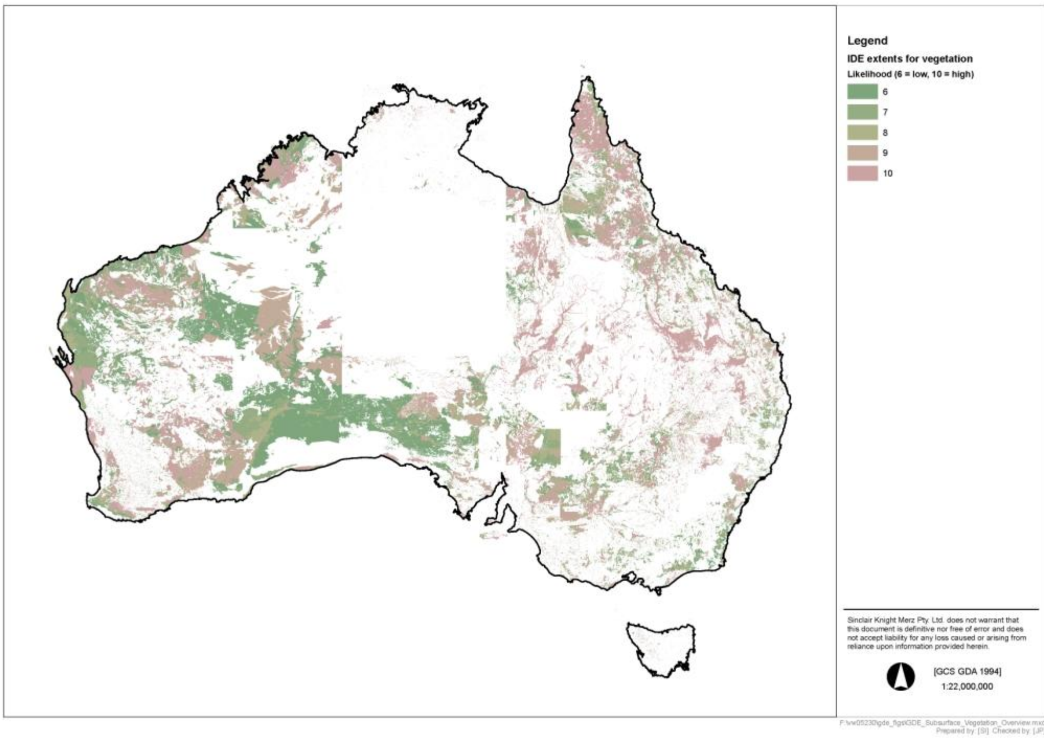
14.1. Inflow Dependent Ecosystems (IDEs)

The IDE layer is a product that was developed by assigning an ID likelihood (from remote sensing data in Task 4) to each vegetation ecosystem polygon from the feature layer datasets listed in sections 6 to 13. The resulting IDE mapping identifies vegetation ecosystems that are likely to use a water source in addition to rainfall, such as water stored in the unsaturated zone, surface water or groundwater. This layer is the basis for further analysis in Task 5 to distinguish the vegetation ecosystems that potentially use groundwater, from those that rely on water stored in the unsaturated zone or surface water. As such, it can be considered as a first step in the analysis to identify GDEs that rely on the subsurface presence of groundwater. Figure 22 shows the extents of vegetation IDEs mapped in the GDE Atlas.

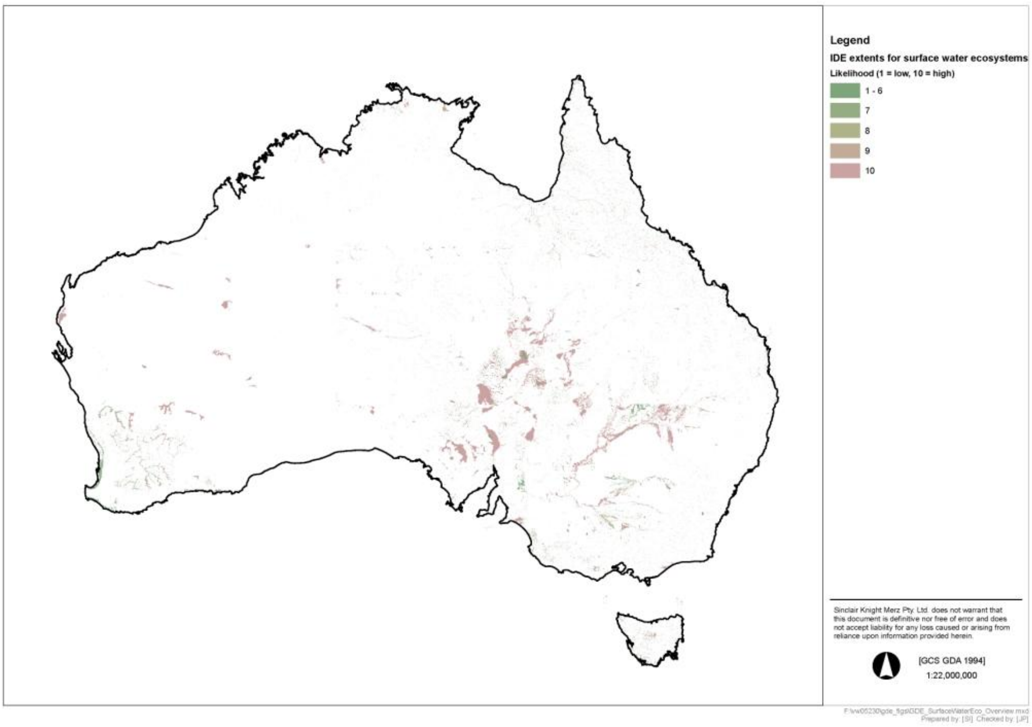
Analysis to identify GDEs that rely on the surface expression of groundwater does not depend so much on the identification of IDEs. All surface water ecosystems (rivers, wetlands and springs) are considered to be IDEs, as they all receive inflows from surface water, and potentially groundwater. However, using the feature datasets available for each work package, the ID likelihood was assigned to each river, wetland and spring polygon to create a map of IDEs. This map forms the basis of the analysis for GDEs that rely on the surface expression of groundwater (wetlands, rivers, springs). Figure 23 shows the extents of river, wetland and spring IDEs mapped in the Atlas.

The benefit of including the IDE layer in the GDE Atlas is that all ecosystems that are using water in addition to rainfall (and could therefore possibly be GDEs) are included in the IDE layer. This enables users to view ecosystems that could not be identified as GDEs due to lack of data, but which may in reality be using groundwater. They allow a more complete understanding of the likely water use of ecosystems analysed during development of the GDE Atlas to be presented.

[14] Note –many small features are not visible when the maps are viewed at a national scale.



- **Figure 22 Inflow Dependent Ecosystems (vegetation)**



- **Figure 23 Inflow Dependent Ecosystems (rivers, wetlands, springs)**

14.2. Groundwater Dependent Ecosystems (GDEs)

Maps of GDEs that rely on the subsurface presence of groundwater (vegetation), and maps of GDEs that rely on the surface expression of groundwater (rivers, wetlands and springs) were developed for each work package. Once finalised, the work package layers were combined into a single layer for Australia showing GDEs that rely on the subsurface presence of groundwater (Figure 24), and a single layer showing GDEs that rely on the surface expression of groundwater (Figure 25). These are the primary products of the GDE Atlas analysis. The final mapping for each work package is shown in Appendix A. The mapping for Subterranean GDEs is shown in Figure 26 and is a collation of existing cave maps for Tasmania.

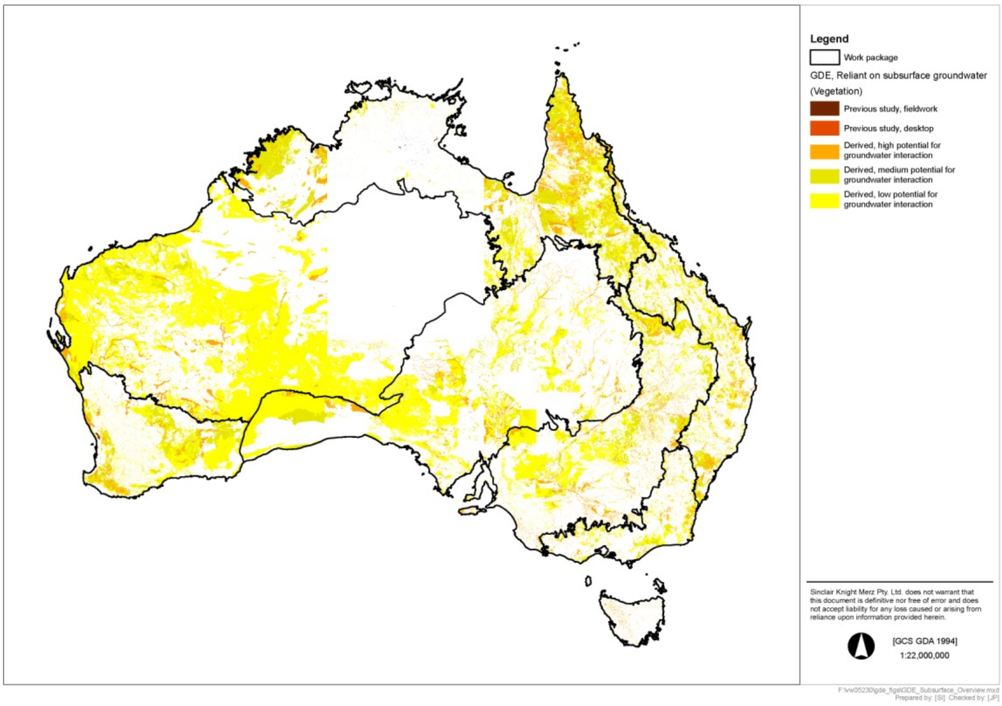
The two final GDE maps show both GDEs that were identified in previous studies, as well as potential GDEs that were derived through the Task 5 analysis described in preceding sections. The resulting GDE maps display the following GDE mapping classifications:

- GDE identified in previous study (fieldwork)
- GDE identified in previous study (desktop)
- High potential for groundwater interaction
- Moderate potential for groundwater interaction
- Low potential for groundwater interaction

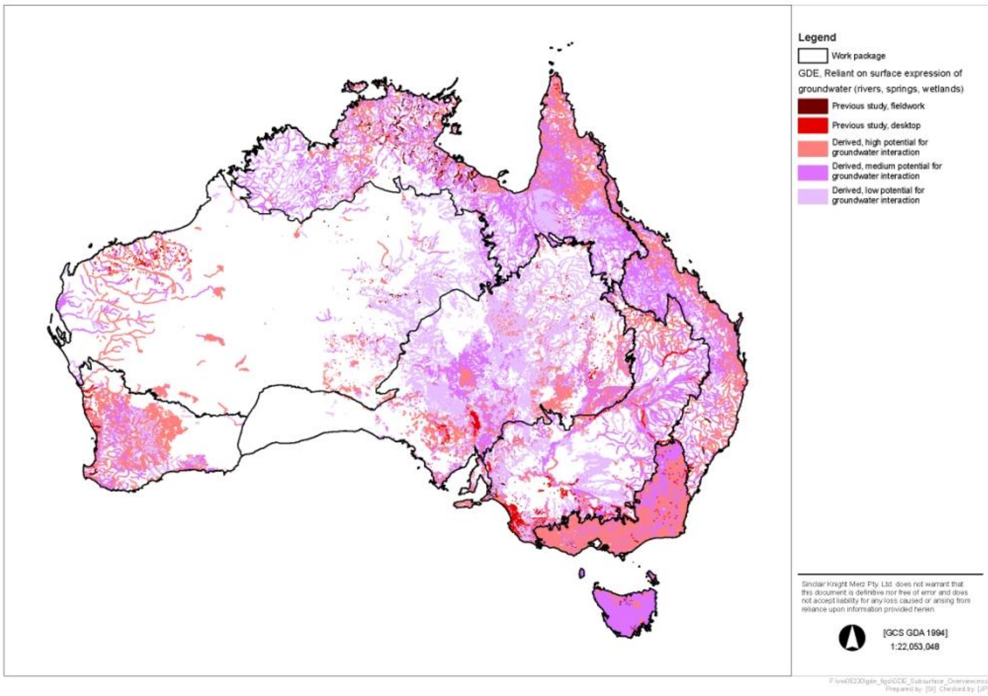
The GDE maps include only the ecosystems where some assessment of the potential for groundwater interaction could be made. Where lack of data prevented potential groundwater interaction to be distinguished from water stored in the unsaturated zone or surface water use, the ecosystem was mapped in the IDE layers rather than the GDE maps.

Ecosystem extents shown in the maps do not necessarily show the spatial extent of groundwater use. Rather, the ecosystem polygons should be interpreted as showing the area within which groundwater interaction may be occurring.

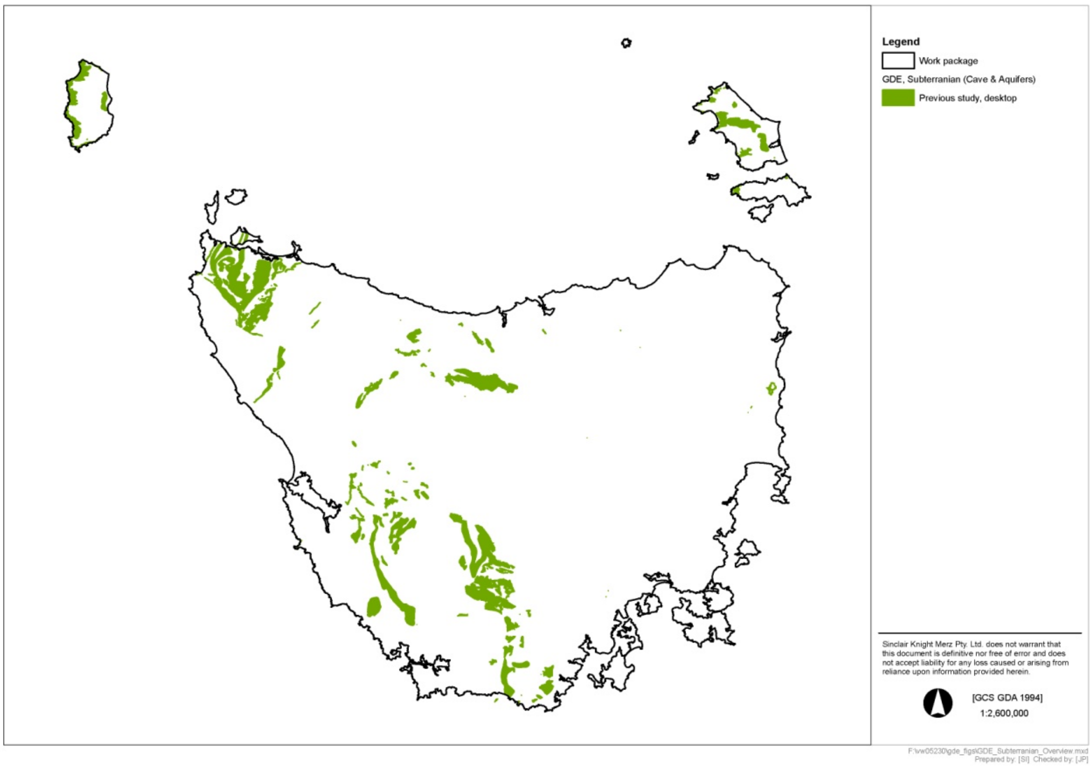
The final GDE maps were uploaded to the geodatabase on the Bureau of Meteorology hosting platform, along with the attributes which describe the nature of groundwater connection for each potential GDE. These attributes were populated using existing national datasets, and jurisdiction datasets. The data used to populate the attributes is summarised in Appendix F.



- **Figure 24 Final map of Potential GDEs that rely on the subsurface presence of groundwater (vegetation)**



- **Figure 25 Final maps of Potential GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs)**



■ **Figure 26 Final map of Subterranean GDEs (caves)**

15. Technical Gaps and Data Gaps

The chapter summarises the major technical and data gaps noted in the development of the GDE Atlas. Recommendations on how these gaps could be addressed are also included.

Technical gaps fall into two categories. The first category relates to the technical systems or information systems programmes used to develop the GDE Atlas maps. There were no noted gaps in this category. The second category relates to the science associated with the concepts that govern groundwater and ecosystem interaction. Data gaps refer to the absence of data required to develop the GDE maps.

15.1. Technical gaps

Information Systems. There were no technical gaps noted with the systems or programmes used to build the GDE Atlas (for example, ESRI ArcGIS or WEAVE). The software had all the functionality required which enabled the analysis to be completed as planned.

Scientific gaps. A robust conceptual understanding of interaction between groundwater and ecosystems was lacking in some areas. For example, in large parts of central Australia there was limited literature available to describe the landscape processes, and the information that did exist was confined to a few areas, such as the Pilbara-Hammersley region, and the Ti-Tree Basin. Added to this, work in the Ti-Tree Basin is not yet conclusive and is therefore of limited value for modelling. For areas where literature was not available to inform the conceptual understanding (Figure 9, section 4.3), broad analysis rules were applied. Some of the factors that are important in controlling the potential for groundwater/ecosystem interaction in central Australia (such as the presence of cracking clay soils) were not documented in the reviewed literature, but were included in the analysis on the recommendations of technical reviewers. A more extensive literature review is unlikely to yield further understanding, since few studies have been conducted in these areas. Addressing this technical gap is likely to require additional field studies and fine scale analysis of these areas.

In Queensland, broad vegetation groups (attribute: DBVG2M in RE06b vegetation mapping) were used to indicate the potential for groundwater interaction. This did not allow distinctions to be made between individual species, which meant the GDE potential result was an equally broad indication of potential groundwater interaction in many cases. The impact of this was greatest where there were not many GIS analysis datasets available to contribute to the overall GDE potential result. In most other areas, the dominant species was used to indicate the potential for groundwater interaction, without consideration of how the sub-dominant species may have influenced the potential for groundwater interaction. The use of a more detailed vegetation attribute such as ‘RE’ (in the Queensland RE06b vegetation mapping) would have provided more information to distinguish the potential groundwater interaction for smaller, more uniform

ecosystems. However, the use of broad, or dominant species to derive GDE potential is an example of the need to prioritise coverage over detail to develop when developing a national map.

Normalising GIS analysis datasets involved assigning a rating of 3 (likely to result in groundwater interaction), 2 (may result in groundwater interaction), or 1 (unlikely to result in groundwater interaction) to each analysis attribute (section 4.6.1). Assigning only 3 categories to every landscape variable is a broad scale approach. However, in general the conceptual understanding was not sufficiently detailed to enable GIS analysis attributes to be broken up any further. For example, no specific knowledge exists to rank vegetation types into any more than three categories (likely, possible, unlikely). Without a significant increase in knowledge of groundwater use for specific vegetation types (which would be likely to require intensive field study) increasing the number of normalisation categories is not recommended.

15.2. Data gaps

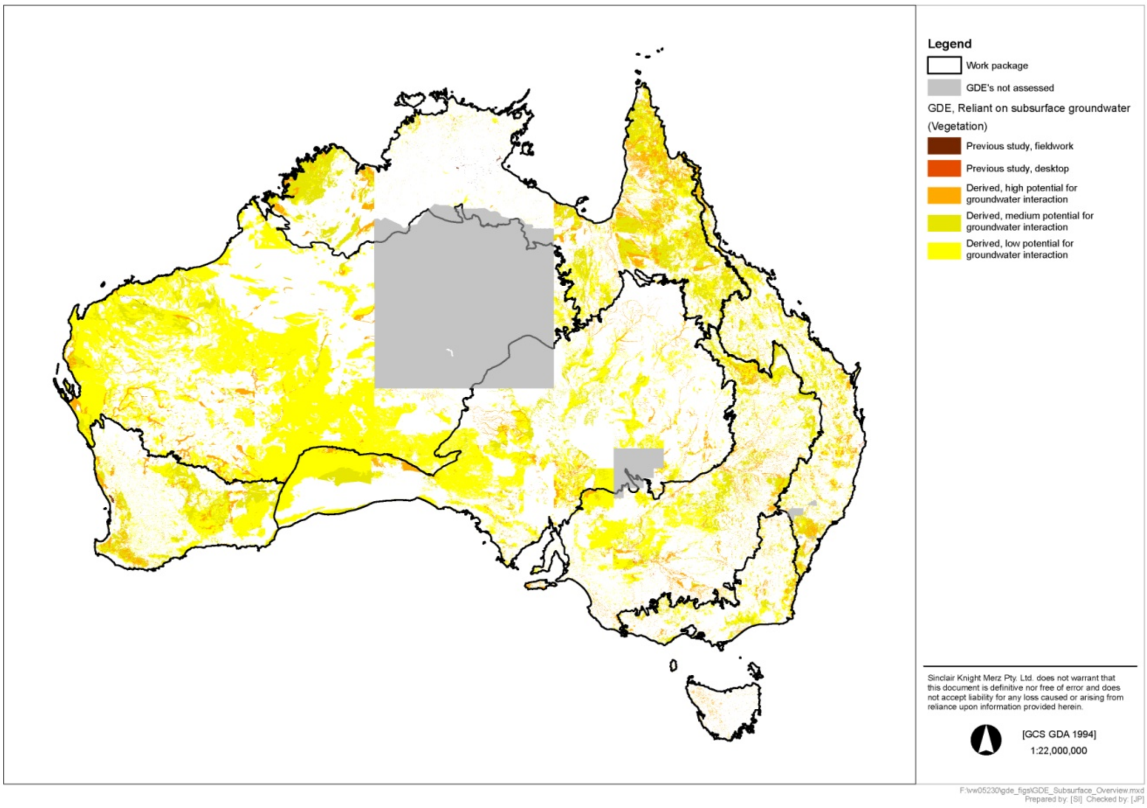
15.2.1. Feature layer datasets

A lack of vegetation feature datasets in certain areas resulted in the most obvious data gaps in the GDE Atlas. Figure 27 shows the map of Ecosystems that rely on the subsurface presence of groundwater, with gaps in the mapping that resulted from lack of vegetation feature layers. These gaps occurred in the NT and NSW.

Many vegetation datasets exist for certain areas in the southern NT, mostly in the form of land unit and land systems mapping. It is recommended that these datasets are combined into a single dataset with more extensive coverage, and that this is reviewed for potential future use in the GDE Atlas, or it is incorporated into a vegetation map (yet to be created) for the whole NT.

Two vegetation feature layers were used for the northern NT in work package 6. The Greater Darwin vegetation map covered a small area immediately around Darwin. The NVIS2005_combo_1_2_3 map covered most of the northern NT, but only included certain vegetation ecosystems (rainforest vegetation and Melaleuca) and is therefore incomplete. The sparsity of vegetation in the feature layer can be observed in the low density of GDEs mapped in the northern NT in Figure 27. It is therefore possible that vegetation types other than rainforest and Melaleuca could be using groundwater but could not be identified in the Atlas. Development of a vegetation feature dataset for NT that includes all vegetation ecosystems is recommended.

The vegetation feature layers available for NSW did not cover small areas on the wetern flank of the Great Dividing Range, and a larger area in north west NSW in the Cooper Creek area. The lack of vegetation feature layers prevented any mapping of GDEs that rely on the subsurface presence of groundwater to be undertaken (Figure 27).



- **Figure 27 Map showing GDEs that rely on subsurface presence of groundwater, and the gaps resulting from lack of vegetation feature datasets**

Inclusion of wetlands in the NT in the map of GDEs that rely on the surface expression of groundwater relied upon the Geodata mapping of lakes, flats and swamps (Geoscience Australia) as feature layers. The analysis would benefit from improved attribution in these layers, as the only useable attribute in the current data was 'perenniality' for the Lakes layer. Adding 'perenniality' to flats and swamps, and other attributes describing the type of lake, flat or swamp would enable these datasets to fulfil more analysis rules and therefore increase the 'lines of evidence' for the GDE potential derived for each ecosystem.

The current statewide wetland map for NSW provides no indication of the hydrology and hydrogeology of the system. In particular, it lacks descriptions of wetland type and water regime, which are useful indicators of potential groundwater connection. It is recommended that the NSW wetland layer be attributed with the ANAE style classification framework, particularly an attribute which describes water regime.

The feature layer dataset used to map wetlands in most of WA (WP6, WP7 and most of WP5) only showed wetlands listed on the DIWA and as such, this is feature layer does not capture all wetlands in WA. Springs mapping with greater coverage of WA would also improve the mapping of GDEs

that rely on the surface expression of groundwater. It is recommended that future updates to the GDE Atlas include these datasets.

15.2.2. GIS analysis datasets

The use of statewide depth to watertable contour maps in the analysis would improve the GDE maps. This is a key data source for mapping of GDEs, and was unavailable for most of Queensland, WA, and Tasmania, and parts of the NT. The depth to watertable mapping used in SA was a valuable analysis dataset, however it was based on sparse data points and may have limited accuracy. This is likely to be the case for any depth to watertable mapping created for areas where groundwater has not been intensively developed or studied.

The analysis in WP2 and WP7 would also benefit from more extensive mapping of cracking clay soils, which are considered to impede groundwater flow across large areas of central Australia. This data was used in the analysis for Queensland and the NT, but was not available for SA and WA.

The capacity of the soil to hold sufficient water to enable vegetation growth throughout dry periods is a key piece of data, along with depth to watertable contours and ID likelihood. Datasets that map the available water capacity of soils was available for Queensland, NSW and southern SA. Northern SA, WA and the NT in particular would benefit from use of these datasets in the analysis, as some vegetation ecosystems in those areas are thought to be able to survive for long periods without rain due to the availability of water stored in the unsaturated zone.

In areas where few GIS datasets are available, the GDE potential result will have a low reliability (few ‘lines of evidence’). Useful datasets include mapped spring locations, previously identified GDE locations, as well as soil water holding capacity and depth to watertable contours. Soil water holding capacity maps are also currently unavailable in northern SA.

15.2.3. GDEs derived in previous studies

‘GDEs identified in previous studies’ are considered to be reliable assessments of groundwater interaction, and were therefore used to validate mapping results. However, this could not occur in areas where limited literature was available for review and as a result few ‘GDEs identified in previous studies’ were mapped. The areas where previously identified GDEs are rare include all WA apart from the south west coastal areas, the northern MDB (in WP3), central Australia, the Nullarbor Plain, and northern Queensland (in WP6). A more extensive literature review may help in some areas, although it is likely that few studies have occurred in these areas.

NRETAS have recently identified an additional dataset which maps salt lakes and has attributes which indicate likely groundwater connection (A. Duguid, pers. comm.) as:

1. known contemporary groundwater connection/discharge
2. probably contemporary groundwater connection/discharge
3. playas with some soil salinity but no knowledge of groundwater

These could be included as 'GDEs identified in previous study' in future updates of the GD Atlas.

Alpine fens and bogs are known GDEs and exist across the Alpine bioregion in Victoria and NSW. However at the completion of project no spatial extents of the fens and bogs for NSW Alpine region were available. It is recommended that when identified or developed, the fens and bog extents in NSW are included in the Atlas as 'GDEs identified in previous study: fieldwork'.

16. Recommendations

The GDE Atlas supports the consideration of ecosystem groundwater requirements in natural resource management. It is recommended that the Atlas is used in the early stages of the planning and approvals processes to flag the location and characteristics of potential GDEs. In high risk locations, or where consequences may be significant, it is recommended that more detailed work is undertaken to assess the water requirements of GDEs. The Atlas can be used as a starting point to direct this further research.

Where more detailed assessments of GDEs are required, the GDE Toolbox (Richardson, et al., 2011) provides a framework and tools for identifying GDEs, assessing ecological water requirements and determining the impacts of changes in the groundwater environment on ecosystems. The GDE Toolbox is recommended to help water managers obtain a more detailed understanding of GDEs and the nature of groundwater connection at a fine scale.

Following on from the technical and data gaps recognised in section 15, recommendations for a future update of the Atlas are discussed below in order of priority.

Address the gaps in vegetation feature layer datasets for NSW.
Small data gaps exist in the mapping of GDEs that rely on the subsurface presence of groundwater in NSW, on the western edge of the Blue Mountains and the north west of NSW. It is understood that vegetation mapping does not exist in these areas. Therefore, it is recommended that vegetation mapping is undertaken to fill these gaps.

Address the gaps in the vegetation feature layer datasets for the NT.
GDE mapping is sparse in the northern NT due to the use of rainforest and Melaleuca datasets to map GDEs. In the southern NT a vegetation layer with sufficiently broad coverage was not available, and so GDEs that rely on the subsurface presence of groundwater' have not been mapped. Development of a vegetation feature dataset for NT that includes all vegetation ecosystems is recommended. Several vegetation (or land unit) datasets exist in the NT, which should be incorporated into a broader statewide map (if developed).

Develop statewide depth to watertable maps.
The use of statewide depth to watertable contour maps in the analysis would improve the GDE maps. This is a key data source for mapping of GDEs, and was unavailable for most of Queensland, WA, and Tasmania, and parts of the NT.

Create datasets that map the majority of wetlands and springs in WA.
The feature layer dataset used to map wetlands in most of WA only showed wetlands listed on the DIWA and as such, this is feature layer does not capture all wetlands in WA. Springs mapping with greater coverage of WA would also improve the mapping of GDEs that rely on the surface

expression of groundwater. It is recommended that these layers are developed for future updates to the GDE Atlas.

Additional attribution of the NSW wetlands layer.
The current statewide wetland map for NSW lacks descriptions of wetland type and water regime, which are useful indicators of potential groundwater connection. It is recommended that the NSW wetland layer be attributed with the ANAE style classification framework, particularly an attribute which describes water regime.

Additional attribution of flats and swamps Geodata used in the northern NT.
The addition of a 'perenniality' attribute to flats and swamps, and other attributes describing the type of lake, flat or swamp would enable these datasets to fulfil more analysis rules.

Map soil available water capacity.
Datasets that map the available water capacity of soils was available for Queensland, NSW and southern SA. Northern SA, WA and the NT in particular would benefit from use of these datasets in the analysis, as some vegetation ecosystems in those areas is thought to be able to survive for long periods without rain due to the availability of soil water stored in the unsaturated zone.

Map cracking clay soils.
The analysis would benefit from more extensive mapping of cracking clay soils, which are considered to impede groundwater flow across large areas of central Australia. This data was not available for SA and WA.

Include more 'GDEs identified in previous studies' in the GDE mapping.
'GDEs identified in previous studies' are considered to be reliable assessments of groundwater interaction, and were therefore used to validate mapping results. However, previously identified GDEs were rare in all WA apart from the south west coastal areas, the northern MDB (in WP3), central Australia, the Nullarbor Plain, and northern Queensland (in WP6). A more extensive literature review is recommended, alhough it is likely that additional fieldwork or fine scale desktop study would be required to address this.

More comrehensive mapping of Subterranean GDEs (caves and aquifers)
Collation of cave mapping for mainland Australia and development of a more comprehensive map of Subterranean GDEs is recommended. In addition, mapping of identified sygofauna locations should be added to the Subterranean GDE map.

Inclusion of estuarine and marine GDEs
Mapping of estuarine and marine GDEs should be developed for a future update of the GDE Atlas. Estuarine GDEs could be mapped using many of the datasets used to develop the current GDE maps, with rules that specifically describe interaction between groundwater and tidal systems. Mapping of marine GDEs would require collection of new data as well as development of rules specific to marine groundwater discharge environments.

Capture of user application of the data through a reporting facility on the website
To facilitate future developments in how information is delivered through the GDE Atlas, it is recommended that a user application be provided that allows users to report on how and why the information was used. This information would build a database of the major user groups, applications and issues for which the information provided by the Atlas bas been applied. This information can be potentially used to tailor and streamline the information delivery mechanism in the future.

Many GDEs projects occurred in parallel to the development of the GDE Atlas. The outcomes of these project should be incorporated into the Atlas is future updates. Table 78 lists the projects that are likely to be available for an update to the Atlas.

- **Table 78 Projects or data that should be considered for future inclusion into the GDE Atlas**

Queensland	The Queensland GDE mapping project will produce layers of “surface” and terrestrial GDEs in the eastern Murray-Darling Basin and the Wide Bay-Burnett regions of Queensland, as well as a layer of stygofaunal records for the State. The Queensland GDE project has also normalised RE attributes according to their potential for interaction with groundwater. This information should be used if GDE mapping is updated. Revisions to datasets that could be used as feature layers is currently ongoing. This includes the Regional Ecosystem vegetation mapping (being updated to RE07), a rivers mapping layer (which has better accuracy than the National Watercourses dataset), mapping of caves Other project mentioned are: ■ Burdekin project ■ Condamine Border Rivers project ■ Qld Gulf WRP area project
Western Australia	Midwest Potential GDE Investigation (NWC funded) ending this 2012. Other investigations are ongoing and not due for publication in the near future.
Northern Territory	Vegetation mapping is occurring at Howard Springs. This could be used as a vegetation feature layer.
Victoria	GDE component of the SAFE program developed by the Department of Sustainability and Environment. This project has compiled recent created information on spring locations and groundwater connection with streams.

Tasmania	Groundwater, surface water interactions and risk, Completed April 2011, Dept Primary Industries, Parks, Water and Environment.
NSW	Coastal Sands GDE mapping project that will be completed this year (2012) funded by the Office of Water

Note to reviewers: please send information for this table, if it exists.

17. Glossary

There are several specific terms that have been used in the GDE Atlas which are useful to understand when reading this report. These relate to the terminology that describes the spatial layers presented on the GDE Atlas, terms used in this report to describe the methodology, and general terms describing GDEs. A more extensive glossary is included on the GDE Atlas website. Table 79 defines these terms.

- **Table 79 Terminology used to describe the mapping layers, the method, and general terms describing GDEs**

Attribute	A characteristic or description of a spatial polygon.
aquifer	An underground layer of saturated rock, sand or gravel that absorbs water and allows it free passage through pore spaces. Source: adapted from Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) http://www.mincos.gov.au/__data/assets/pdf_file/0016/316123/wqg-apps.pdf.
aquifer, confined	An aquifer that is overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer. Source: National Water Commission Water Dictionary http://dictionary.nwc.gov.au/water_dictionary/pdf/WaterDictionary.pdf
aquifer, perched	A region in the unsaturated zone where the soil or rock may be locally saturated because it overlies a low-permeability unit. Source: National Water Commission Water Dictionary http://dictionary.nwc.gov.au/water_dictionary/pdf/WaterDictionary.pdf
aquifer, unconfined	An aquifer in which there are no confining beds between the saturated zone and the surface. There will be a watertable in an unconfined aquifer. Source: National Water Commission Water Dictionary http://dictionary.nwc.gov.au/water_dictionary/pdf/WaterDictionary.pdf
baseflow	The component of streamflow supplied by groundwater discharge. Source: National Water Commission Water Dictionary http://dictionary.nwc.gov.au/water_dictionary/pdf/WaterDictionary.pdf

capillary zone	The zone of soil moisture above the watertable where water is drawn upwards by capillary tension in which the water is at less than atmospheric pressure. Source: Richardson, S., et al., (2011). Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf
Dampland	A seasonally waterlogged basin. Source: Semeniuk, A. and V. (1995). A geomorphic approach to global classification for inland wetlands. Vegetation 118:103-124
Eco-Hydrogeological zone (EHZ)	GDE Atlas terminology identifying regions where similar processes are likely to determine the interaction between groundwater and ecosystems, due to similar ecology, geology, climate, and groundwater/surface water connections.
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. *Source:* Environmental Protection and Biodiversity Conservation Act 1999 (Cth).
ecological water requirement (EWR)	Descriptions of the water regimes needed to sustain the ecological values of water-dependent ecosystems at a low level of risk. Source: adapted from definition for Environmental Water Requirements in ARMCANZ & ANZECC 1996, National principles for the provision of water for ecosystems, Sustainable Land and Water Resources Management Committee Subcommittee on Water Resources Occasional Paper SWR No 3 July 1996 http://www.environment.gov.au/water/publications/environmental/ecosystems/pubs/water-provision.pdf.
electrical conductivity (EC)	Electrical conductivity (EC) measures dissolved salt in water. The standard EC unit is microSiemens per centimetre (µS/cm) at 25 °C. Source: National Water Commission Water Dictionary http://dictionary.nwc.gov.au/water_dictionary/pdf/WaterDictionary.pdf
evapotranspiration (ET)	The combined loss of water from a given area during a specified period of time by evaporation from the soil or water surface and by transpiration from plants. Source: Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) http://www.mincos.gov.au/__data/assets/pdf_file/0016/316123/wqg-apps.pdf.
Feature	This refers to the individual polygons (features) in the feature layer datasets. A 'feature' is an ecosystem mapped in these datasets.

Feature Layers	The fundamental spatial datasets which map all vegetation, rivers, wetlands and spring ecosystems. They provide the linework, or the polygons, which are the basis for the GDE mapping – that is, the GDE Atlas layers adopt these polygons. Therefore, complete national coverage of feature layers is required to achieve complete national coverage of GDE mapping. Where feature layers are absent, GDE mapping is therefore also absent. The feature layers are national datasets and datasets received from jurisdictions.
gaining stream	A stream where groundwater discharge contributes to stream flow. Source: Richardson, S., et al., (2011). Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf
GDE Potential	GDE Atlas terminology that describes ecosystems in terms of their 'potential to be interacting with groundwater'. The categories within 'GDE Potential' are high, moderate and low, described below. The language uses the word 'potential' to reflect the uncertainty inherent in assigning the term GDE to ecosystems using remote analysis methods, since anything more definite would have to be supported by finer scale studies, or fieldwork. The GDE potential classifications mapped within the Atlas are: ▪ High potential for groundwater interaction ▪ Moderate potential for groundwater interaction ▪ Low potential for groundwater interaction
GDE - High potential for groundwater interaction	GDE Atlas terminology which classifies ecosystems that are likely to be interacting with groundwater. Groundwater is likely to be present, and the ecosystem is likely to be using it. This category means that either the majority of data analysed indicated a high potential for groundwater interaction, or that the most reliable datasets (which therefore have the most influence on the result), indicates a high potential.
GDE - Moderate potential for groundwater interaction	GDE Atlas terminology which classifies ecosystems that may be interacting with groundwater. Groundwater is possibly present, and the ecosystem may be using it. Where data is conflicting (some data suggests that groundwater interaction is occurring, while other data suggests it is not), and it is weighted equally (both datasets are considered equally good indicators of groundwater interaction), this will be the resulting category assigned.
GDE - Low potential for groundwater interaction	GDE Atlas terminology which classifies ecosystems that are unlikely to be interacting with groundwater. Either groundwater is unlikely to be present, or if groundwater is present, the ecosystem is unlikely to be using it. This category means that either all datasets suggest groundwater interaction is unlikely, or the most heavily weighted (the most reliable) dataset suggests that groundwater interaction is unlikely.

GDEs identified in previous study, fieldwork	GDE Atlas terminology that describes GDEs within the Atlas that were identified through fieldwork. Since the result for these GDEs was not derived during the GDE Atlas analysis, no GDE potential result could be applied to these ecosystems. This also means no 'Lines of Evidence' attribute is necessary. However, it is considered that the identification of these ecosystems as GDEs is very reliable since fieldwork has demonstrated the interaction between ecosystem and groundwater.
GDEs identified in previous study, desktop	GDE Atlas terminology that describes GDEs within the Atlas that were identified through desktop analysis in previous studies. Since the result for these GDEs was not derived during the GDE Atlas analysis, no GDE potential result could be applied to these ecosystems. This also means no 'Lines of Evidence' attribute is necessary. However, it is considered that the identification of these ecosystems as GDEs is relatively reliable, since previous studies have usually focussed on smaller areas than the Atlas, and have been able to analyse the potential interaction between ecosystems and groundwater in more detail.
Groundwater	Groundwater is defined as: (a) water occurring naturally below ground level (whether in an aquifer or otherwise); or (b) water occurring at a place below ground that has been pumped, diverted or released to that place for the purpose of being stored there; but does not include water held in underground tanks, pipes or other works. Source: Water Act 2007. **Clarification for the GDE Atlas:** This definition includes the capillary zone, but water held within the soil above the capillary zone is not included. Water within caves that is sourced from groundwater is also included.
Groundwater Dependent Ecosystem (GDE)	Natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis, so as to maintain their communities of plants and animals, ecosystem processes and ecosystem services. Source: Richardson, S., et al., (2011). Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf
groundwater flow system	The total system which describes the movement of water in the subsurface from the point where it enters the ground to where it leaves. Source: Richardson, S., et al., (2011). Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf

GIS Analysis attribute	The specific attributes within the GIS Analysis datasets that are used to determine the potential for groundwater interaction to be occurring. For example, in the GIS Analysis dataset 'National Watercourses', in the attribute field 'Perenniality', the GIS Analysis attributes are 'perennial' and 'non-perennial'.
GIS Analysis dataset	The datasets used in the Task 5 methodology to apply each GIS analysis rule to the ecosystem features in each feature layer. Examples of GIS analysis datasets are depth to watertable mapping, aquifer and geology mapping, remote sensing. Section 4.5 describes how GIS Analysis datasets were used in the methodology.
GIS Analysis rule	The rules derived from literature that describe the processes that are likely to result in groundwater/ecology interaction. These rules are applied to each ecosystems feature using the GIS Analysis datasets. An example of a GIS Analysis rule is 'vegetation that occurs over shallow watertables is more likely to be using groundwater'. Section 1 gives more detail on GIS Analysis rules.
Inflow Dependence (ID)	GDE Atlas terminology used to describe landscapes within the GDE Atlas that are wetter than surrounding areas either seasonally or permanently, because they receive water from inflows in addition to rainfall. IDs include groundwater dependent ecosystems as well as ecosystems which use sources of water other than rainfall (e.g. Surface water, water stored in the unsaturated zone, irrigation). The layer that shows IDs is a derivative of the remote sensing layer, in which pixels that have ID likelihoods of between 6 and 10 only are included. The pixels are a combination of MODIS and Landsat data and are at a resolution of 25m.
ID Likelihood	GDE Atlas terminology to describe the likelihood that a landscape within the GDE Atlas is accessing a source of water in addition to rainfall (that it is Inflow Dependent), expressed in the ID layer as values between 6 (low) and 10 (high), where 10 indicates landscapes that are most likely to be accessing additional water sources. A likelihood value of 6 indicates landscapes that are marginally more likely to be accessing an additional source of water than they are to be relying solely on rainfall. Values of less than 6 represent landscapes that are more likely to rely solely on rainfall and are therefore not inflow dependent.
Inflow Dependent Ecosystem (IDE)	GDE Atlas terminology that describes ecosystems that are likely to be using another source of water in addition to rainfall. IDEs include groundwater dependent ecosystems as well as ecosystems which use sources of water other than rainfall (e.g. surface water, water stored in the unsaturated zone, irrigation). IDEs are effectively the ID pixels assigned onto a previously mapped ecosystem polygon. The pixel ID likelihood value was assigned to each ecosystem polygon using a majority rules approach. This means that the ID likelihood value which occurred most often within the ecosystem polygon, was the likelihood value assigned to the polygon overall.

karst	Terrain characterised by sinkholes, caves and springs, developed most commonly in carbonate rocks, where significant dissolution of the rock has occurred due to flowing water. Source: Jennings 1985; Culver et al. 1995; Fetter 2001 as referenced in M Tomlinson and A Boulton 2008, Subsurface groundwater dependent ecosystems: a review of biodiversity, ecological processes and ecosystem services, National Water Commission Waterlines Occasional Paper No. 8, October 2008 http://www.nwc.gov.au/resources/documents/Waterlines__subsurface_full_version.pdf
LandsatTM5	Landsat Thematic Mapper 5 – a medium resolution satellite image sensor obtained twice monthly over Australia. Data can be obtained from United States Geological Survey. Source: Engel, J., and Weinstein, O., (1983). The Thematic Mapper – an overview, IEEE Transactions On Geoscience and Remote Sensing, GE-21:258-265
Lines of Evidence	GDE Atlas terminology identifying the number of rules that could be applied to a polygon given the GIS data available for the analysis. The 'Lines of Evidence' result shows how much data the GDE potential result was based on, and therefore is a pragmatic indicator of the reliability of the GDE potential result. This is an attribute for each derived GDE polygon.
losing stream	A stream from which water is lost to the surrounding and underlying substrate via infiltration through the streambed and banks. Source: Richardson, S., et al., (2011). Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf
model, conceptual	Documentation of a conceptual understanding of the location of GDEs and interaction between ecosystems and groundwater. Source: Richardson, S., et al., (2011). Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf
MODIS	MODerate resolution Imaging Spectrometer – a sensor mounted on NASA's TERRA and AQUA satellites that orbits the Earth collecting data in visible and infrared wavelengths. The data used in this project was the MOD43B4 Nadir BRDF (NBAR) product disseminated by NASA and post-processed by CSIRO. Source: Paget, M.J. and King, E.A., (2008). MODIS Land data sets for the Australian region. CSIRO Marine and Atmospheric Research internal report 004, CSIRO Canberra, Australia, ISBN 978192142432(pdf).

MSSR	Mean Seasonal Storage Range – expresses the estimated mean seasonal range in the amount of water stored in all water stores (surface, soil and groundwater). A large range is likely to indicate a large use of water from storage during periods with low rainfall, for example through root water uptake from deeper soil or groundwater stores. Source: Van Dijk, A., Warren, G., Van Niel, T., Byrne, G., Pollock. D., Doody, T., (2011). Derivation of data layers from medium resolution remote sensing to support mapping of groundwater dependent ecosystems. CSIRO Land and Water, Internal Document for National Water Commission GDE Atlas.
Normalisation	The process used to translate attributes from GIS Anlaysis datasets into numbers that describe the relative likelihood of groundwater interaction of each attribute. More detail on normalisation is given in section 4.6.1.
OWL	Optical Water Likelihood –developed for quantifying temporal and spatial patterns of open water surfaces in Australia (Guerschman et al., 2008) and is produced by using reflectance observations from red, near infrared, blue and shortwave infrared MODIS spectral bands based on the relationship between enhanced vegetation index and global vegetation moisture index.
Palusplain	A seasonally waterlogged flat. Source: Semeniuk, A. and V. (1995). A geomorphic approach to global classification for inland wetlands. Vegetation 118:103-124
Permutation table	The output of the GIS analysis which shows all possible combinations of the GIS analysis attributes for each GIS Analysis dataset/rule. More information in section 4.5.
pH	Value that represents the acidity or alkalinity of an aqueous solution. It is defined as the negative logarithm of the hydrogen ion concentration of the solution. Source: Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) http://www.mincos.gov.au/__data/assets/pdf_file/0016/316123/wqg-apps.pdf
potentiometric surface	A surface representing the hydraulic head of ground water; represented by the watertable altitude in an unconfined aquifer or by the altitude to which water will rise in a properly constructed well in a confined aquifer. Source: USGS Definition of Terms http://pubs.usgs.gov/ha/ha747/pdf/definition.pdf
remote sensing	Any kind of data recording by a sensor which measures energy emitted or reflected by objects located at some distance from the sensor (i.e. no direct ground contact). Can include aerial photographs, airborne digital sensors and satellite imagery. Source: Richardson, S., et al., (2011). Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf

riparian	An area or zone within or along the banks of a stream or adjacent to a watercourse or wetland; relating to a riverbank and its environment, particularly to the vegetation. Source: eWater Toolkit Glossary http://www.toolkit.net.au/support/Glossary.aspx
salinity	The concentration of soluble salts in a solution, soil or other medium. Source: eWater Toolkit Glossary http://www.toolkit.net.au/support/Glossary.aspx
saturated zone	The part of the lithosphere where each void space in subsurface material is filled with water, or is saturated, under greater pressure than that of the atmosphere. Source: Poehls DJ and Smith GJ 2009, Encyclopedic dictionary of hydrogeology, Elsevier Inc., 517 pp.
stratification	The formation of layers in a water body, showing differences in temperature, turbidity, pH, nutrients, salinity, dissolved oxygen and light penetration at various depths; lack of mixing within a water storage. Source: eWater Toolkit Glossary http://www.toolkit.net.au/support/Glossary.aspx
stygofauna	Aquatic animals found in groundwater; sometimes used as a synonym of stygobite. Source: Tomlinson M and Boulton A 2008, Subsurface groundwater dependent ecosystems: a review of biodiversity, ecological processes and ecosystem services, National Water Commission Waterlines Occasional Paper No. 8, October 2008 http://www.nwc.gov.au/resources/documents/Waterlines__subsurface_full_version.pdf
Subterranean GDE (caves and aquifers)	A term used within the GDE Atlas to describe any water-dependent ecosystem occurring below the surface of the ground within fractured, porous or unconsolidated aquifers, and in caves in both the saturated and vadose zones. Source: Australian National Aquatic Ecosystem Classification, Subterranean Class – Background briefing note. Aquatic Ecosystems Task Group.
Sumpland	A seasonally inundated basin. Source: Semeniuk, A. and V. (1995). A geomorphic approach to global classification for inland wetlands. Vegetation 118:103-124
Surface GDEs that rely on the Subsurface presence of groundwater	A term used within the GDE Atlas to describe any GDE that accesses subsurface groundwater to meet all or some of its water requirements. This includes terrestrial vegetation, subsurface fauna communities (e.g. burrowing crayfish), and some vegetation which is associated with a surface water body. Source: Eamus, D., Froend, R., Loomes, R., Hose, G., Murray, B., (2006). A functional methodology for determining the groundwater regime needed to maintain the health of groundwater-dependent vegetation, Australian Journal of Botany, 2006, 54, 97–114, 2006.

Surface GDEs that rely on the Surface expression of groundwater	A term used within the GDE Atlas to describe any GDE which uses groundwater after it has been discharged to the surface. This includes all groundwater-fed surface water bodies, such as rivers, wetlands, lakes and springs. This definition refers only to the aquatic (inundated) component of a system, and therefore excludes any vegetation which may fringe a surface water body. Source: Eamus, D., Froend, R., Loomes, R., Hose, G., Murray, B., (2006). A functional methodology for determining the groundwater regime needed to maintain the health of groundwater-dependent vegetation, Australian Journal of Botany, 2006, 54, 97–114, 2006.
total dissolved solids (TDS)	A measure of the inorganic salts (and organic compounds) dissolved in water. Source: Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) http://www.mincos.gov.au/__data/assets/pdf_file/0016/316123/wqg-apps.pdf
transmissivity	The rate at which water moves through a unit width of aquifer or aquitard under a unit hydraulic gradient. It is the product of aquifer thickness and hydraulic conductivity. Source: Richardson, S., et al., (2011). Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf
transpiration	Evaporation loss of water from the leaves of plants through the stomata; the flow of water through plants from soil to atmosphere. Source: eWater Toolkit Glossary http://www.toolkit.net.au/support/Glossary.aspx
troglofauna	Terrestrial animals living in caves and other air-filled subterranean spaces. Source: Tomlinson M and Boulton A 2008, Subsurface Groundwater Dependent Ecosystems: a review of biodiversity, ecological processes and ecosystem services, National Water Commission Waterlines Occasional Paper No 8, October 2008 http://www.nwc.gov.au/resources/documents/Waterlines__subsurface_full_version.pdf
unsaturated zone	The areas below the ground where void spaces are filled with a mixture of water under pressure less than atmospheric which includes water held by capillarity and air (gases) under atmospheric pressure. Source: Poehls DJ and Smith GJ 2009, Encyclopedic dictionary of hydrogeology, Elsevier Inc., 517 pp.
vadose zone	See 'unsaturated zone'.
watertable	The top of the water surface in the saturated zone of an unconfined aquifer. Source: USGS Definition of Terms http://pubs.usgs.gov/ha/ha747/pdf/definition.pdf

Work package	GDE Atlas terminology to describe eight regions which cover Australia, where the broad rules which describe groundwater/ecosystem interaction are likely to be similar. These regions were used to implement the methodology for identifying and mapping GDEs in the development of the GDE Atlas.

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Appendix A Attribute Table

A.1 Attribute table

The attribute table was developed during the Proof of Concept task of the GDE Atlas project (Task 1), and lists attributes that describe the relevant characteristics of the 3 types of GDEs mapped in the Atlas (GDEs that rely on the subsurface presence of groundwater (vegetation); GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs); and Subterranean GDEs (caves and aquifers). Attributes are classified as:

- Tier 1 attributes which were derived from national datasets,
- Tier 2 attributes which were derived from remote sensing, and
- Tier 3 attributes which were derived from jurisdiction datasets.

Tier 3 attributes were fulfilled using existing literature or spatial datasets that contained information which could be appropriately entered into the Atlas attribute table. Relatively few Tier 3 attributes were fulfilled in the current version of the Atlas however the intention is to provide space so that when new information becomes available, it can be included in the attribute table.

The attribute table below shows each attribute that can be applied to the 3 different GDE types, and the options available to fulfil each attribute (where the attributes are not free text). These attributes were developed to be consistent with the ANAE framework for classifying wetlands (Auricht, 2010).

GENERIC ATTRIBUTE TABLE

TIER 1	GENERAL ECOSYSTEM SETTING		Confidence	Attribute	Confidence	Attribute	Confidence
Ecosystem Attributes	**Ecosystem type**	Derived from a standard list of 47 ecosystem types developed in the literature review		Derived from a standard list of 47 ecosystem types developed in the literature review		Derived from a standard list of 47 ecosystem types developed in the literature review	
	Supplied ecosystem type	Attribute source: Ecosystem descriptions contained in cave and aquifer feature layer datasets		Attribute source: Ecosystem descriptions contained in river, wetland, spring or waterhole feature layer datasets		Attribute source: Ecosystem descriptions contained in vegeation feature layer datasets	
	Name	Attribute source: Name details contained in cave and aquifer feature layer datasets		Attribute source: Name details contained in river, wetland, spring or waterhole feature layer datasets		Attribute source: Name details contained in vegeation feature layer datasets	
	State	Attribute source: Geodata V3 (Geoscience Australia)		Attribute source: Geodata V3 (Geoscience Australia)		Attribute source: Geodata V3 (Geoscience Australia)	
	EHZ	Attribute source: GDE Atlas basemap		Attribute source: GDE Atlas basemap		Attribute source: GDE Atlas basemap	
	Drainage Basin	Attribute source: Australian drainage divisions and river basins (BOM)		Attribute source: Australian drainage divisions and river basins (BOM)		Attribute source: Australian drainage divisions and river basins (BOM)	
	Occurrence on other ecosystem inventories	Not fulfilled		Attribute source: DIWA, Ramsar and EPBC listings	NA	Attribute source: EPBC listings	NA
	Ecosystem salinity	Attribute source: Cave and aquifer mapping with salinity attributes; details in literature. 1) < 1500 mg/L TDS 2) 1500 - 3000 mg/L TDS 3) 3000 - 35000 mg/L TDS 4) > 35000 mg/L TDS 5) Fluctuating 6) Stratified 7) Unknown 8) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: River, wetland, springs mapping with salinity attributes; details in literature. 1) < 1500 mg/L TDS 2) 1500 - 3000 mg/L TDS 3) 3000 - 35000 mg/L TDS 4) > 35000 mg/L TDS 5) Fluctuating 6) Stratified 7) Unknown 8) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	NA	NA
	Ecosystem salinity measurement period	Attribute source: Cave and aquifer mapping with salinity attributes; details in literature.		Attribute source: River, wetland, mapping with salinity attributes; details in literature.		Attribute source: Vegetation mapping with salinity attributes	
	Condition of ecosystem assessment	Not fulfilled	NA	Not fulfilled	NA	Not fulfilled	NA
	Water Regime	NA	NA	Attribute source: River, wetland, springs mapping with water regime attributes; details in literature. 1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent (flowing) 5) Permanent, near permanent (static) 6) Unknown 7) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	NA	NA
	Soil/Substrate	NA	NA	Attribute source: Not fulfilled 1) Organic 2) Mineral 3) Rock 4) Unknown 5) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	NA	NA
Climate Attributes	**Seasonal Rainfall Zone**	Attribute source: Australian climatic zones (BOM)		Attribute source: Australian climatic zones (BOM)		Attribute source: Australian climatic zones (BOM)	
	Length of dry season	Not fulfilled		Not fulfilled		Not fulfilled	
	Wettest 4 months	Not fulfilled		Not fulfilled		Not fulfilled	
	Aridity Index	Not fulfilled		Not fulfilled		Not fulfilled	
	Physiography	Attributed source: ASRIS PhysiographicRegions 2009		Attributed source: ASRIS PhysiographicRegions 2009		Attributed source: ASRIS PhysiographicRegions 2009	
	Landscape assessment, DEM analyses	Attribute source: FLAG dataset created for the GDE Atlas analysis 1) Plateau 2) Slope 3) Low lying		Attribute source: FLAG dataset created for the GDE Atlas analysis 1) Plateau 2) Slope 3) Low lying		Attribute source: FLAG dataset created for the GDE Atlas analysis 1) Plateau 2) Slope 3) Low lying	
	Average slope	Not fulfilled		Not fulfilled		Not fulfilled	

Landscape Attributes	**Bioregionalisation**	Attribute source: Subregions (IBRA Bioregions, DEH, 2005)		Attribute source: Subregions (IBRA Bioregions, DEH, 2005)		Attribute source: Subregions (IBRA Bioregions, DEH, 2005)	
	Broad hydrogeological setting / Groundwater Flow System	Attribute source: National Groundwater Flow System mapping (National Land and Water Resource Audit) 1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Nested		Attribute source: National Groundwater Flow System mapping (National Land and Water Resource Audit) 1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Nested		Attribute source: National Groundwater Flow System mapping (National Land and Water Resource Audit) 1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Nested	
	Groundwater Province	Attribute source: National Groundwater Province mapping (National Land and Watre Resource Audit)		Attribute source: National Groundwater Province mapping (National Land and Watre Resource Audit)		Attribute source: National Groundwater Province mapping (National Land and Watre Resource Audit)	
	Watertable aquifer	Attribute source: NGIS watertable aquifer mapping (BOM)		Attribute source: NGIS watertable aquifer mapping (BOM)		Attribute source: NGIS watertable aquifer mapping (BOM)	
	Broad landuse type	Attribute source: National Land Use mapping (BRS)		Attribute source: National Land Use mapping (BRS)		Attribute source: National Land Use mapping (BRS)	
	Water Management Areas	Attribute source: National Groundwater management unit mapping (BOM)		Attribute source: National Groundwater management unit mapping (BOM)		Attribute source: National Groundwater management unit mapping (BOM)	

TIER 2	INFLOW DEPENDENT ECOSYSTEMS (IDEs)						
	IDE	Attribute source: remote sensing data developed for the GDE Atlas.		Attribute source: remote sensing data developed for the GDE Atlas.		Attribute source: remote sensing data developed for the GDE Atlas.	

TIER 3	DESCRIPTION OF GROUNDWATER DEPENDENCE AND INTERACTION		Confidence	Attribute	Confidence	Attribute	Confidence
	GDE class	**Subterranean (caves and aquifers)**	NA	Derived from Eamus et al. (2006) GDE classes **Surface ecosystems dependent on surface expression of groundwater**	NA	Derived from Eamus et al. (2006) GDE classes **Surface ecosystems dependent on subsurface presence of groundwater**	NA
	Potential of ecosystem to be a GDE	Attribute source: literature and existing spatial datasets that indicate groundwater connection. 1) GDE identified in previous study (fieldwork) 2) GDE identified in previous study (desktop)	NA	Attribute source: literature and existing spatial datasets that indicate groundwater connection; analysis in Task 5 of GDE Atlas project. 1) GDE identified in previous study (fieldwork) 2) GDE identified in previous study (desktop) 3) High potential for groundwater interaction 4) Moderate potential for groundwater interaction 5) Low potential for groundwater interaction	NA	Attribute source: literature and existing spatial datasets that indicate groundwater connection; analysis in Task 5 of GDE Atlas project. 1) GDE identified in previous study (fieldwork) 2) GDE identified in previous study (desktop) 3) High potential for groundwater interaction 4) Moderate potential for groundwater interaction 5) Low potential for groundwater interaction	NA
Connectivity	**Spatial connectivity between GDE and groundwater**	Attribute source: literature and existing spatial datasets. 1) Connected, gaining (includes springs, terminal wetlands) 2) Connected, losing 3) Connected, variable gaining / losing (incl. flow through wetlands) 4) Disconnected, losing 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature and existing spatial datasets. 1) Connected, gaining (includes springs, terminal wetlands) 2) Connected, losing 3) Connected, variable gaining / losing (incl. flow through wetlands) 4) Disconnected, losing 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature and existing spatial datasets. 1) Connected, gaining (includes springs, terminal wetlands) 2) Connected, losing 3) Connected, variable gaining / losing (incl. flow through wetlands) 4) Disconnected, losing 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.
	Temporal nature of groundwater connectivity/use Derived from i) existing mapping where available ii) existing site-specific literature where available iii) extrapolation of GIS rule sets.	Attribute source: literature and existing spatial datasets 1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature and existing spatial datasets 1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature and existing spatial datasets 1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.
	Residence time Derived from previous studies	Attribute source: not fulfilled 1) Short 2) Long 3) Unknown 4) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	NA	NA	NA	NA
	Saturation regime Derived from previous studies	Attribute source: not fulfilled 1) Permanent 2) Intermittent 3) Ephemeral 4) Unsaturated 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	NA	NA	NA	NA
	Source Aquifer Confinement	Attribute source: literature 1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature 1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature 1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.

Groundwater Source	**Source Aquifer name**	Attribute source: literature	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.
	Broad geology type of source aquifer	Attribute source: literature 1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	NA	Attribute source: literature 1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	NA	Attribute source: literature 1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	NA
	Porosity of source aquifer	Attribute source: literature 1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	NA	Attribute source: literature 1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	NA	Attribute source: literature 1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	NA
	Groundwater Flow System of source aquifer	Attribute source: literature and national Groundwater Flow System mapping (National Land and Water Resource Audit) 1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched	NA	Attribute source: literature and national Groundwater Flow System mapping (National Land and Water Resource Audit) 1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched	NA	Attribute source: literature and national Groundwater Flow System mapping (National Land and Water Resource Audit) 1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched	NA
	Salinity of Groundwater Source	Attribute source: literature and aquifer mapping with salinity attributes 1) < 1500 mg/L TDS 2) 1500 - 3000 mg/L TDS 3) 3000 - 35000 mg/L TDS 4) > 35000 mg/L TDS 5) Fluctuating 6) Stratified 7) Unknown 8) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature and aquifer mapping with salinity attributes 1) < 1500 mg/L TDS 2) 1500 - 3000 mg/L TDS 3) 3000 - 35000 mg/L TDS 4) > 35000 mg/L TDS 5) Fluctuating 6) Stratified 7) Unknown 8) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature and aquifer mapping with salinity attributes 1) < 1500 mg/L TDS 2) 1500 - 3000 mg/L TDS 3) 3000 - 35000 mg/L TDS 4) > 35000 mg/L TDS 5) Fluctuating 6) Stratified 7) Unknown 8) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.
	Groundwater source salinity measurement date	Attribute source: literature and aquifer mapping with salinity attributes and measurement dates		Attribute source: literature and aquifer mapping with salinity attributes and measurement dates		Attribute source: literature and aquifer mapping with salinity attributes and measurement dates	
	Ph of Groundwater Source	Attribute source: literature or aquifer mapping with pH attributes 1) <6 2) 6 - 8 3) >8 4) Fluctuating 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature or aquifer mapping with pH attributes 1) <6 2) 6 - 8 3) >8 4) Fluctuating 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature or aquifer mapping with pH attributes 1) <6 2) 6 - 8 3) >8 4) Fluctuating 5) Unknown 6) No data	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.
	Groundwater source pH measurement date	Attribute source: literature and aquifer mapping with pH attributes and measurement dates		Attribute source: literature and aquifer mapping with pH attributes and measurement dates		Attribute source: literature and aquifer mapping with pH attributes and measurement dates	
	Dominant recharge process of groundwater source	Attribute source: literature 1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature 1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature 1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.
	Hydrogeological capture zone#	Attribute source: literature 1) Free text 2) No data	NA	Attribute source: literature 1) Free text 2) No data	NA	Attribute source: literature 1) Free text 2) No data	NA

Nature of groundwater dependency	**Relative requirement of groundwater vs. other source (overall)**	NA	NA	Attribute source: literature 1) Dominant groundwater (>70%) 2) Both surface water and groundwater 3) Dominant surface water (>70%) 4) No data 5) Unknown	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature 1) Dominant groundwater (> 70%) 2) Groundwater and other source 3) Dominant other water source (>70%) 4) No data 5) Unknown	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.
	Critical groundwater service	Attribute source: literature 1) Habitat	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature 1) Water source (when surface flows cease) 2) Habitat 3) Artesian pressure 4) Thermal water supply 5) No data 6) Other (Physical integrity) 7) Water quality	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.	Attribute source: literature 1) Water availability (water capacity above wilting) 2) Water capacity provides reduced salt concentrations to below osmotic limit 3) Dry period water supply 4) No data 5) Other (Physical integrity) 6) Water quality	H - site-specific literature, field validation. M - derived, extrapolation from site-specific literature. L - derived, extrapolation using general GW logic.
	Example Indicative species	Attribute source: literature and existing spatial datasets containing species information 1) Free text 2) No data	NA	Attribute source: literature and existing spatial datasets containing species information 1) Free text 2) No data	NA	Attribute source: literature and existing spatial datasets containing species information 1) Free text 2) No data	NA
	Environmental Groundwater Requirement	Attribute source: literature 1) Free text 2) No data	NA	Attribute source: literature 1) Free text 2) No data	NA	Attribute source: literature 1) Free text 2) No data	NA
	Additional information on dependency/ resilience/ sensitivity	Attribute source: literature 1) Free text 2) No data	NA	Attribute source: literature 1) Free text 2) No data	NA	Attribute source: literature 1) Free text 2) No data	NA

Appendix B GDEs identified in previous studies

B.1 GDEs identified in previous studies

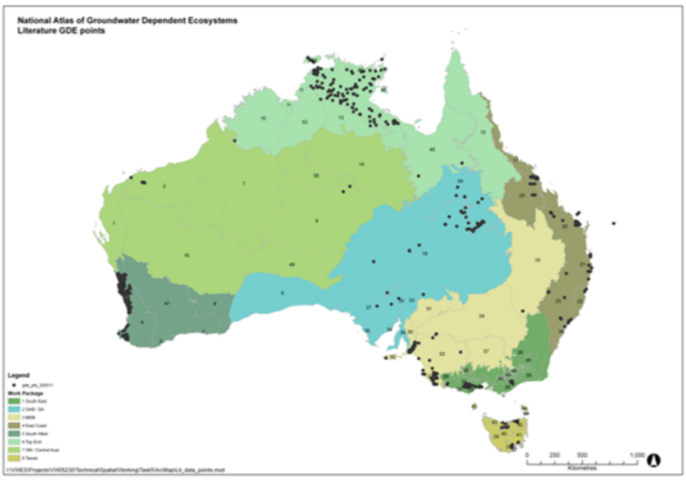
GDEs identified in previous studies were collated from two sources:

- From literature that identifies ecosystems as GDEs, and
- From existing spatial datasets that map GDEs.

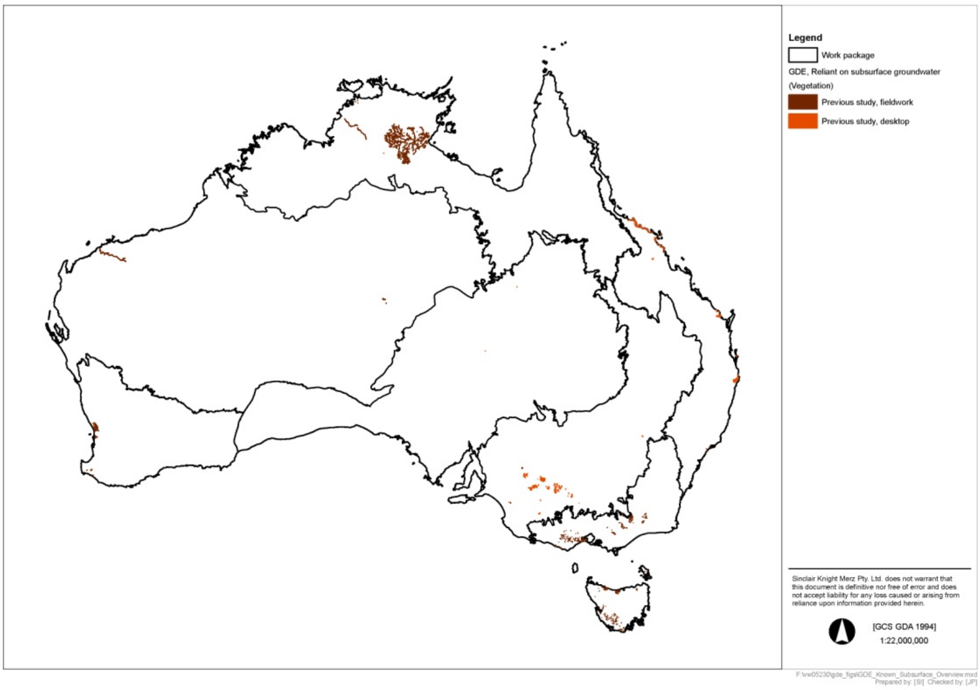
GDEs identified in literature were initially mapped as points on a spatial interface (Figure 1). Towards the end of the project (in Task 5), the points were matched with the ecosystem polygon (i.e. the river, wetland or vegetation) they represented. Likewise, GDE polygons that were identified in existing spatial datasets were matched with the appropriate ecosystem polygon in the GDE Atlas feature layers. Figure 2 and Figure 3 show the GDEs which were identified in either literature or existing spatial datasets. These are mapped in the GDE Atlas as 'GDEs identified in previous studies'.

The feature layer polygons that had been matched with either points from the literature review, or GDEs mapped in an existing spatial dataset were classified and mapped as:

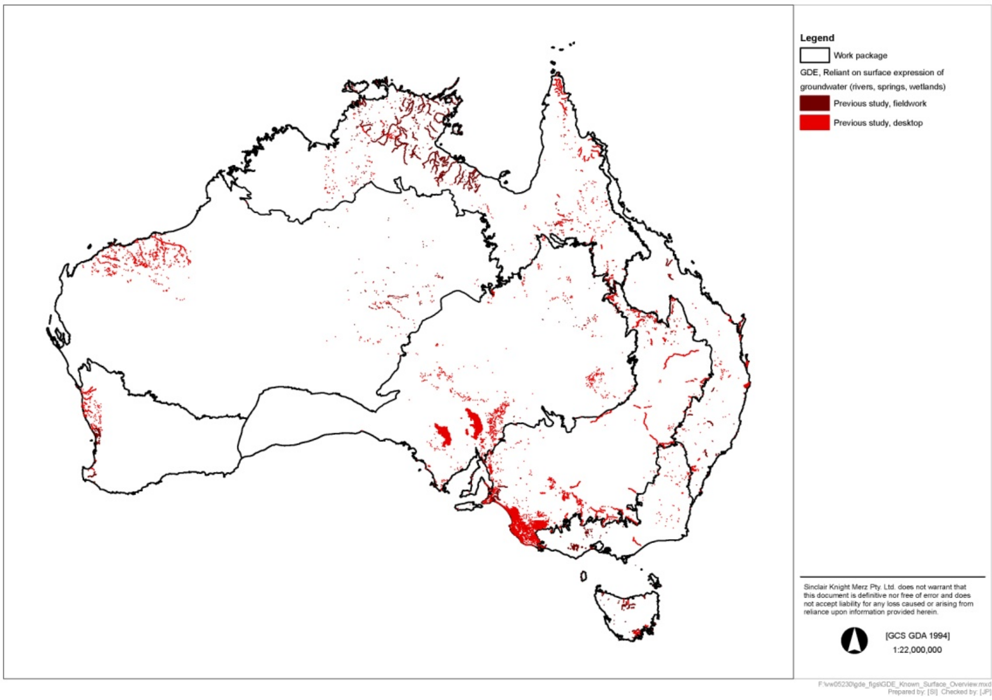
- GDEs identified in previous study: fieldwork
- GDEs identified in previous study: desktop



- **Figure 1 Points showing ecosystems where a groundwater connection was reported in the literature**



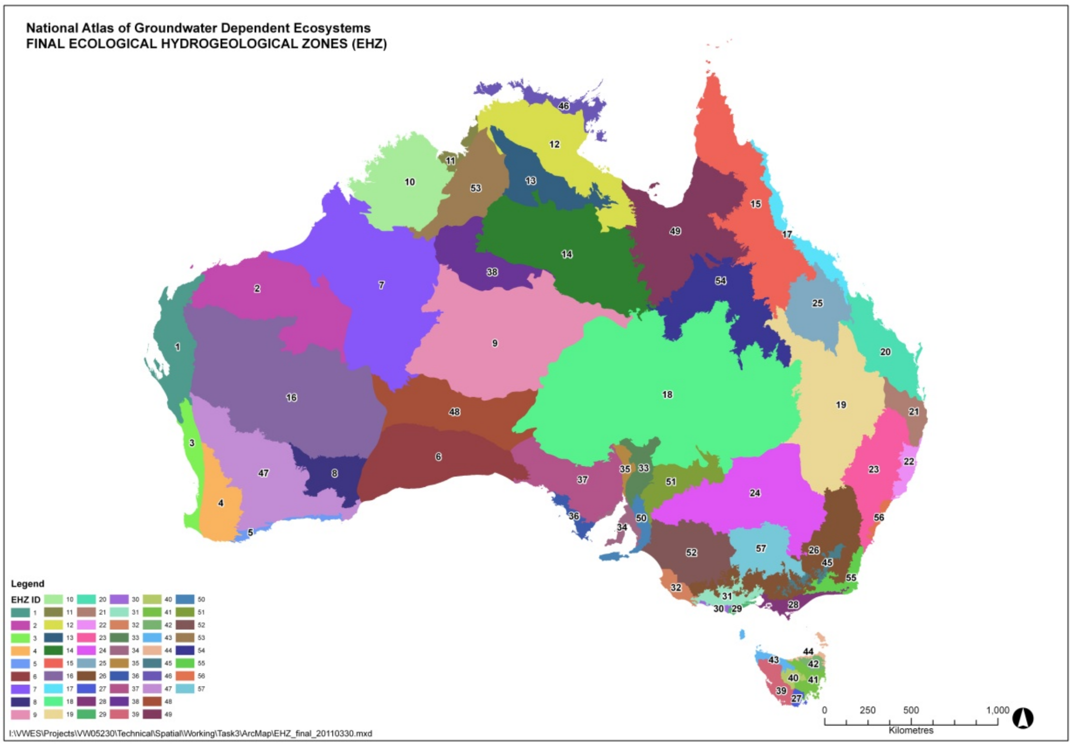
- **Figure 2 GDEs identified in previous studies for GDEs that rely on the subsurface presence of groundwater (vegetation)**



- **Figure 3 GDEs identified in previous studies for GDEs that rely on the surface expression of groundwater (rivers, wetlands, springs)**

Appendix C Task 3 Outputs

C.1 C.1 EHZs



C.2 C.2 Basemap Technical Paper

Technical Paper– Task 3.8

Date 1 April 2011

Project No VW05320

Subject **EHZ Explanatory Paper**

1. Introduction

This document provides background to the development of the Basemap for the GDE Atlas project. Selected Basemap layers will form the backdrop to the final on-line version of the GDE Atlas. The datasets that may be utilised to create the Basemap have been identified and reported in an earlier document. This has been reviewed by jurisdictions and feedback has been incorporated into the Basemap.

A primary component of the Basemap development task (Task 3 in the project schedule) is the development of Ecological – Hydrogeological Zones (EHZs). This document describes the inputs and methodology used to create the EHZs, and outlines the process of review by the jurisdictions and finalisation of the data set.

2. Background

The purpose of EHZs is to delineate regions with similar ecology, geology, climate, groundwater/surface water connections and expected type and behaviour of GDEs. The theory behind this approach is that similar processes will determine the interaction between groundwater and ecology within these zones, and these processes can be analysed using GIS analysis rules to identify the presence of GDEs. These analysis rules will be based on existing information which describes how known GDEs function within a particular EHZ (i.e. the outcomes of previous GDE studies) or on basic logic of how groundwater would be expected to interact with ecology in each EHZ. As such the assumptions and the rules used to identify GDEs of a particular type will apply across an EHZ. The approach of using EHZs provides a logical break down for the GIS analysis based on landscape features.

In addition, the selection of suitable Landsat imagery and remote sensing analysis will be applied across a particular EHZ, with the scene selection and methodologies varying between EHZs.

Therefore, the purpose of the EHZs for the GDE Atlas project is to:

- Break Australia up into zones to manage the workflow for remote sensing and analysis (Tasks 4 and 5 of the Atlas).
- Define regions where similar remote sensing and GIS analyses can be applied based upon the expected GDE types and ecology.

- Provide practical regions for the display of high level information within the web base Atlas system.

It is important to note that the same rules or analyses may be applied to more than one EHZ. In addition, as the EHZs are developed for a national scale, they cannot capture small unique areas however, analysis approaches will be developed that can be applied within EHZs to account for these areas (depending on available supporting data).

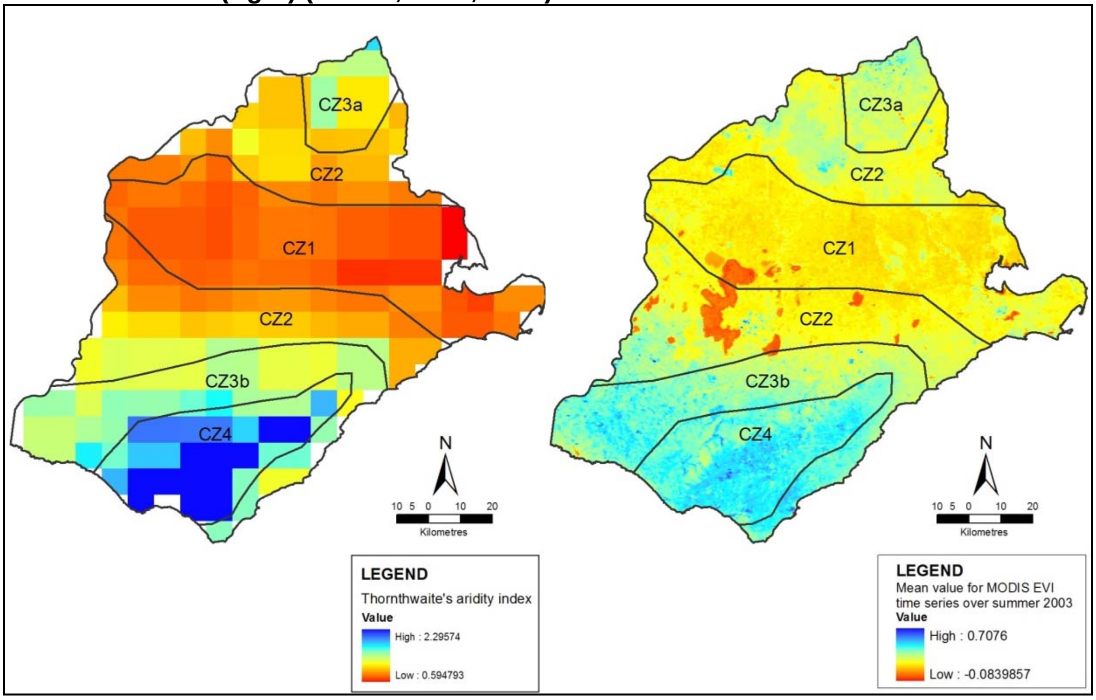
The EHZ primary function is to assist in data analyses and to act as spatial communication tool. The zones are not intended to provide delineation of surface or groundwater management zones or replace existing national data sets. It is expected however, that the information within the zones (i.e. the processes which have been described by the GIS rule sets) will prove useful when considering GDEs within management plans.

An example of a regionalisation based on a similar approach to the EHZs is given below. This example illustrates that the spectral response of vegetation is closely related to climate, geology and geomorphology. The example demonstrates that the data sets which are being used to define the EHZs will also have the effect of grouping areas where vegetation responds to seasonal and actual rainfall and climate events in similar ways. This justifies the use of the rule sets to be applied across an EHZ to identify interaction between groundwater and ecology (GDEs) within that EHZ.

2.1 Example of regionalisation

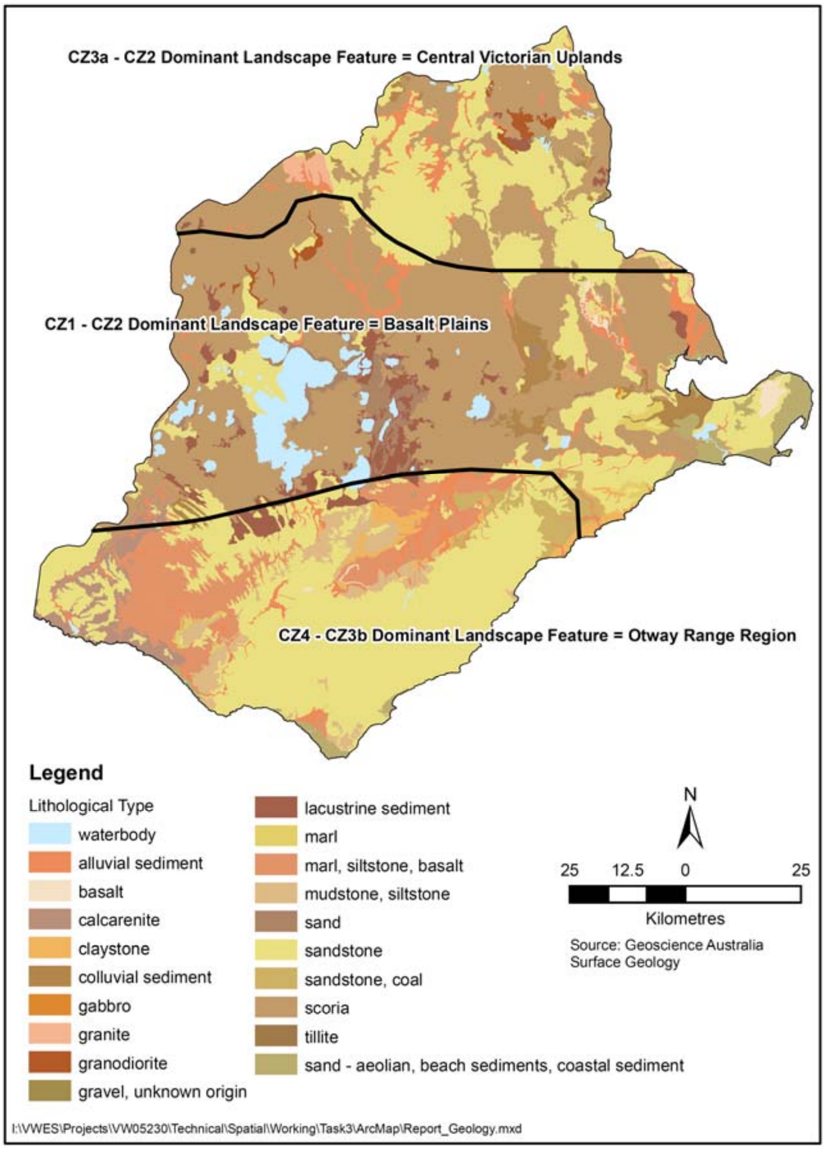
The climate (amount of and timing of precipitation) has a large impact on vegetation communities within terrestrial and wetland settings. Dresel et. al, 2010, provide an example application of how zones have been developed to assist in remote sensing analyses and mapping of potential GDEs. Dresel et al 2010 stratified the Victorian landscape into climate zones (Figure 1) base upon Thornthwaite's aridity index (Thornthwaite, 1948). It is evident by the 2003 summer mean EVI MODIS imagery (Figure 1), that the different aridity zones contain vegetation and landscapes that have different spectral responses.

- **Figure 1 Climate zones for the Corangamite CMA region derived from aridity indices (left) and comparing the climate zones to the MODIS EVI time series data for summer 2003 (right) (Dresel, et. al, 2010).**



In this example the different zones relate to different geomorphological and geological landscapes (Figure 2). Zones CZ3b, CZ4 contain the higher rainfall Otway Ranges, Zones CZ1 and CZ2 contain the dryer basalt plains, and zones CZ3a and CZ2 contain the central Victorian Palaeozoic uplands. As the different spectral responses coincide with the different geological and geomorphological landscapes, this example demonstrates how landscape regionalisation can be used to characterise, and establish rules for vegetation responses.

- **Figure 2 Geology of the Corangamite CMA**



3. Data sets used to create EHZs

The data sets which will comprise the Basemap have been identified and reported in an earlier document ('Technical Paper: Task 2.2 Data Collation for Basemap', attached in Appendix B for reference). It is anticipated that a selection of the Basemap datasets will be available to view in the final on-line version of the Atlas. Relevant Basemap data sets are also available to view in the on-line portal which accompanies this document, but are not discussed further here as they are not the subject of the required review.

The data sets specifically used to define the EHZ boundaries are:

- Bioregions (source: Geoscience Australia): brings climate as well as ecology into the EHZs;

- Hydro-ecological Zones (HEZs) (source: Pusey et al. 2009) : eco-hydrology zonation which brings in hydrological characterisation;
- Groundwater flow systems (source: BRS) : Delineates regional, local, intermediate flow systems;
- Groundwater provinces (source: Geoscience Australia): defines hydrogeological extents such as the Great Artesian Basin (GAB), Murray Darling Basin, etc.
- Water Table Aquifer map (source Bureau of Meteorology, Interim groundwater data sets): identifies water table aquifers across Australia.

These data sets were chosen to define the EHZs as they have national coverage and, when combined, reflect key hydro-ecological processes at this scale. The advantage of using existing information is to build upon the knowledge collated in deriving the data sets, and where possible maintain consistency with other national spatial data sets. Maps of these layers are provided in Appendix A.

4. Methodology

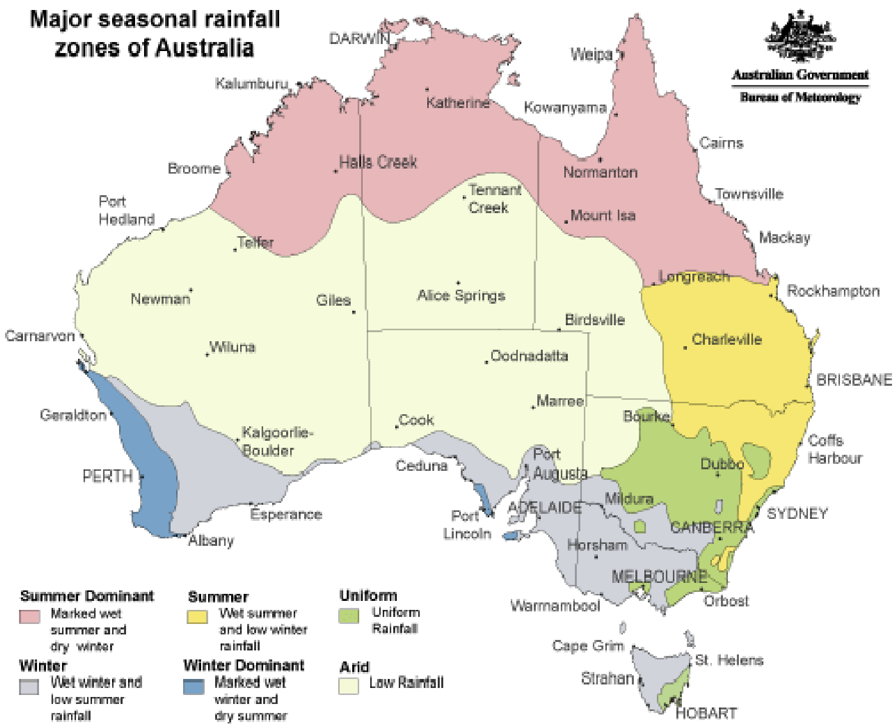
The master EHZ data set was derived by intersecting the following data sets:

- Biogregions, attributed with the majority eco-grouping of rivers derived from Pusey et al. 2009;
- Groundwater provinces.

Additional data sets that were used in aggregating areas defined by bioregions and groundwater provinces into EHZs included:

- Surface geology;
- Watertable Aquifer;
- Climate data – a number of rainfall zone maps were identified during this task including maps that delineate the winter / summer rainfall zones. The map ultimately used as a reference includes the arid zone (see **Error! Reference source not found.**).

- **Figure 3 Climate regions of Australia (source: Bureau of Meteorology)**



It was decided that in the development of the EHZs no new line work would be developed, such that the boundary of each EHZ was obtained from an existing input data set. In doing this, the reasoning for boundaries is transparent, and the end user will be able identify the source spatial data sets within the final EHZ layer.

The use of groundwater by terrestrial vegetation is largely controlled by the availability of soil water and rainfall patterns. Therefore, one of the controlling layers in developing EHZs is climate zones. The Bioregions incorporate the changes in the landscape climate and topography and along with eco-groupings of rivers and when combined with groundwater provinces, create a logical base map for the development of EHZs. The groundwater flow systems and Watertable Aquifer data sets were used as references for decision making to ensure similar hydrogeological units are captured within zones. The final boundaries between different EHZs therefore follow either Bioregion or Groundwater Province boundaries. The exceptions are EHZ #1 and EHZ #7 where unique boundaries have been captured to encapsulate unique geology along the coast of Western Australia.

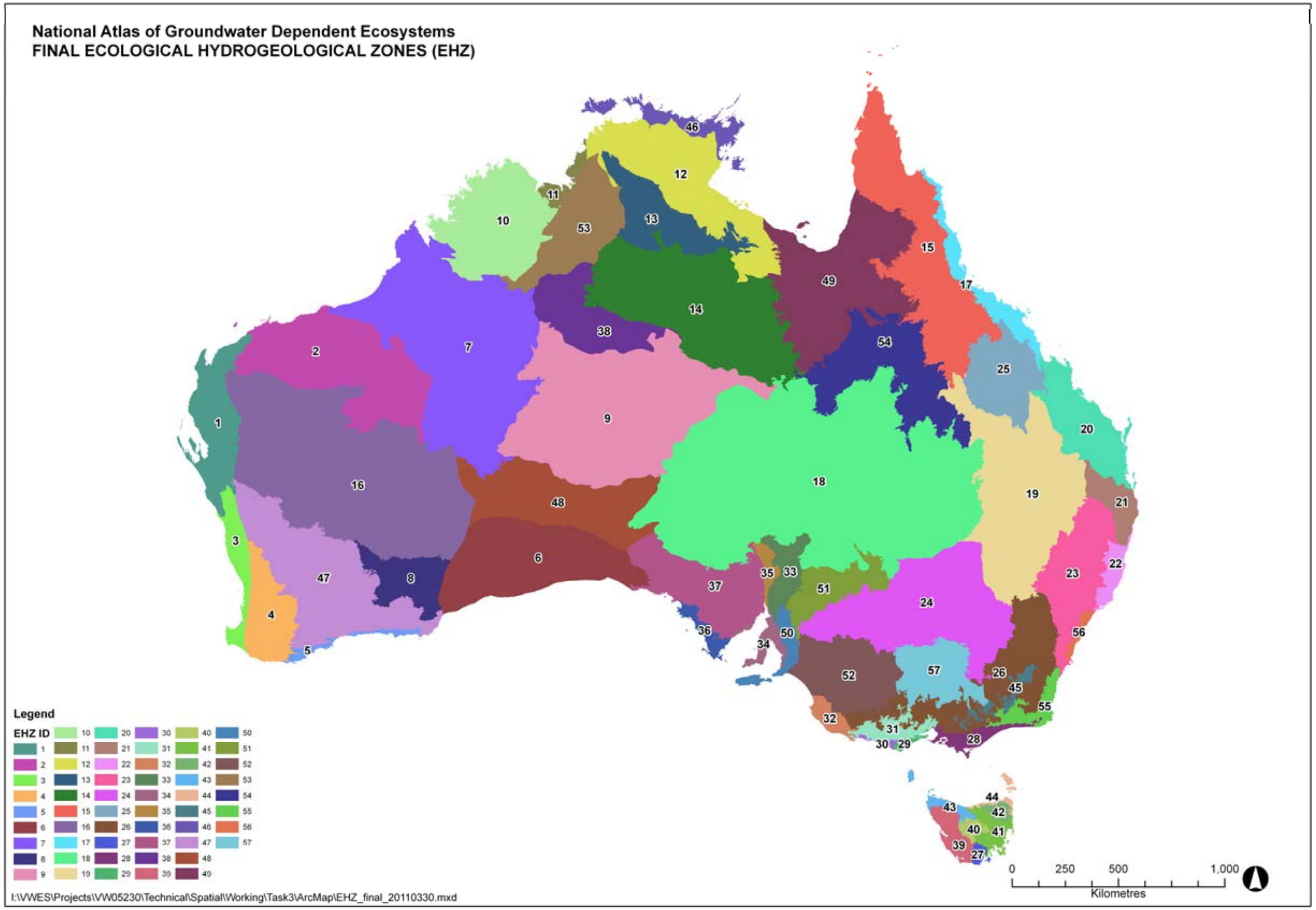
Following the initial delineation, a review of zones against the climate data – specifically the summer / winter and arid rainfall zones was undertaken. This resulted in the splitting of a

number of EHZs along bioregional boundaries which most closely aligned to the rainfall zones.

A draft version of the EHZs were provided to the jurisdictions on 15 February 2011 and detailed comments were received. Appendix B lists the comments and revisions undertaken. Following this step, jurisdictions were able to undertake a final review during which one comment was received and addressed (relating to the border between EHZ # 19 and EHZ #20).

A total of 57 EHZs have been defined in the final EHZ data set which is slightly more than the 40 estimated. The smallest EHZ is 2,586 sq kilometres representing the south west coastal region of Victoria (EHZ # 30). Islands less than 10 square kilometres have been removed and those remaining have been grouped to the nearest mainland EHZ (except for Tasmania). Figure 4 below provides the map of the EHZs and Table 1 provides a list of each EHZ with the predominant Bioregion, Sub region, dominant rainfall, and predominant groundwater province.

- **Figure 4 Final EHZs for the GDE Atlas Basemap**



■ **Table 2. List of EHZs with predominant rainfall zone, bioregions and groundwater provinces**

EHZ_ID	Rainfall	Bioregion	Subregion	Groundwater Province
1	Low rainfall	Carnarvon	Wooramel	Carnarvon
2	Low rainfall	Pilbara	Chichester	Hamersley
3	Marked wet winter and dry summer	Swan Coastal Plain	Perth	Perth
4	Marked wet winter and dry summer	Avon Wheatbelt	Avon Wheatbelt P2	Yilgarn-Southwest
5	Wet winter and low summer rainfall	Esperance Plains	Recherche	Bremer 2
6	Low rainfall	Nullarbor	Central band, Nullabor Plain	Eucla
7	Low rainfall	Gibson Desert	Lateritic Plain	Canning
8	Low rainfall	Coolgardie	Eastern Goldfield	Yilgarn-Gold Fields
9	Low rainfall	Great Sandy Desert	Mackay	Amadeus
10	Very wet summer & dry winter	Northern Kimberley	Mitchell	Kimberley
11	Very wet summer & dry winter	Victoria Bonaparte	Victoria Bonaparte P1	Bonaparte
12	Very wet summer & dry winter	Gulf Fall and Uplands	McArthur - South Nicholson Basins	Mcarthur
13	Very wet summer & dry winter	Sturt Plateau	Sturt Plateau P2	Daly River
14	Low rainfall	Mitchell Grass Downs	Barkly Tableland	Georgina
15	Very wet summer & dry winter	Einasleigh Uplands	Broken River	Tasman
16	Low rainfall	Murchison	Eastern Murchison	Yilgarn-Gold Fields
17	Very wet summer & dry winter	Brigalow Belt North	Bogie River Hills	Tasman
18	Low rainfall	Simpson Strzelecki Dunefields	Simpson Desert	Great Artesian
19	Wet summer and low winter rainfall	Darling Riverine Plains	Castlereagh-Barwon	Great Artesian
20	Wet summer and low winter rainfall	Brigalow Belt South	Banana - Auburn Ranges	Tasman
21	Wet summer and low winter rainfall	Brigalow Belt South	Eastern Darling Downs	Clarence-Morton
22	Wet summer and low winter rainfall	NSW North Coast	Macleay Hastings	New England
23	Wet summer and low winter rainfall	Nandewar	Peel	New England
24	Uniform rainfall	Murray Darling Depression	South Olary Plain, Murray Basin Sands	Lachlan

EHZ_ID	Rainfall	Bioregion	Subregion	Groundwater Province
25	Wet summer and low winter rainfall	Brigalow Belt North	Isaac - Comet Downs	Tasman
26	Wet winter and low summer rainfall	NSW South Western Slopes	Northern Inland Slopes, Upper Slopes	Lachlan
27	Uniform rainfall	Tasmanian Southern Ranges	Southern Ranges	Tasmania 2
28	Wet winter and low summer rainfall	South East Coastal Plain	Gippsland Plain	Gippsland
29	Wet winter and low summer rainfall	South East Coastal Plain	Otway Plain	Otway Highlands
30	Wet winter and low summer rainfall	South East Coastal Plain	Warrnambool Plain	Otways
31	Wet winter and low summer rainfall	Victorian Volcanic Plain	Victorian Volcanic Plain	Otways
32	Wet winter and low summer rainfall	Naracoorte Coastal Plain	Lucindale	Otways
33	Low rainfall	Flinders Lofty Block	Southern Flinders	Adelaide Geosyncline
34	Wet winter and low summer rainfall	Eyre Yorke Block	St Vincent	Gawler
35	Low rainfall	Gawler	Gawler Lakes	Pirie-Torrens
36	Wet winter and low summer rainfall	Eyre Yorke Block	Talia	Eyre Pennisula
37	Low rainfall	Great Victoria Desert	Yellabinna	Gawler
38	Low rainfall	Tanami	Tanami P1	Tanami
39	Wet winter and low summer rainfall	Tasmanian West	West	Tasmania 1
40	Wet winter and low summer rainfall	Tasmanian Central Highlands	Central Highlands	Tasmania 2
41	Uniform rainfall	Tasmanian South East	South East	Tasmania 2
42	Wet winter and low summer rainfall	Ben Lomond	Ben Lomond	Tasmania 3
43	Wet winter and low summer rainfall	Tasmanian Northern Slopes	Northern Slopes	Tasmania 1
44	Wet winter and low summer rainfall	Flinders	Flinders	Tasmania 3
45	Uniform rainfall	Australian Alps	Victorian Alps	Lachlan
46	Very wet summer & dry winter	Arnhem Coast	Arnhem Coast P2	Mcarthur
47	Wet winter and low summer rainfall	Avon Wheatbelt	Avon Wheatbelt P1	Yilgarn-Southwest
48	Low rainfall	Great Victoria Desert	Eastern, Maralinga	Officer
49	Very wet summer & dry winter	Gulf Plains	Mitchell - Gilbert Fans	Great Artesian
50	Wet winter and low summer rainfall	Flinders Lofty Block	Broughton	Adelaide Geosyncline

EHZ_ID	Rainfall	Bioregion	Subregion	Groundwater Province
51	Low rainfall	Broken Hill Complex	Barrier Range	Adelaide Geosyncline
52	Wet winter and low summer rainfall	Murray Darling Depression	Murray Mallee	Murray
53	Very wet summer & dry winter	Ord Victoria Plain	South Kimberley Interzone	Ord-Victoria
54	Very wet summer & dry winter	Mitchell Grass Downs	Central Downs	Great Artesian
55	Uniform rainfall	South East Corner	South East Coastal Ranges	Lachlan
56	Uniform rainfall	Sydney Basin	Wyong	Sydney
57	Wet winter and low summer rainfall	Riverina	Murrumbidgee	Murray

5. References

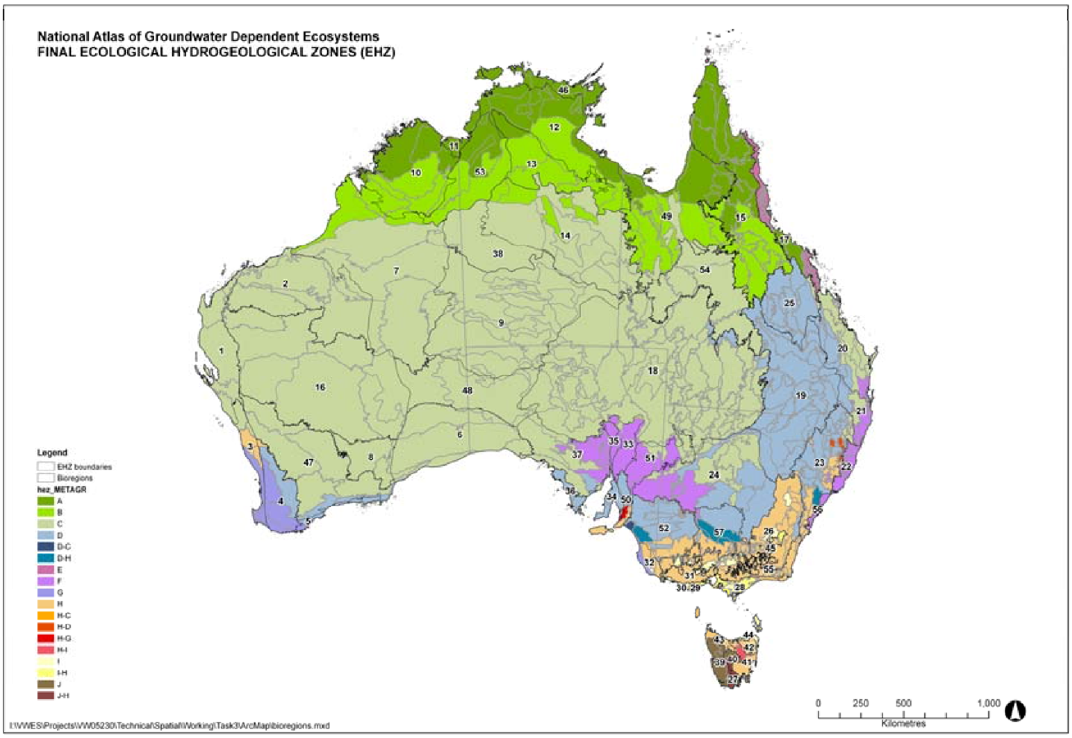
Dresel, P. E., Clark, R. Cheng, X., Reid, M., Fawcett, J., and Cochraine, D. (2010) Mapping Terrestrial Groundwater Dependent Ecosystems: Method Development and Example Output. Victoria Department of Primary Industries, Melbourne VIC. 66 pp.

Pusey, B., Kennard, M., Hutchinson, M., Sheldon, F., Stein, J., Olden, J. And McKay, S. (2009). Ecohydrological regionalisation of Australia : A tool for management and science. Technical Report. Land & Water Australia, Canberra.

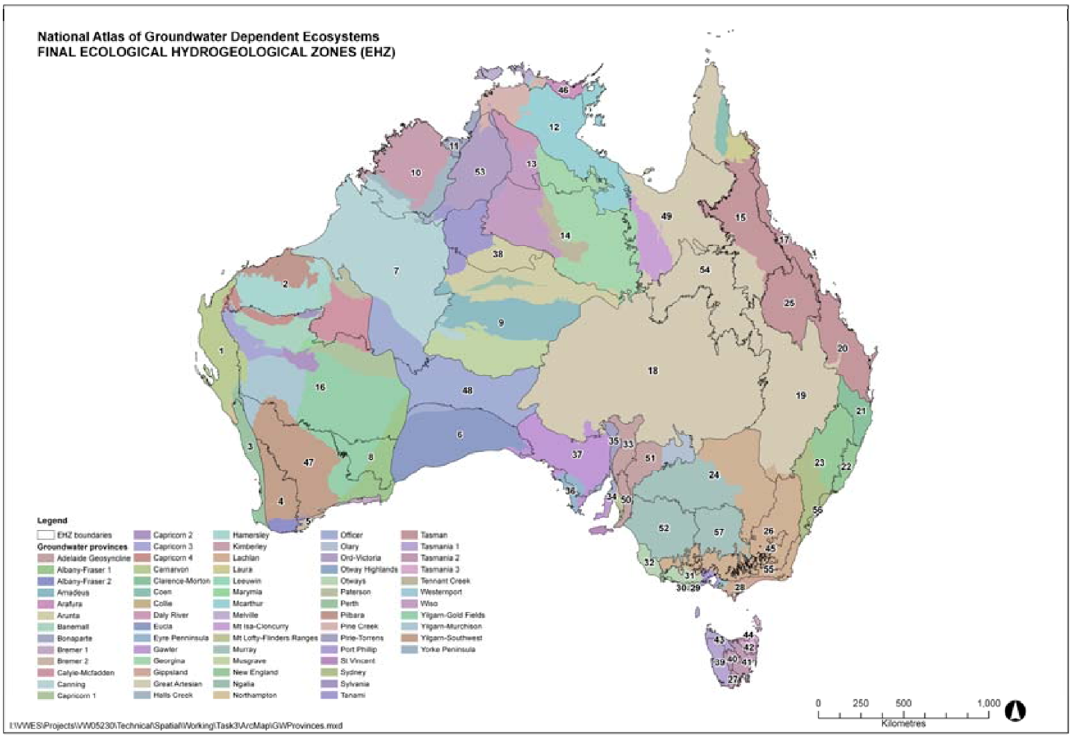
Thornthwaite, C. W. (1948) An Approach toward a Rational Classification of Climate. Geographical Review 38, 55-94.

Appendix A : Input data sets

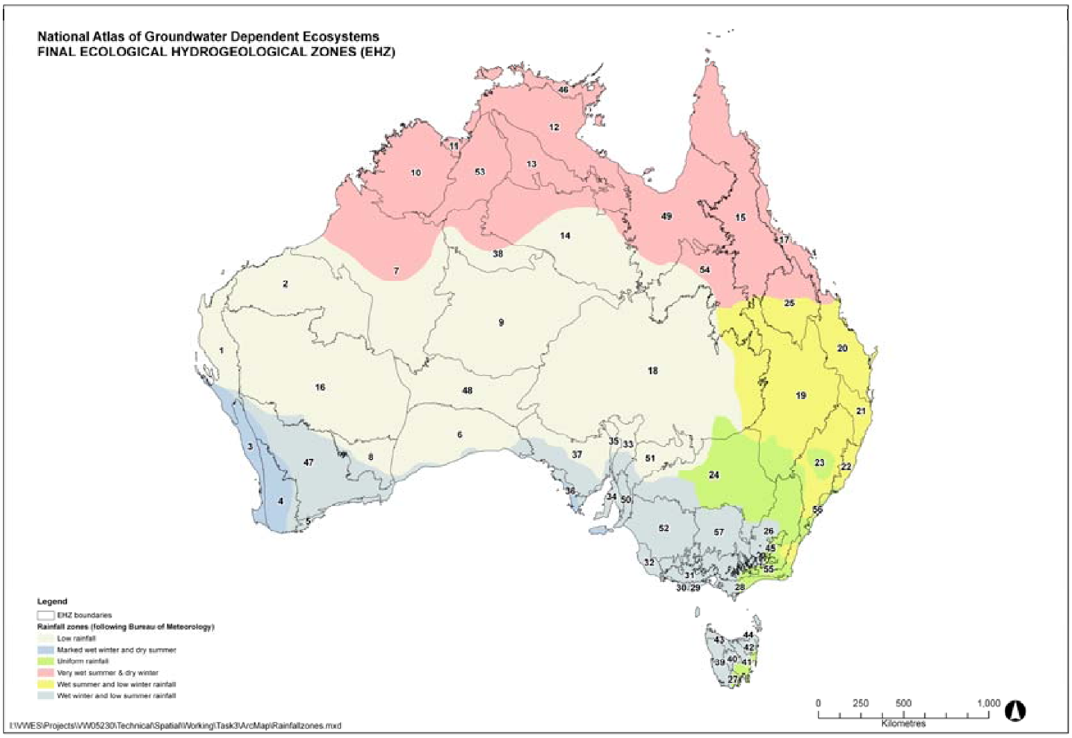
- **Figure A.1 Bioregions and HEZ groups**



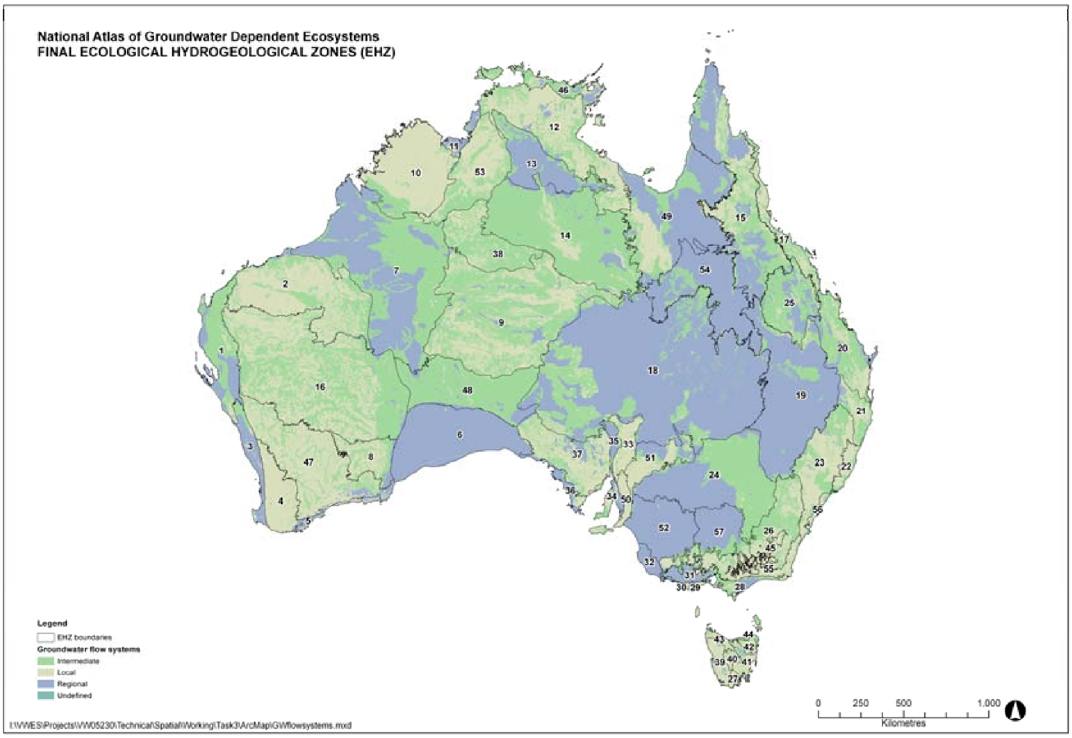
- **Figure A.2 Groundwater provinces**



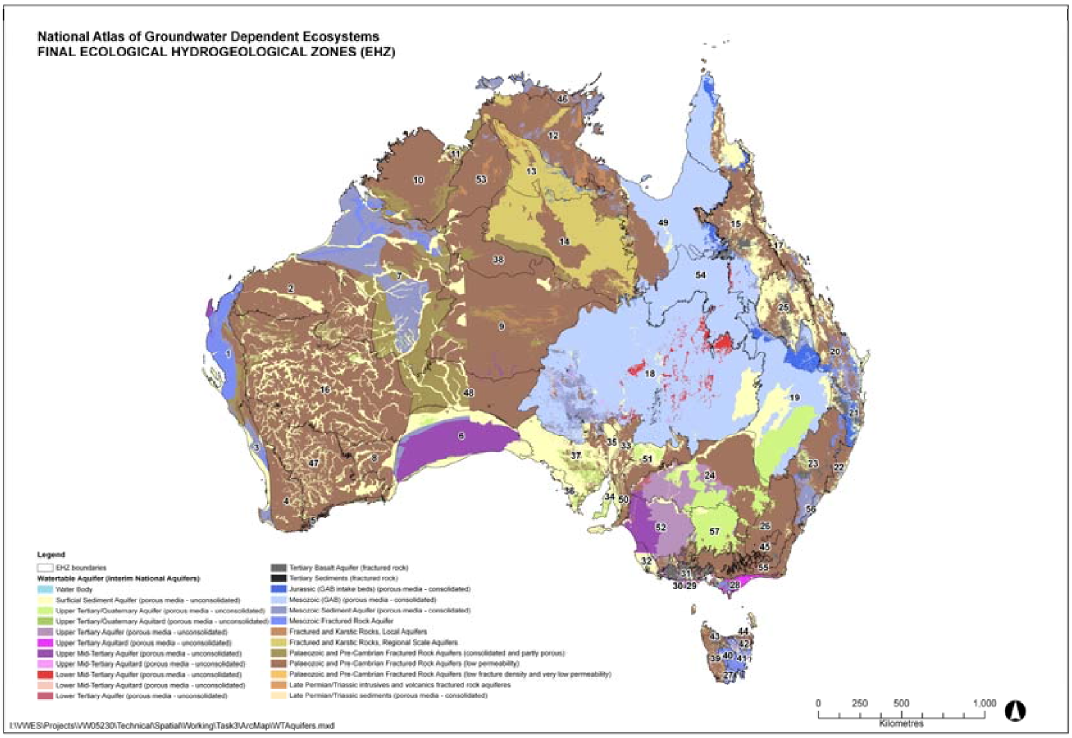
- **Figure A.3 Rainfall zones (following Bureau of Meteorology)**



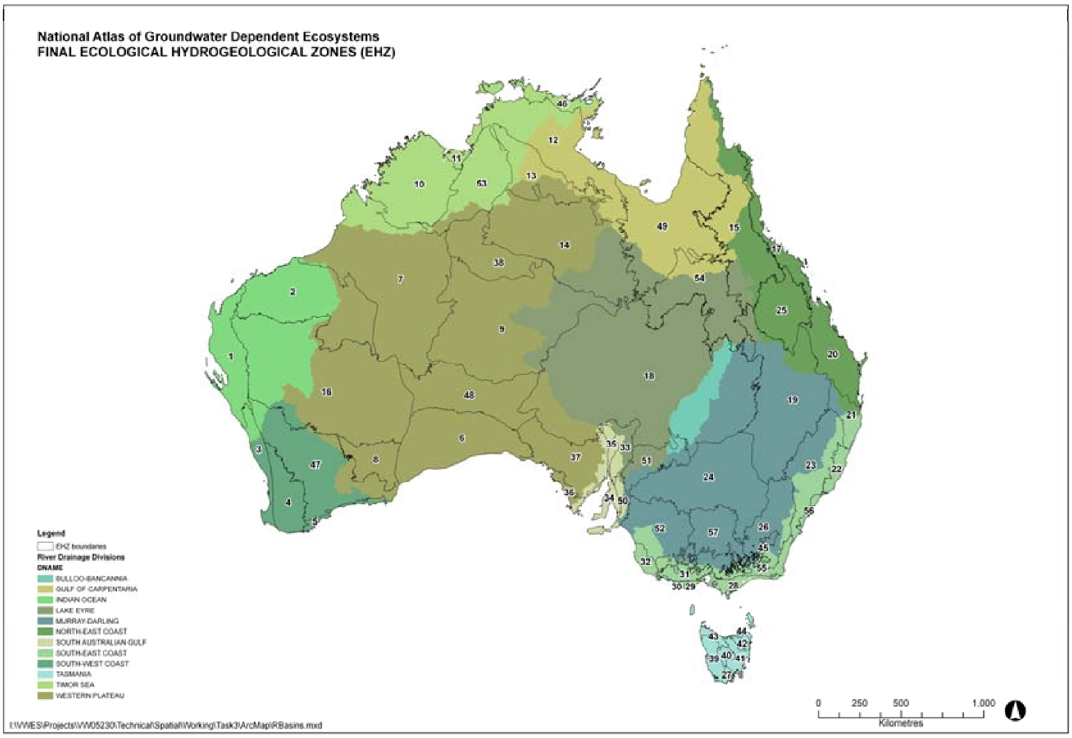
- **Figure A.4 Groundwater flow systems**



- **Figure A.5 Watertable Aquifers**



- **Figure A.6 River Basins**



Appendix B – Jurisdictional review

#	Jurisdiction	EHZs	Action	Reference data set
1	WA	47	Merge northern tip with EHZ 1	Bioregions
		Comment	*Done, using bioregions*	
2	WA	7 and 8	Merge	
		Comment	*Done*	
3	WA	2	Split into 3	Bioregions, climate regions
		Comment	*Created EHZ 2, 16, and 8*[1]	
4	SA	37 and 38	Merge	
		Comment	*Done*	
5	NT	53	Split at south-east end and merge with 14	Bioregions
		Comment	*Done*	
6	NT	9	Split	Bioregions , climate regions
		Comment	*Done, using bioregions, created EHZ 38*	
7	QLD	12	Split east / west and merge eastern part with 49	Bioregions
		Comment	*Done, using bioregions*	
8	QLD	18	Split and merge north with 49	Bioregions
		Comment	*Done, using bioregions but created EHZ 54 to create an inland zone rather than merge with coastal region, the Gulf Plains bioregion area has been merged with EHZ 49*	
9	QLD	15 and 16	Merge	
		Comment	*Done*	
10	QLD	20	Split to limit inland extent	Bioregions
		Comment	*Done, using bioregions, created EHZ 25*	
11	NSW	24, 25, 27	Merge	
		Comment	*Done*	
12	NSW	26	Split (coastal region)	Bioregions
		Comment	*Done, using bioregion created EHZ 55*	
13	NSW	22	Split (north and south of Sydney)	Bioregions, climate regions
		Comment	*Done, using bioregion, created EHZ 56*	

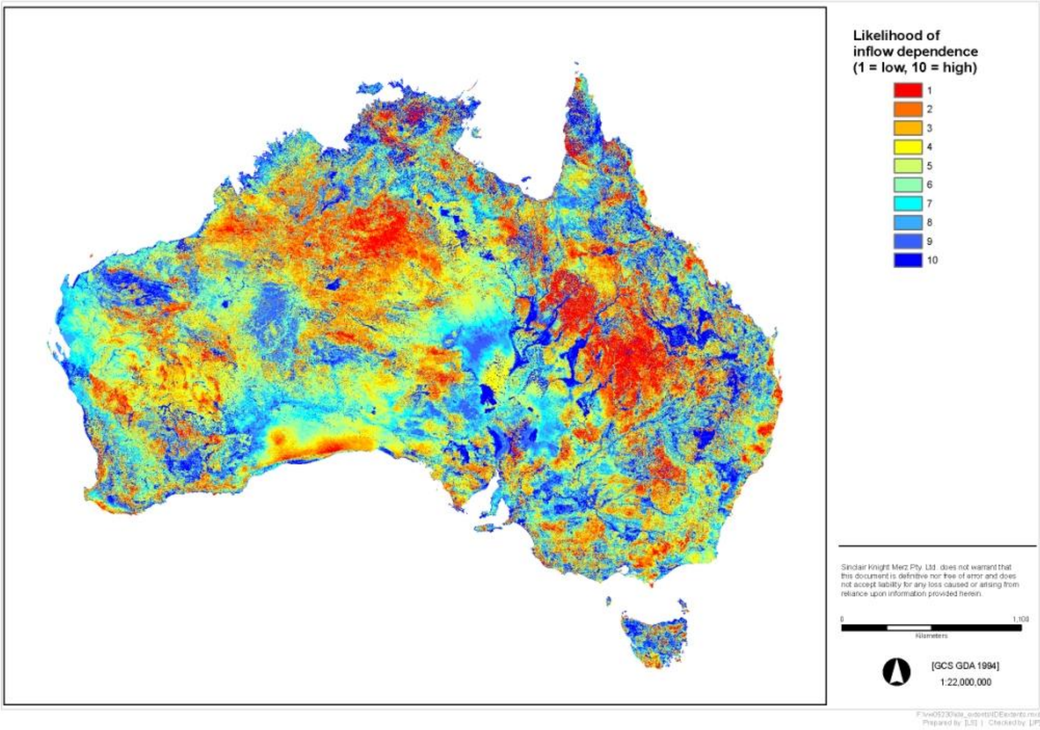
[1] Note: to keep continuity of EHZ numbers, some numbers have been 'recycled' where numbers have been freed up due to merging. These were reassigned based on order of processing.

#	Jurisdiction	EHZs	Action	Reference data set
14	Vic	52	Split (east /west divide aligning with Loddon and Campaspe catchments)	Bioregions
		Comment	*Done, using bioregion, created EHZ 57*	
15	Vic	26	Split (aligning with EHZ 52 split)	Bioregions
		Comment	*Did not do as this is a single bioregion here*	
16	TAS	41	Split (Ben Lamond as distinct rainfall)	Climate regions
		Comment	*Done, separated out the Ben Lamond bioregion, created EHZ 42*	
17	TAS	40	Split	Bioregions, climate regions
		Comment	*Done, using bioregions, created EHZ 27*	

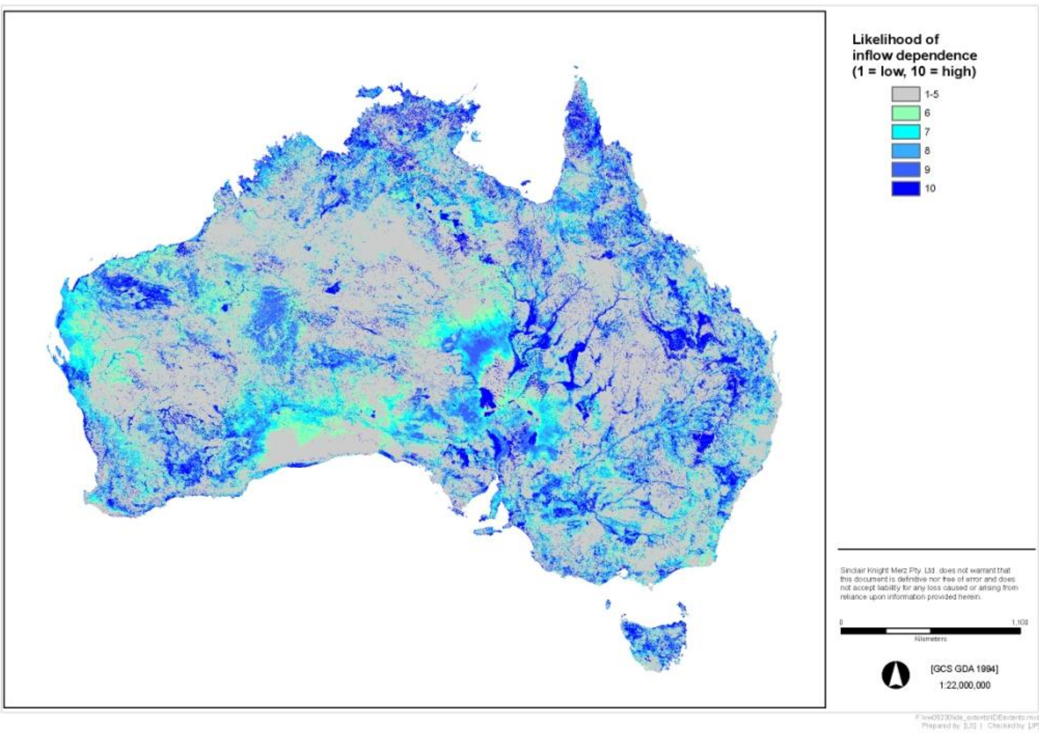
Additional Comment received from Queensland (18 March 2011):
Mulgildie appendix in EHZ 19 should be included in EHZ 20 using the rainfall district line
Action : Applied border using river basins boundary to split off appendix.

Appendix D Task 4 Outputs

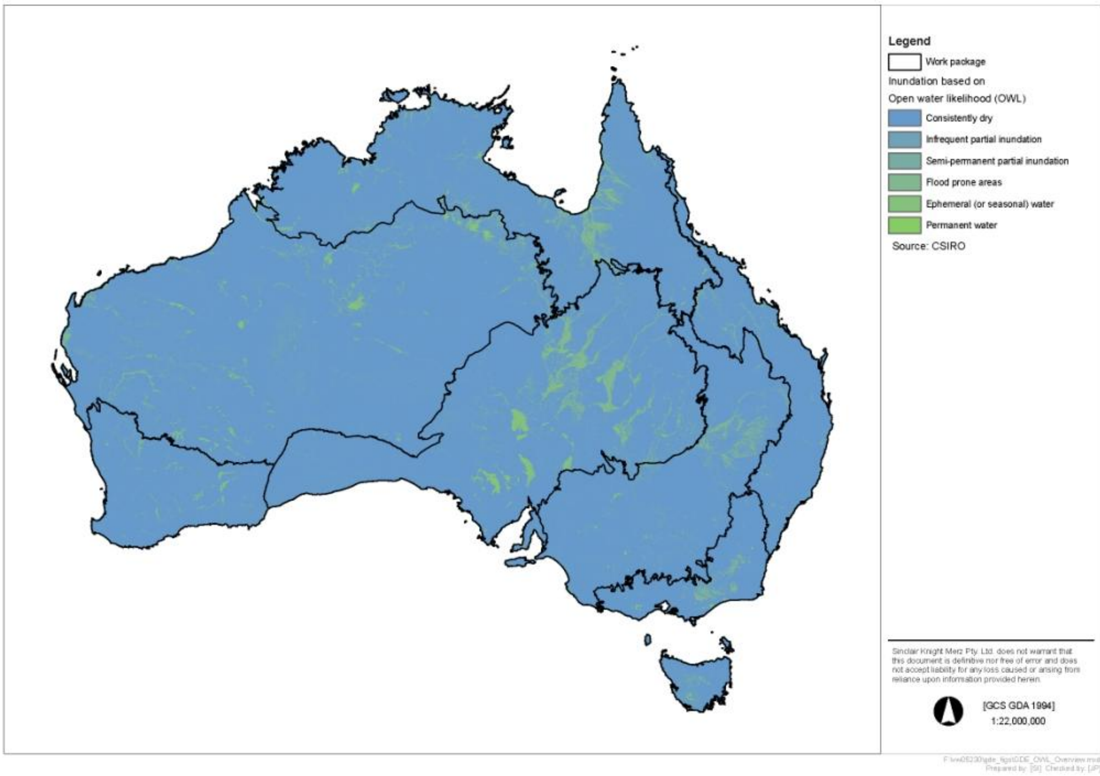
D.1 Remote sensing layer



D.2 ID Layer



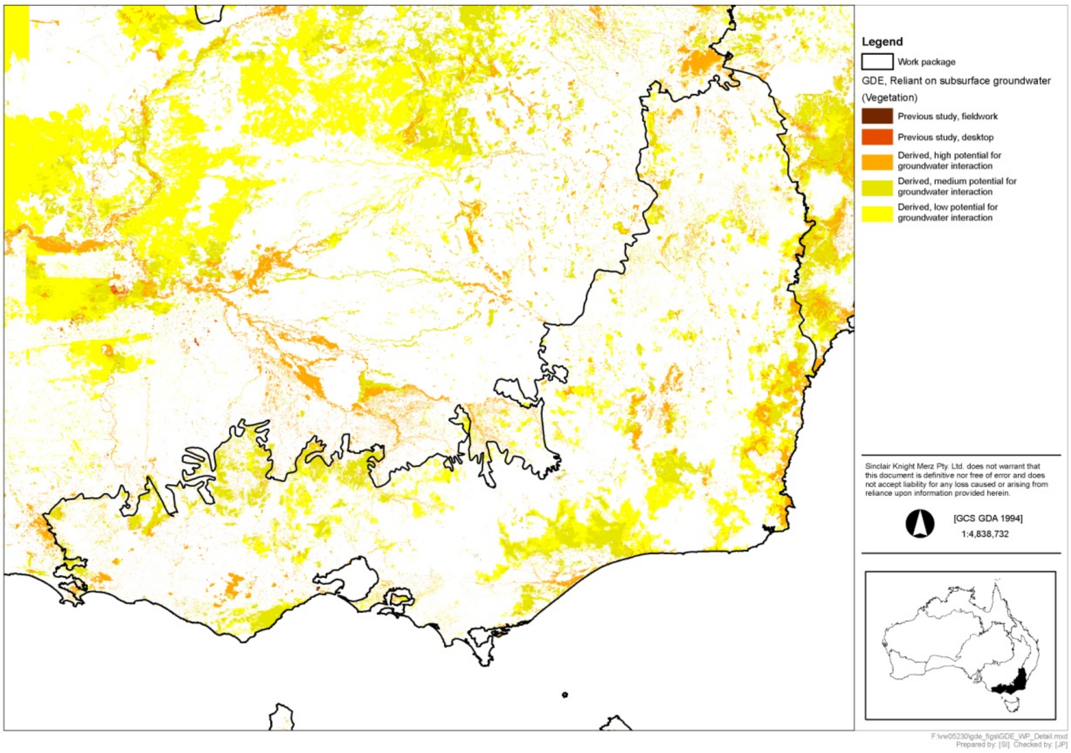
D.3 MODIS optical water likelihood



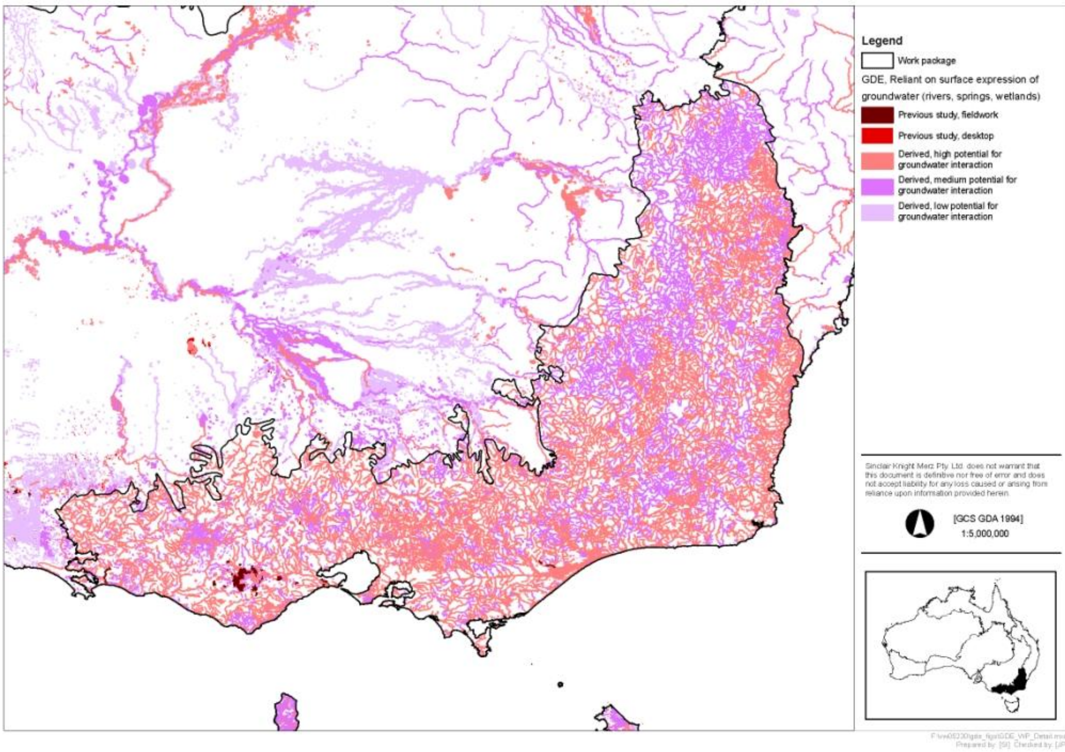
Appendix E Final GDE maps for each work package

E.1 South eastern Australia (WP1)

E.1.1 Ecosystems that rely on the subsurface presence of groundwater

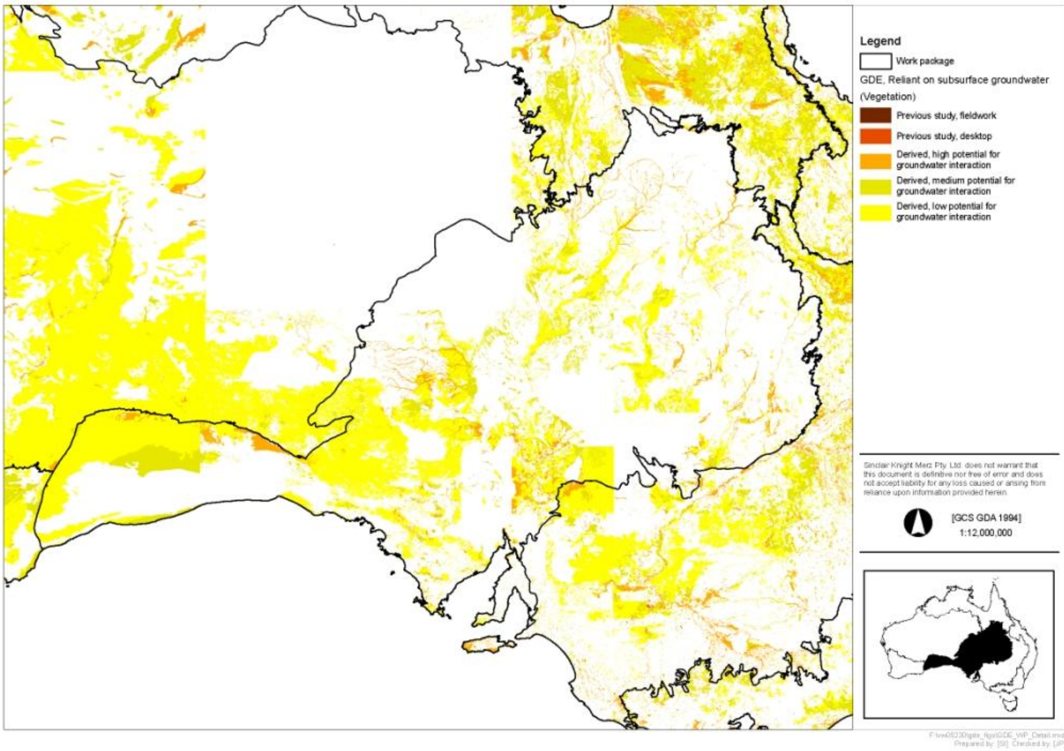


E.1.2 Ecosystems that rely on the surface expression of groundwater

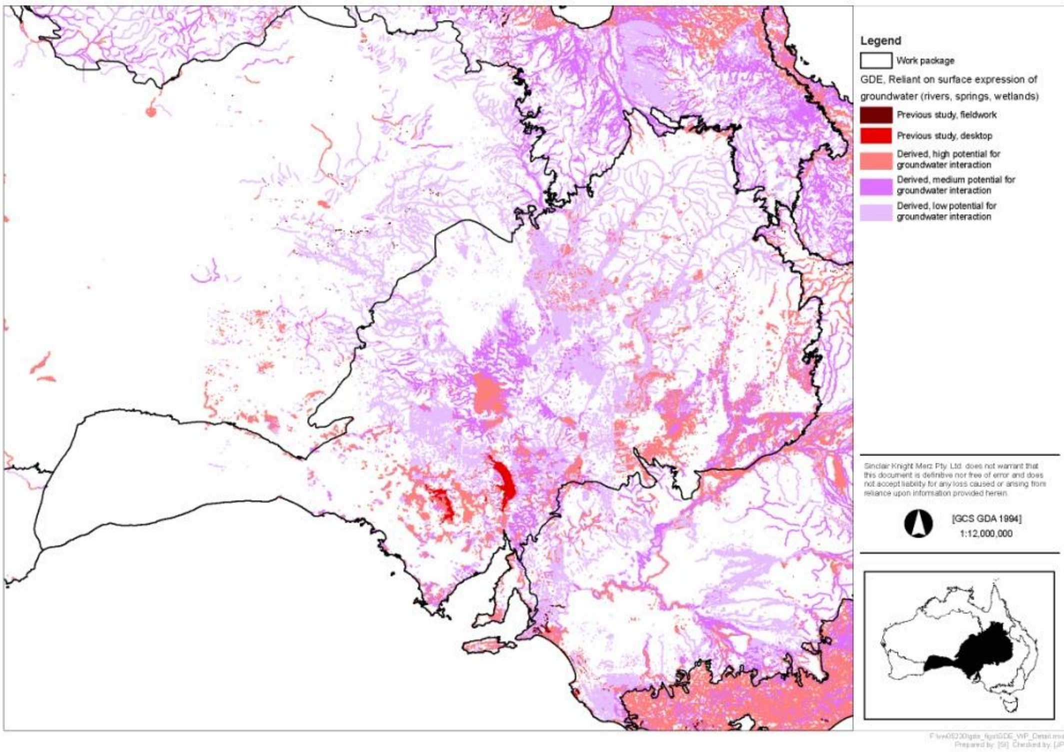


E.2 Eastern central Australia and the Nullarbor Plain (WP2)

E.2.1 Ecosystems that rely on the subsurface presence of groundwater

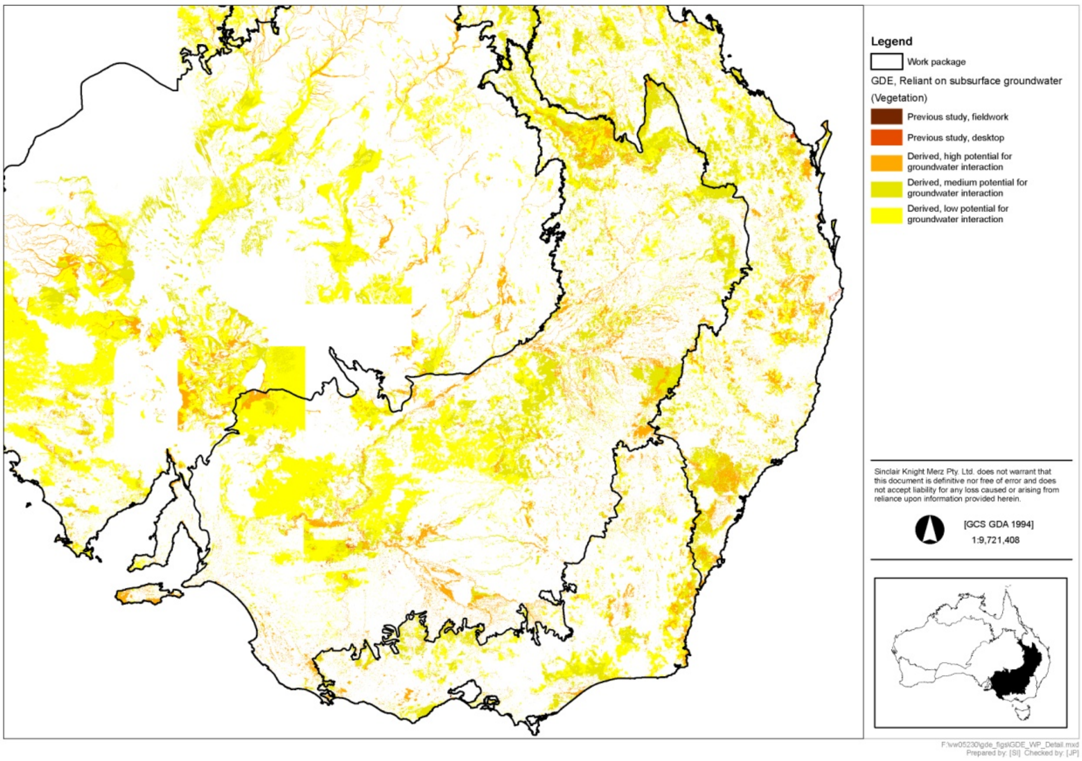


E.2.2 Ecosystems that rely on the surface expression of groundwater

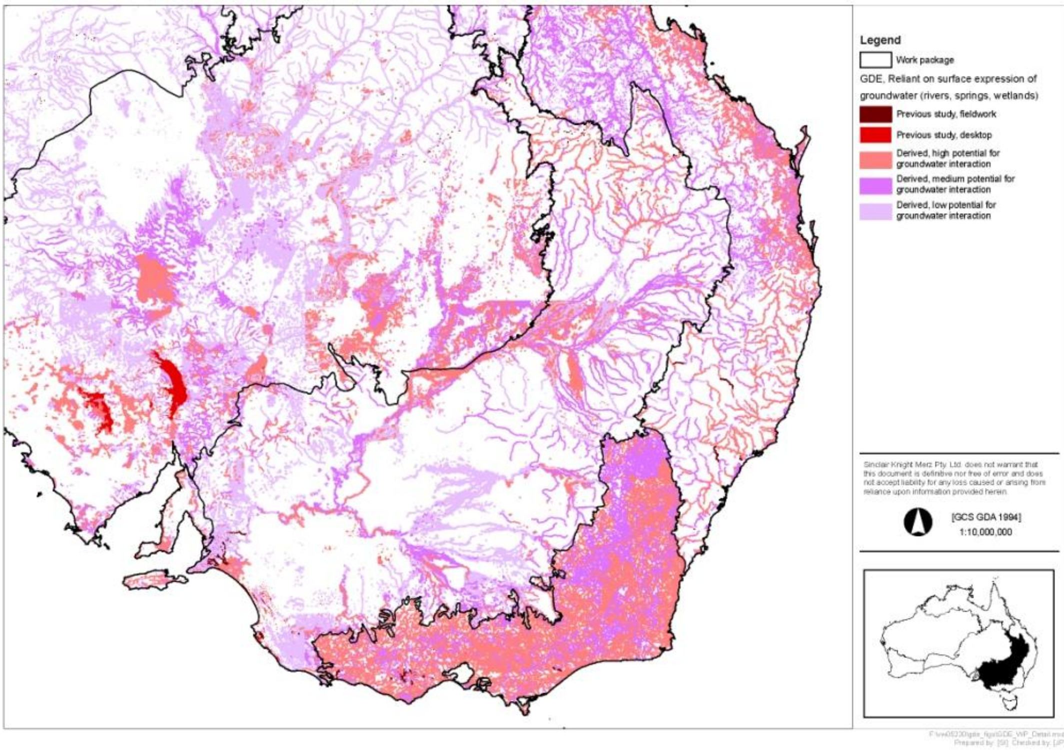


E.3 Southern and eastern Murray-Darling Basin (WP3)

E.3.1 Ecosystems that rely on the subsurface presence of groundwater

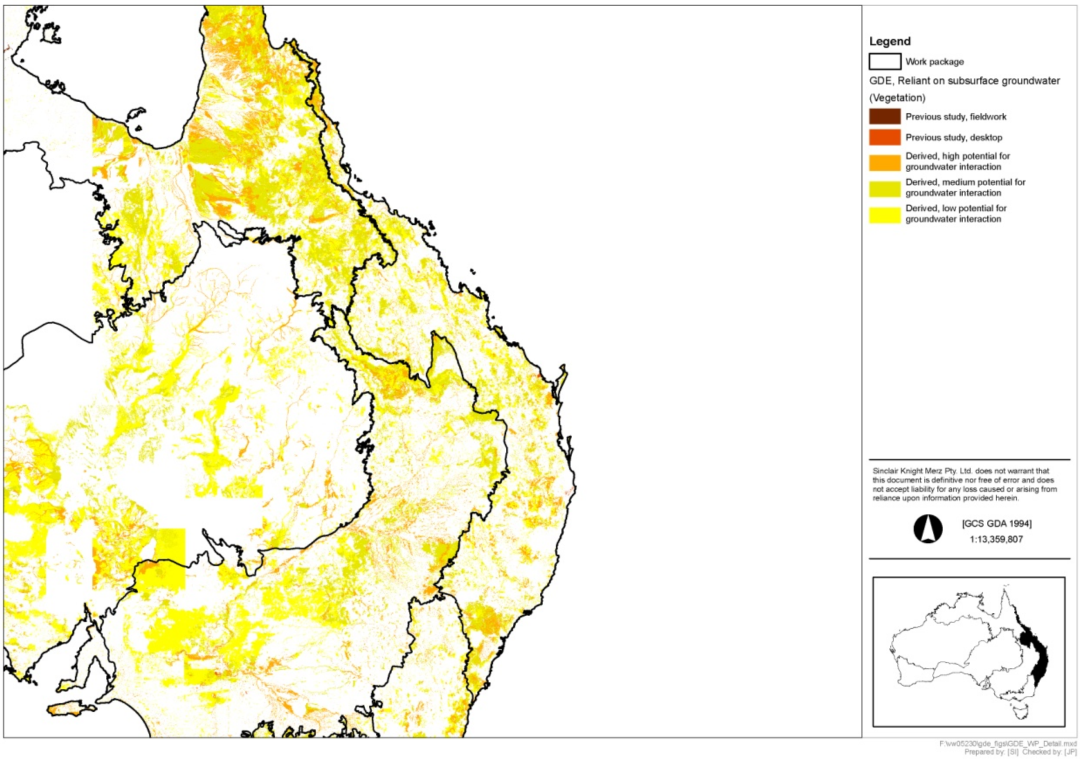


E.3.2 Ecosystems that rely on the surface expression of groundwater

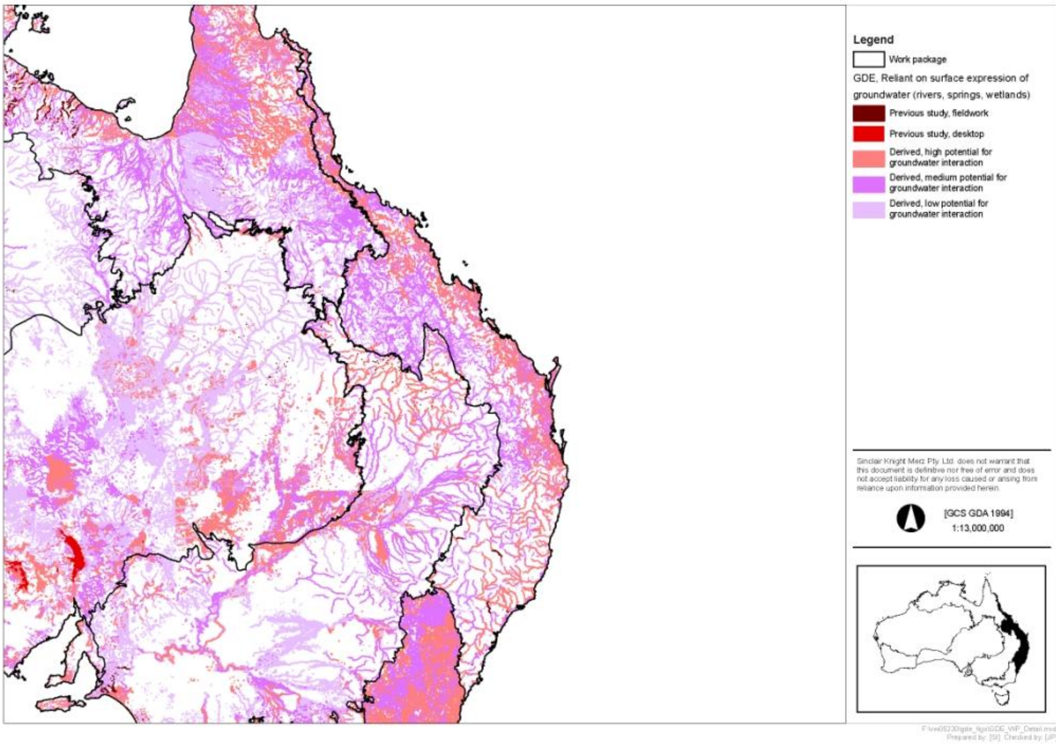


E.4 East coast Australia (WP4)

E.4.1 Ecosystems that rely on the subsurface presence of groundwater

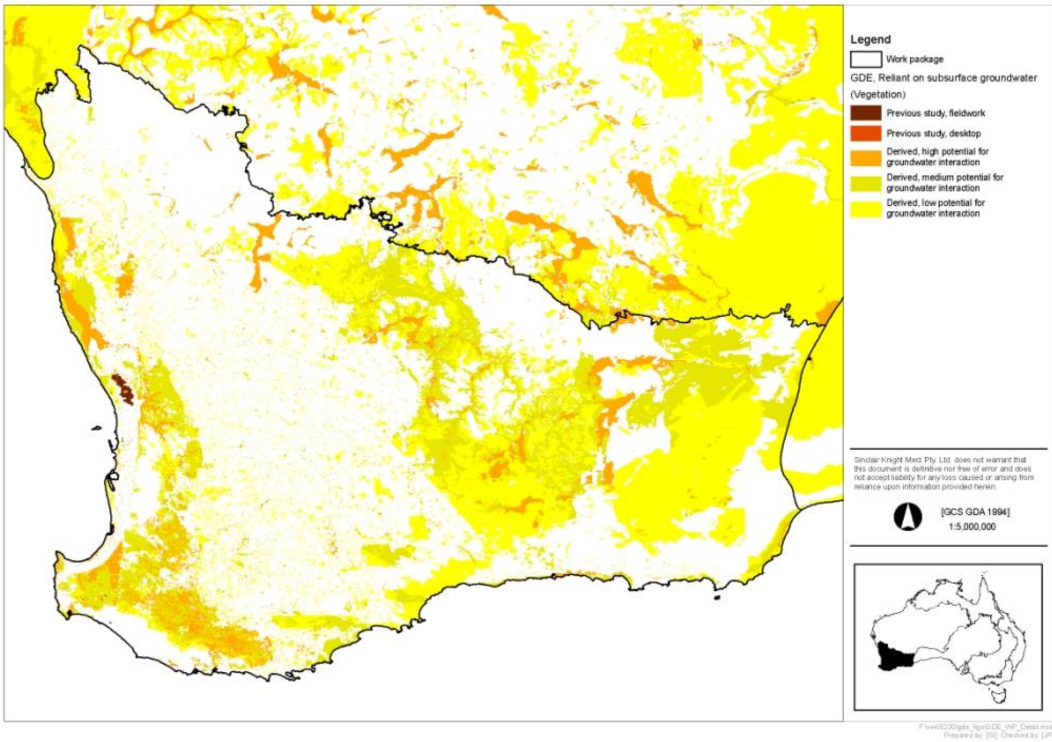


E.4.2 Ecosystems that rely on the surface expression of groundwater

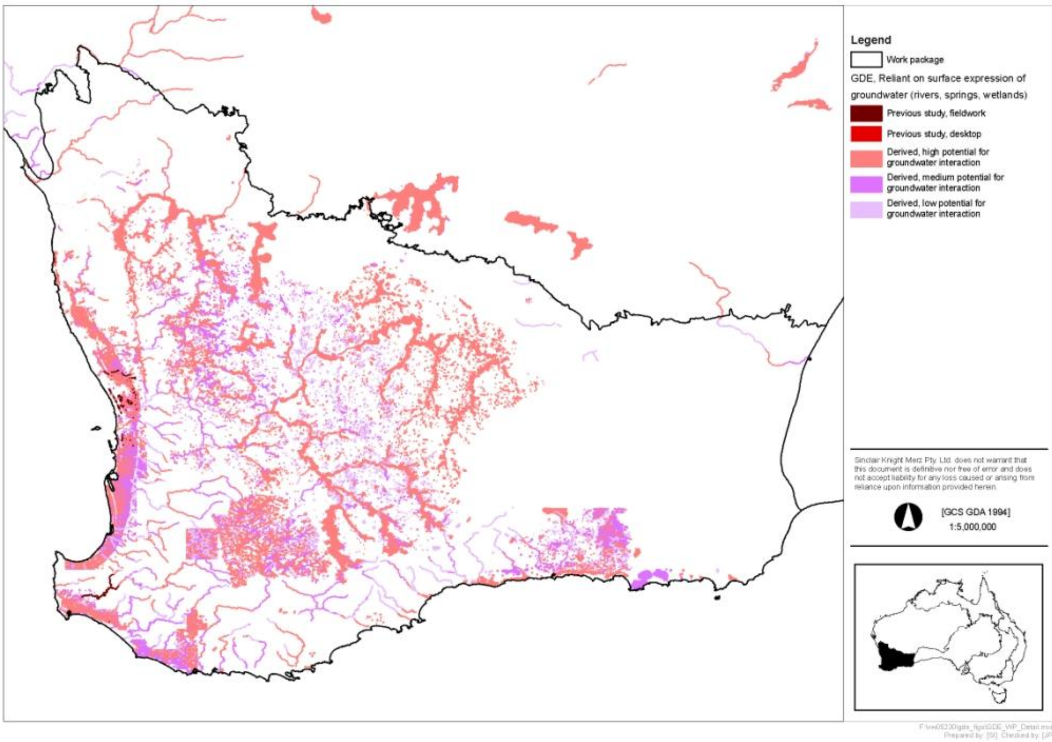


E.5 South west Western Australia (WP5)

E.5.1 Ecosystems that rely on the subsurface presence of groundwater

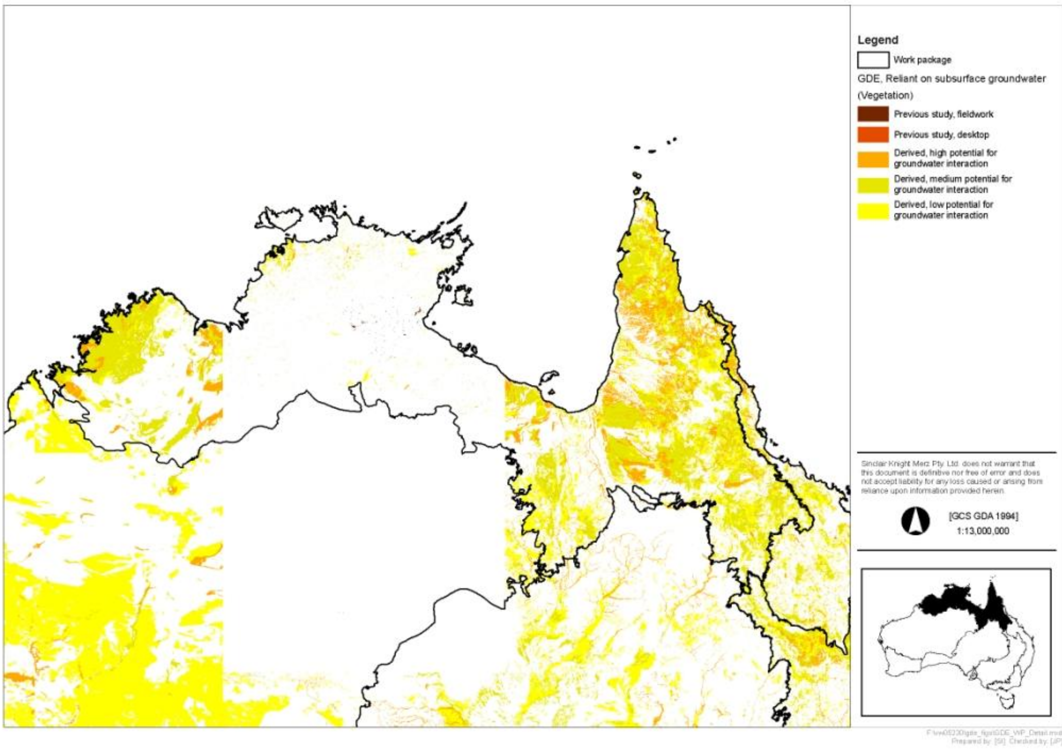


E.5.2 Ecosystems that rely on the surface expression of groundwater

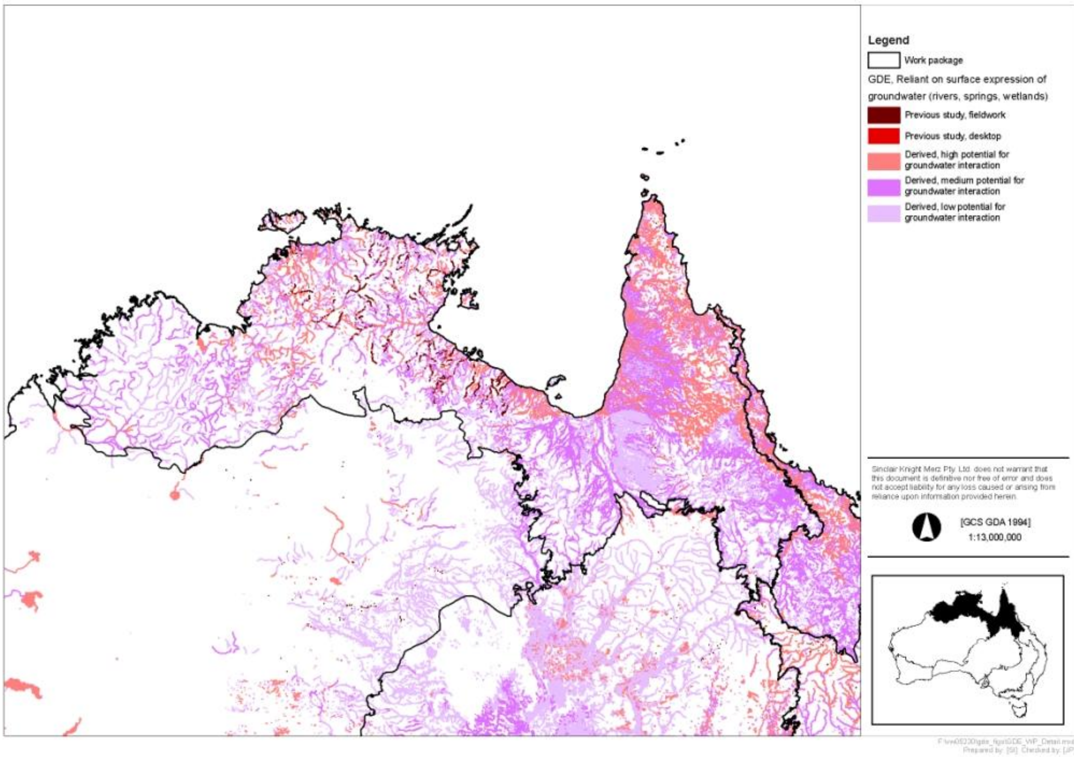


E.6 Northern Australia (WP6)

E.6.1 Ecosystems that rely on the subsurface presence of groundwater

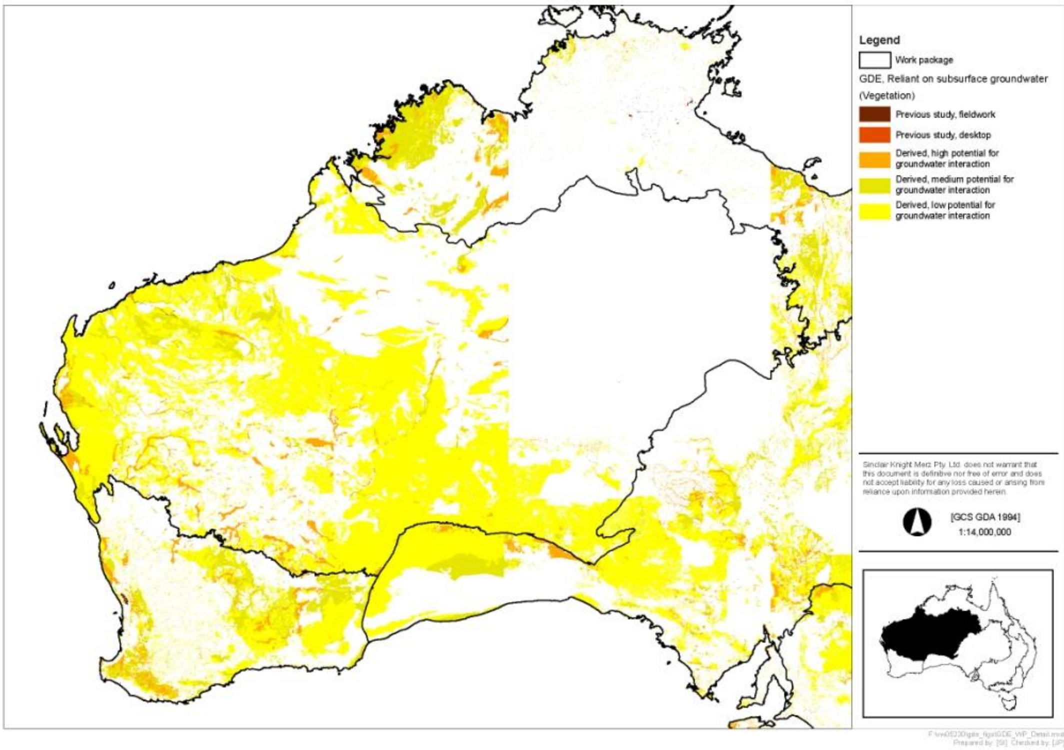


E.6.2 Ecosystems that rely on the surface expression of groundwater

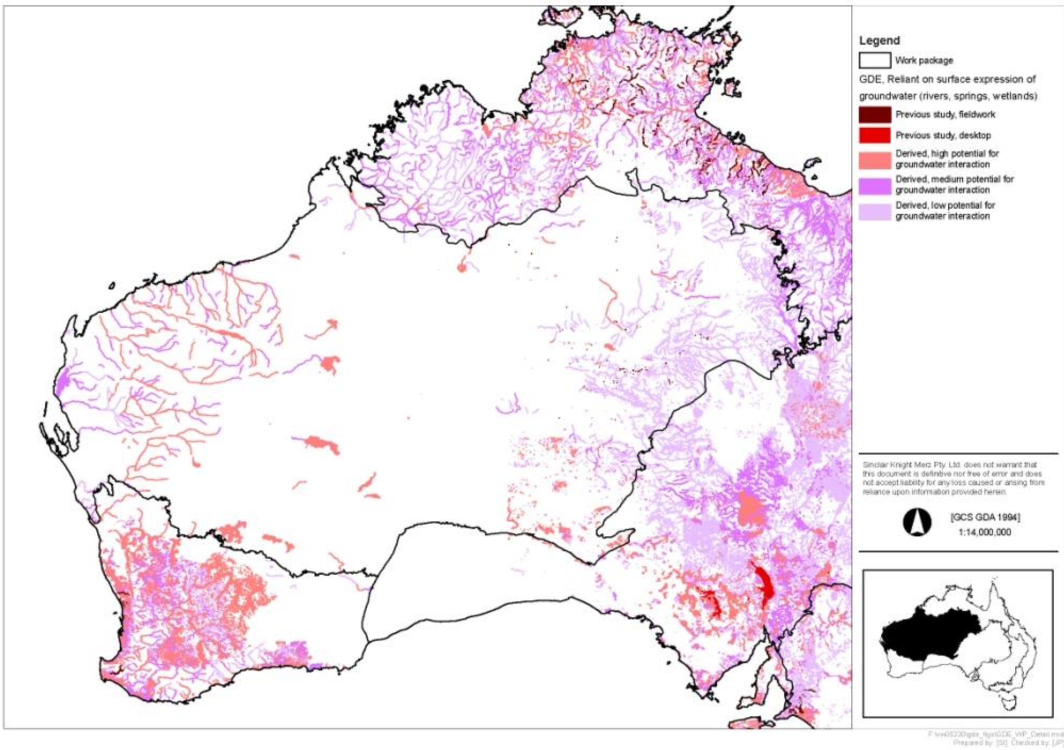


E.7 West central Australia and central western coast (WP7)

E.7.1 Ecosystems that rely on the subsurface presence of groundwater

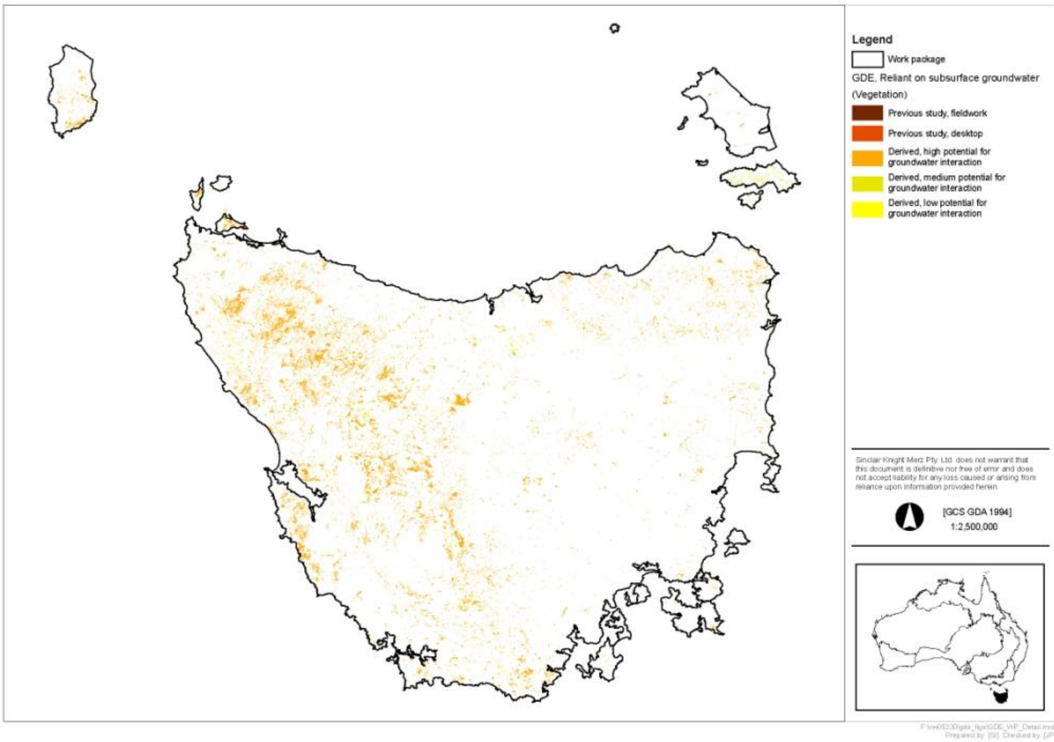


E.7.2 Ecosystems that rely on the surface expression of groundwater

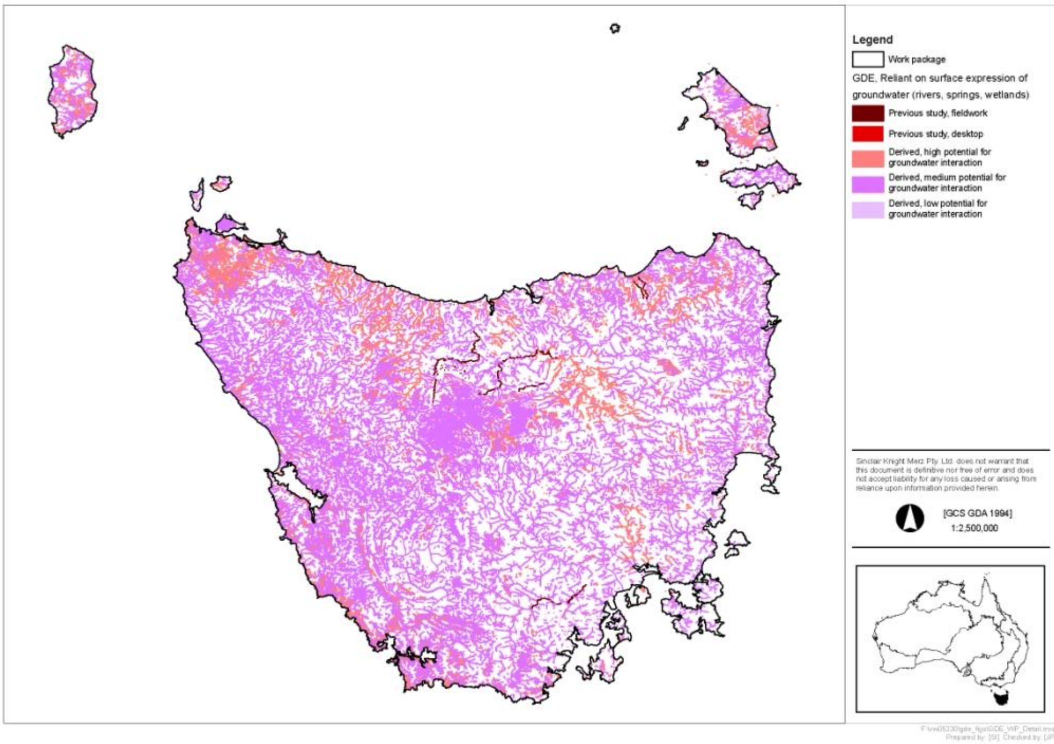


E.8 Tasmania (WP8)

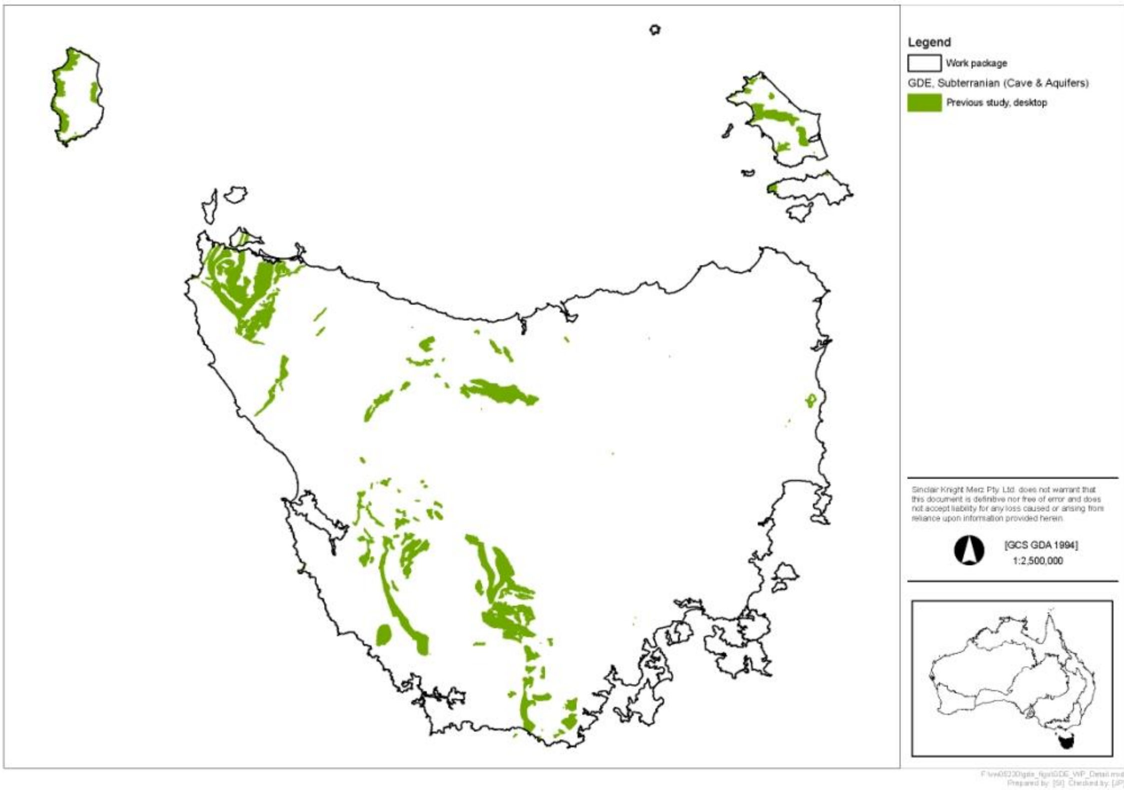
E.8.1 Ecosystems that rely on the subsurface presence of groundwater



E.8.2 Ecosystems that rely on the surface expression of groundwater



E.8.3 Subterranean GDEs (caves and aquifers)



Appendix F Spatial data used to populate GDE Atlas attribute table

F.1 Attributes populated from existing spatial datasets – WP1

			Surface ecosystems dependent on SURFACE expression of groundwater		Surface ecosystems dependent on SUBSURFACE presence of groundwater	
GENERAL ECOSYSTEM SETTING		Database Reference	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute
Ecosystem Attributes	**Ecosystem type**	**ECOTYPE_DS**	NA	From standard list of ecosystem types	NA	From standard list of ecosystem types
	Supplied Ecosystem type	**S_ETYPE_DS**	NA	WETLAND_1994 NSW_WETLANDS_2006	NA	NV2005_EVCBCS NSW_er_scivi NSW_m305_9171 NSW_south_cra.csv
	Name	**NAME**	NA	from feature data set	NA	From feature datasets
	Occurrence on other ecosystem inventories	**ECO_OCC_DS**	NA	No attribute entered	NA	NA
	Ecosystem salinity	**SALINE_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attribute entered	NA	NA
	Water Regime	**WREGIME_DS**	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent (flowing) 5) Permanent, near permanent (static) 6) Unknown 7) No data	Vic_MIneral Springs GDEs from literature, field validated spatial datasets; GDEs from spatial datasets given to SKM; Entire WP_MDB_SW_GW_V05_LCC	NA	NA
	Soil/Substrate	**SOILSUB_DS**	1) Organic 2) Mineral 3) Rock 4) Unknown 5) No data	NA	NA	NA

INFLOW DEPENDENT ECOSYSTEMS (IDEs)		Database Reference				
	IDE	**IDE_N**	Class combo	ID Likelihood (1 to 10)	Class combo	ID Likelihood (6 to 10)

DESCRIPTION OF GW INTERACTION		Database Reference	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute
	GDE class	**ECOCLS_DS**	**Surface ecosystems dependent on surface expression of groundwater**	Derived from river, wetland, springs feature datasets	**Surface ecosystems dependent on subsurface presence of groundwater**	Derived fromvegetation feature datasets
	Confidence of ecosystem being a GDE	**GWDEP_DS**	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM; 3 - 1) GDEs derived during the project	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM; 3 - 1) GDEs derived during the project
Connectivity	**Spatial connectivity between GDE and groundwater**	**SP_CONN_DS**	1) Connected, gaining (includes springs, terminal wetlands) 2) Connected, losing 3) Connected, variable gaining / losing (includes flow through wetlands) 4) Disconnected, losing 5) Unknown 6) No data	Vic_MIneral Springs GDEs from literature, field validated spatial datasets; GDEs from spatial datasets given to SKM; Entire WP_MDB_SW_GW_V05_LCC	1) Connected, gaining (includes springs, terminal wetlands) 2) Connected, losing 3) Connected, variable gaining / losing (includes flow through wetlands) 4) Disconnected, losing 5) Unknown 6) No data	No attributes entered
	Temporal nature of groundwater connectivity/use	**PERMCON_DS**	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	Vic_MIneral Springs GDEs from literature, field validated spatial datasets; GDEs from spatial datasets given to SKM; Entire WP_MDB_SW_GW_V05_LCC	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	No attributes entered
	Residence time	**RTIME_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Saturation regime	**SAT_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Source Aquifer Confinement	**AQ_SRCT_DS**	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered
	Source Aquifer name	**AQ_NAME_DS**	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered

Groundwater Source	**Broad geology type of source aquifer**	**AQ_GEOL_DS**	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	No attributes entered	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	No attributes entered
	Porosity of source aquifer	**AQ_POR_DS**	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	No attributes entered	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	No attributes entered
	Groundwater Flow System of source aquifer	**AQ_GWFL_DS**	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered
	Salinity of Groundwater Source	**GW_SAL_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered
	Ph of Groundwater Source	**GW_PH_DS**	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered
	Dominant recharge process of groundwater source	**GW_RECH_DS**	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered
	Hydrogeological capture zone#	**HCZONE_DS**		No attributes entered		No attributes entered
Nature of groundwater dependency	**Relative requirement of groundwater vs. other source (overall)**	**GW_REL_DS**	1) Dominant groundwater 2) Both surface water and groundwater 3) Dominant surface water 4) No data 5) Unknown	Vic_MIneral Springs GDEs from literature, field validated spatial datasets; GDEs from spatial datasets given to SKM; Entire WP_MDB_SW_GW_V05_LCC	1) Dominant groundwater 2) Both unsaturated zone water and groundwater 3) Dominant unsaturated zone water 4) No data 5) Unknown	Alpine Bog and wetlands
	Critical groundwater service	**GW_REQ_DS**	Water source (when surface flows cease) Habitat Artesian pressure Thermal water supply No data Other (Physical integrity) Water quality No data	Vic_MIneral Springs GDEs from literature, field validated spatial datasets; GDEs from spatial datasets given to SKM; Entire WP_MDB_SW_GW_V05_LCC	Water availability (water capacity above wilting) Water capacity provides reduced salt concentrations to below osmotic limit Dry period water supply No data Other (Physical integrity) Water quality No data	No attributes entered
	Example Indicative species	**END_SPEC_DS**	Free text No data	GDEs from literature, field validated spatial datasets; GDEs from spatial datasets given to SKM;	Free text No data	NA
	Environmental Groundwater Requirement	**ENV_WAT_DS**	Free text No data	GDEs from literature, field validated spatial datasets; GDEs from spatial datasets given to SKM;	Free text No data	GDEs from literature, field validated spatial datasets; GDEs from spatial datasets given to SKM;
	Additional information on dependency/ resilience/ sensitivity	**DETAILS_DS**	Free text No data	GDEs from spatial datasets given to SKM;	Free text No data	GDEs from spatial datasets given to SKM;

F.2 Attributes populated from existing spatial datasets – WP2

			Surface ecosystems dependent on SURFACE expression of groundwater		Surface ecosystems dependent on SUBSURFACE presence of groundwater	
GENERAL ECOSYSTEM SETTING		Database Reference	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute
Ecosystem Attributes	Ecosystem type	ECOTYPE_DS	NA	From standard list of ecosystem types	NA	From standard list of ecosystem types
	Ecosystem type	S_ETYPE_DS	NA	QLD: QLD_WETLAND_SYSTEM_100K: HAB_L attribute NSW: NSW_Wetlands_2006: SUBGROUP attribute SA: Wetlands_gde_Classification_v1: WETLANDSYS attribute SA: wetlands_gde_Classification_v1: WETLANDTYP attribute	NA	QLD: QLD_RE06b: DBVG2M attribute NSW: murray_darling_M305_VISmap_917: GENUS1/SPECIES1 attributes (concatenated) SA: SA_VEG_DATA: BROAD_VEGD attribute SA: SKM 2009 EP GDE Scoping Study: ECOSYSTEM attribute
	Name	NAME	NA	From feature datasets	NA	From feature datasets
	Occurrence on other ecosystem inventories	ECO_OCC_DS	NA	QLD: Qld_Directory of important wetlands: intersect QLD: Ramsar sites: intersect SA: wetlands_gde: internatio attribute SA: wetlands_gde: nationalst attribute	NA	NA
	Ecosystem salinity	SALINE_DS	< 1500 mg/L TDS	QLD: QLD_WETLANDS SYSTEM_100K: SALINMOD attribute field: 'fresh' QLD: HYD_SPRINGS_V2: SALINMOD attribute field: 'fresh' SA: wetlands_gde: TDS attribute SA: Watercourse_250K_Classification_v1: FRESH attribute	NA	
			1500 - 3000 mg/L TDS	SA: wetlands_gde: TDS attribute	NA	
			3000 - 35000 mg/L TDS	QLD: QLD_WETLANDS SYSTEM_100K: SALINMOD attribute field: 'hyposaline' SA: wetlands_gde: TDS attribute	NA	
			> 35000 mg/L TDS	QLD: QLD_WETLANDS SYSTEM_100K: SALINMOD attribute field: 'saline'	NA	
			Fluctuating Stratified Unknown No data * include measurement date	not attributed	NA	NA
	Water Regime	WREGIME_DS	1) Ephemeral (unpredictable, short term)	QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR1 (Rarely (20% of images)) SA: Wetlands_gde_Classification_v1: WATERREGIM attribute; EPISODIC attribute	NA	
			2) Intermittent (irregular, persists for medium term)	not attributed	NA	
			3) Seasonal (annual, regular)	QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR2 (Intermediately (40 - 60% of images)) SA: Wetlands_gde_Classification_v1: WATERREGIM attribute; SEASONAL attribute	NA	
			4) Permanent, near permanent (flowing)	SA: Watercourse_250K_Classification_v1: PERENNIAL attribute	NA	
			5) Permanent, near permanent (static)	QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR3 (Commonly (80 - 100% of images)) SA: Wetlands_gde_Classification_v1: WATERREGIM attribute; PERMANENT attribute SA: Hydro_Pool_dam_15m; DRY SEASON POOL attribute SA: Watercourse_250K_Classification_v1: PERMANENCE attribute SA: Riparian_baseflow_light: Permanent baseflow attribute SA: Riparian_baseflow_broughton: Permanent baseflow attribute	NA	
			6) Unknown	QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR0 (Uncertain) QLD: HYD_SPRINGS_V2 = WTRREGIME attribute: WR0 (Uncertain)	NA	
			7) No data	not attributed	NA	NA
	Soil/Substrate	SOILSUB_DS	1) Organic 2) Mineral 3) Rock 4) Unknown 5) No data	not attributed	NA	NA
INFLOW DEPENDENT ECOSYSTEMS (IDEs)		Database Reference				
	IDE	IDE_N	Class combo	ID Likelihood (1 to 10)	Class combo	ID Likelihood (6 to 10)
DESCRIPTION OF GW INTERACTION		Database Reference	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute

	GDE class	**ECOCLS_DS**	**Surface ecosystems dependent on surface expression of groundwater**	Derived from feature datasets (includes wetlands, rivers, springs)	**Surface ecosystems dependent on subsurface presence of groundwater**	Derived from feature datasets (includes vegetation)
	Confidence of ecosystem being a GDE	**GWDEP_DS**	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM 3 - 1) GDEs derived during the project	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	3 - 1) GDEs derived during the project
Connectivity	**Spatial connectivity between GDE and groundwater**	**SP_CONN_DS**	1) Connected, gaining (includes springs, terminal wetlands)	SA: Baseflow MLR; baseflow attribute;' DRY SEASON FLOW attribute field SA: Hydro_Pool_dam_15m; DRY SEASON POOL attribute SA: Gazeteer_aquaticecosystems: DIST_ADM_2 attribute SA: Baseflow_Willochra: BASEFLOW attribute SA: Pool_or_dam_15m: intersect SA: Pools_baseflows: intersect SA: Pools_Willochra: intersect NSW: adminGDE_highpriority_point: GDETYPE attribute SA: Mambpools: intersect SA: Riparian_baseflow_light: Permanent baseflow attribute SA: Riparian_baseflow_broughton: Permanent baseflow attribute	1) Watertable <2m	Not attributed
			2) Connected, losing	SA_ Pools_Baseflow; BASEFLOW attribute; BASEFLOW attribute field	2) Watertable 2m - 20m	SA: Gwater_Shallow_SWL; SWL_MIN attribute field; attributes 2, 5 and 10
			3) Connected, variable gaining / losing (includes flow through wetlands)	Not attributed	3) Watertable >20m	SA: Gwater_Shallow_SWL; SWL_MIN attribute field; attribute 20
			4) Disconnected, losing 5) Unknown 6) No data	Not attributed	4) Unknown 5) No data	Not attributed
	Temporal nature of groundwater connectivity/use	**PERMCON_DS**	1) Ephemeral (unpredictable, short term)	Not attributed	1) Ephemeral (unpredictable, short term)	Not attributed
			2) Intermittent (irregular, persists for medium term)	Not attributed	2) Intermittent (irregular, persists for medium term)	Not attributed
			3) Seasonal (annual, regular)	SA: Baseflow MLR; baseflow attribute;' DRY SEASON FLOW attribute field	3) Seasonal (annual, regular)	Not attributed
			4) Permanent, near permanent	SA: Hydro_Pool_dam_15m; DRY SEASON POOL attribute SA: Riparian_baseflow_light: Permanent baseflow attribute SA: Riparian_baseflow_broughton: Permanent baseflow attribute	4) Permanent, near permanent	Not attributed
			5) Unknown 6) No data	Not attributed	5) Unknown 6) No data	Not attributed
	Residence time	**RTIME_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Saturation regime	**SAT_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
Groundwater Source	**Source Aquifer Confinement**	**AQ_SRCT_DS**	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered
	Source Aquifer name	**AQ_NAME_DS**	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered
	Broad geology type of source aquifer	**AQ_GEOL_DS**	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	No attributes entered	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	No attributes entered
	Porosity of source aquifer	**AQ_POR_DS**	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	No attributes entered	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	No attributes entered
	Groundwater Flow System of source aquifer	**AQ_GWFL_DS**	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered

	Salinity of Groundwater Source	**GW_SAL_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered
	Ph of Groundwater Source	**GW_PH_DS**	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered
	Dominant recharge process of groundwater source	**GW_RECH_DS**	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered
	Hydrogeological capture zone#	**HCZONE_DS**		No attributes entered		No attributes entered
Nature of groundwater dependency	**Relative requirement of groundwater vs. other source (overall)**	**GW_REL_DS**	1) Dominant groundwater	SA: Baseflow MLR; baseflow attribute;' DRY SEASON FLOW attribute field SA: Gazeteer_aquaticecosystems: DIST_ADM_2 attribute SA: watercourse_250K_classification_v1: GW attribute NSW: adminGDE_highpriority_point: GDETYPE attribute	1) Dominant groundwater 2) Both unsaturated zone water and groundwater 3) Dominant unsaturated zone water 4) No data 5) Unknown	No attributes entered
			2) Both surface water and groundwater 3) Dominant surface water 4) No data 5) Unknown	SA: watercourse_250K_classification_v1: SW attribute		
	Critical groundwater service	**GW_REQ_DS**	Water source (when surface flows cease) Habitat Artesian pressure Thermal water supply No data Other (Physical integrity) Water quality No data	SA: Baseflow MLR; baseflow attribute;' DRY SEASON FLOW attribute field SA: Gazeteer_aquaticecosystems: DIST_ADM_2 attribute SA: Baseflow_Willochra: BASEFLOW attribute SA: Pool_or_dam_15m: intersect SA: Pools_baseflows: intersect SA: Pools_Willochra: intersect SA: Mambpools: intersect SA: Riparian_baseflow_light: Permanent baseflow attribute SA: Riparian_baseflow_broughton: Permanent baseflow attribute NSW: adminGDE_highpriority_point: GDETYPE attribute	Water availability (water capacity above wilting) Water capacity provides reduced salt concentrations to below osmotic limit Dry period water supply No data Other (Physical integrity) Water quality No data	No attributes entered
	Example Indicative species	**END_SPEC_DS**	Free text No data	No attributes entered	Free text No data	NA
	Environmental Groundwater Requirement	**ENV_WAT_DS**	Free text No data	No attributes entered	Free text No data	No attributes entered
	Additional information on dependency/ resilience/ sensitivity	**DETAILS_DS**	Free text No data	NA	Free text No data	NA

F.3 Attributes populated from existing spatial datasets – WP3

			Surface ecosystems dependent on SURFACE expression of groundwater		Surface ecosystems dependent on SUBSURFACE presence of groundwater	
GENERAL ECOSYSTEM SETTING		Database Reference	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute
Ecosystem Attributes	**Ecosystem type**	**ECOTYPE_DS**	NA	NSW: Admin_HighPriority_GDEpoints_Jan2011 (All features) SA: Gazeteer_AquaticEcosystems (SPRG & WTRH features) QLD: HYD_springsV3 (All features) SA: Pools_Willochra (All features) VIC: springs (All features)	NA	
	Ecosystem type	**S_ETYPE_DS**	NA	NSW: Admin_HighPriority_GDEpoints_Jan2011 (All features) SA: Gazeteer_AquaticEcosystems (SPRG & WTRH features) QLD: HYD_springsV3 (All features) SA: Wetlands_GDE_Classification_v1 (WETLANDTYP field; All features)	NA	QLD: QLD_RE06b: DBVG2M attribute NSW: murray_darling_M305_VISmap_917: GENUS1/SPECIES1 attributes (concatenated)
	Name	**NAME**	NA		NA	
	State	**STATE_DS**	NA		NA	
	EHZ	**EHZ_DS**	NA		NA	
	Drainage Basin	**DRBASIN_DS**	NA		NA	
	Occurrence on other ecosystem inventories	**ECO_OCC_DS**	NA	QLD: Qld_Directory of important wetlands: intersect	NA	
	Ecosystem salinity	**SALINE_DS**	< 1500 mg/L TDS	QLD: HYD_springsV3 (SALINMOD attribute; field 'S1') QLD: QLD_WETLANDS SYSTEM_100K: SALINMOD attribute field: 'fresh'	NA	
			1500 - 3000 mg/L TDS		NA	
			3000 - 35000 mg/L TDS		NA	
			> 35000 mg/L TDS		NA	
			Fluctuating Stratified Unknown No data * include measurement date		NA	
	Condition of ecosystem assessment	**COND_DS**	NA		NA	
	Water Regime	**WREGIME_DS**	1) Ephemeral (unpredictable, short term)	QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR1 (Rarely (20% of images)) VIC: Wetlands_1994 (FOI field; 'Episodic' attribute) SA: Wetlands_GDE_Classification_v1 (WATERREGIM field; EPISODIC attributes)	NA	
			2) Intermittent (irregular, persists for medium term)	VIC: Wetlands_1994 (FOI field; 'Intermittant' attribute) SA: Wetlands_GDE_Classification_v1 (WATERREGIM field; INTERMITTANT attributes)	NA	
			3) Seasonal (annual, regular)	QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR2 (Intermediately (40 - 60% of images)) VIC: Wetlands_1994 (FOI field; 'Seasonal' attribute) SA: Wetlands_GDE_Classification_v1 (WATERREGIM field; RUNOFF/TEMPORARY COMBINATION, SEASONAL, SEASONAL/PERMANENT, SEASONAL SOAK, SEMI-PERM/TEMP COMBINATION, TEMPORARY attributes)	NA	
			4) Permanent, near permanent (flowing)		NA	
			5) Permanent, near permanent (static)	QLD: HYD_springsV3 (WTRREGIME attribute: field 'WR3' (Commonly (80 - 100% of images)) QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR3 (Commonly (80 - 100% of images)) SA: MOSQCK_PERMPOOLS (STATUS attribute; all 'permanent pool' fields) VIC: Wetlands_1994 (FOI field; 'Permanent' attribute) SA: Wetlands_GDE_Classification_v1 (WATERREGIM field; PERM/TEMP COMBINATION, PERMANENT, PERMAMENT/SEASONAL, PERMANENT SOAK, RUNOFF/PERMANENT, PUNOFF/PERMANENT COMBINATION, SEMI-PERMANENT attributes)	NA	
			6) Unknown	QLD: HYD_springsV3 (WTRREGIME attribute: field 'WR0' (Uncertain))	NA	
			7) No data		NA	
	Soil/Substrate	**SOILSUB_DS**	1) Organic 2) Mineral 3) Rock 4) Unknown 5) No data		NA	
Climate Attributes	**Seasonal Rainfall Zone**	**RAINF_DS**				
	Length of dry season	**DRYSEAS_DS**				
	Wettest 4 months	**WETMTHS_DS**				
	Aridity Index	**ARIDITY_N**				
	Physiography	**GMORPH_DS**				

Landscape Attributes	**Landscape assessment** **DEM analyses (i.e. MrVBF - FLAG)**	**LSCAPE_DS**	1) Plateau 2) Slope 3) Low lying		1) Plateau 2) Slope 3) Low lying	
	Bioregionalisation	**BIOREG_DS**				
	Broad hydrogeological setting / Groundwater Flow System	**GWFLOW_DS**	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Nested 11) Perched		1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Nested 11) Perched	
	Broad landuse type	**LANDUSE_DS**				
	Water Management Areas	**GMA_DS**				
INFLOW DEPENDENT ECOSYSTEMS (IDEs)		**Database Reference**				
	IDE	**IDE_N**	Class combo	ID Likelihood (1 to 10)	Class combo	ID Likelihood (6 to 10)
DESCRIPTION OF GW INTERACTION		**Database Reference**	**Categories**		**Categories**	
	GDE class	**ECOCLS_DS**	**Surface ecosystems dependent on surface expression of groundwater**	NSW: Admin_HighPriority_GDEpoints_Jan2011 (All features) SA: Gazeteer_AquaticEcosystems (SPRG features) QLD: HYD_springsV3 (All features) SA: MOSQCK_PERMPOOLS (STATUS attribute; all 'permanent pool' fields) SA: HYDRO_BASEFLOW_MLR (BASEFLOW field; 'Dry season baseflow' field) SA: Streams_ord_EMLRCopy (GWSWCAT field; 'stream gaining from groundwater' attribute) SA: Pools_Willochra (All features) VIC: springs (All features) QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR1 (Rarely (20% of images)) VIC: Wetlands_1994 (PWS field; 'Groundwater' attribute) SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (FLOWREG field; 'Gaining', 'Potentially gaining' attributes) SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (INTERACFRM field; All 'PermDep' & 'SeasDep' attributes) CSIRO GW-SW Connectivity mapping: Gaining attributes QLD: GAB springs: intersect	**Surface ecosystems dependent on subsurface presence of groundwater**	
	Confidence of ecosystem being a GDE	**GWDEP_DS**	5) Known/Established (by field validation)		5) Known/Established (by field validation)	
			4) Derived - identified by third party	NSW: Admin_HighPriority_GDEpoints_Jan2011 (All features) SA: Gazeteer_AquaticEcosystems (SPRG features) QLD: HYD_springsV3 (All features) QLD: GAB_Watercourse_springs (All features) SA: MOSQCK_PERMPOOLS (STATUS attribute; all 'permanent pool' fields) SA: HYDRO_BASEFLOW_MLR (BASEFLOW field; 'Dry season baseflow' field) SA: Streams_ord_EMLRCopy (GWSWCAT field; 'stream gaining from groundwater' attribute) SA: Pools_Willochra (All features) VIC: springs (All features) VIC: Wetlands_1994 (PWS field; 'Groundwater' attribute)	4) Derived - identified by third party	
			3) Derived – high confidence	3 - 1) GDEs derived during the project	3) Derived – high confidence	
			2) Derived - low confidence	3 - 1) GDEs derived during the project	2) Derived - low confidence	
			1) IDE	3 - 1) GDEs derived during the project	1) IDE	

Connectivity	**Spatial connectivity between GDE and groundwater**	**SP_CONN_DS**	1) Connected, gaining (includes springs, terminal wetlands)	NSW: Admin_HighPriority_GDEpoints_Jan2011 (All features) SA: Gazeteer_AquaticEcosystems (SPRG features) QLD: HYD_springsV3 (All features) SA: MOSQCK_PERMPOOLS (STATUS attribute; all 'permanent pool' fields) SA: HYDRO_BASEFLOW_MLR (BASEFLOW field; 'Dry season baseflow' field) SA: Streams_ord_EMLRCopy (GWSWCAT field; 'stream gaining from groundwater' attribute) SA: Pools_Willochra (All features) SA: Gazeteer_aquaticecosystems: DIST_ADM_2 attribute SA: Baseflow_Willochra: BASEFLOW attribute SA: Pool_or_dam_15m: intersect SA: Pool_or_Dam_greater than 15m SA: Pools_baseflows: intersect SA: Riparian_baseflow_light: Permanent baseflow attribute SA: Riparian_baseflow_broughton: Permanent baseflow attribute VIC: springs (All features) VIC: Wetlands_1994 (PWS field; 'Groundwater' attribute) SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (FLOWREG field; 'Gaining', 'Potentially gaining' attributes) SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (INTERACFRM field; All 'PermDep' & 'SeasDep' attributes) CSIRO GW-SW Connectivity mapping: Gaining attributes	1) Watertable <2m	SA: Gwater_Shallow_SWL; SWL_MIN attribute field; attributes 0
			2) Connected, losing	SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (FLOWREG field; 'Loosing' attribute) CSIRO GW-SW Connectivity mapping: Losing attributes	2) Watertable 2m - 20m	SA: Gwater_Shallow_SWL; SWL_MIN attribute field; attributes 2, 5 and 10 VIC: Vic_dtwt: DTWT_RANGE 5, 10, 20
			3) Connected, variable gaining / losing (includes flow through wetlands)		3) Watertable >20m	SA: Gwater_Shallow_SWL; SWL_MIN attribute field; attribute 20 VIC: Vic_dtwt: DTWT_RANGE 30
			4) Disconnected, losing 5) Unknown 6) No data		4) Unknown 5) No data	
	Temporal nature of groundwater connectivity/use	**PERMCON_DS**	1) Ephemeral (unpredictable, short term)		1) Ephemeral (unpredictable, short term)	
			2) Intermittent (irregular, persists for medium term)		2) Intermittent (irregular, persists for medium term)	
			3) Seasonal (annual, regular)	SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (INTERACFRM field; All 'SeasDep' attributes)	3) Seasonal (annual, regular)	
			4) Permanent, near permanent	SA: HYDRO_BASEFLOW_MLR (BASEFLOW field; 'Dry season baseflow' field) SA: Pools_Willochra (intersect) SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (INTERACFRM field; All 'PermDep' attributes) SA: Hydro_Pool_dam_15m; DRY SEASON POOL attribute SA: Pool_or_Dam_greater than 15m SA: Riparian_baseflow_light: Permanent baseflow attribute SA: Riparian_baseflow_broughton: Permanent baseflow attribute	4) Permanent, near permanent	
			5) Unknown 6) No data		5) Unknown 6) No data	
	Residence time	**RTIME_DS**	For Cave & aquifer ecosystems only		For Cave & aquifer ecosystems only	
	Saturation regime	**SAT_DS**	For Cave & aquifer ecosystems only		For Cave & aquifer ecosystems only	
	Source Aquifer Confinement	**AQ_SRCT_DS**	1) Unconfined (watertable aquifer)	SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (INTERACFRM field; All 'PermDep' and 'SeasDep' attributes)	1) Unconfined (watertable aquifer)	
			2) Confined & semi-confined aquifers		2) Confined & semi-confined aquifers	
			3) Unknown 4) No data		3) Unknown 4) No data	
	Source Aquifer name	**AQ_NAME_DS**	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (where INTERACFRM field = 'PermDep' and 'SeasDep' attributes, 'Tertiary Limestone Aquifer' entered)	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	
	Broad geology type of source aquifer	**AQ_GEOL_DS**	1) Fractured rock		1) Fractured rock	
			2) Cavernous (includes karstic)	SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (INTERACFRM field; All 'PermDep' and 'SeasDep' attributes)	2) Cavernous (includes karstic)	
			3) Unconsolidated sedimentary		3) Unconsolidated sedimentary	
			4) Consolidated sedimentary		4) Consolidated sedimentary	
			5) Fractured & cavernous		5) Fractured & cavernous	
			6) Fractured & consolidated sedimentary		6) Fractured & consolidated sedimentary	
			7) Cavernous & consolidated sedimentary		7) Cavernous & consolidated sedimentary	
			8) Unknown 9) No data		8) Unknown 9) No data	
	Porosity of source aquifer	**AQ_POR_DS**	1) Primary		1) Primary	
			2) Secondary		2) Secondary	
			3) Tertiary	SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (INTERACFRM field; All 'PermDep' and 'SeasDep' attributes)	3) Tertiary	
			4) Primary & Secondary		4) Primary & Secondary	
			5) Primary & Tertiary		5) Primary & Tertiary	

Groundwater Source			6) Secondary & Tertiary		6) Secondary & Tertiary	
			7) All 8) Unknown 9) No data		7) All 8) Unknown 9) No data	
	Groundwater Flow System of source aquifer	**AQ_GWFL_DS**	1) Shallow alluvial, Local		1) Shallow alluvial, Local	
			2) Shallow alluvial, Intermediate		2) Shallow alluvial, Intermediate	
			3) Shallow alluvial, Regional		3) Shallow alluvial, Regional	
			4) Basin, Local		4) Basin, Local	
			5) Basin, Intermediate		5) Basin, Intermediate	
			6) Basin, Regional	SA: Wetlands_SAWID_Classified_MIN_Apr109_V4 (INTERACFRM field; All 'PermDep' and 'SeasDep' attributes)	6) Basin, Regional	
			7) Bedrock, Local		7) Bedrock, Local	
			8) Bedrock, Intermediate		8) Bedrock, Intermediate	
			9) Bedrock, Regional		9) Bedrock, Regional	
			10) Perched 11) Nested		10) Perched 11) Nested	
	Salinity of Groundwater Source	**GW_SAL_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date		< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	
	Ph of Groundwater Source	**GW_PH_DS**	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date		<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	
	Dominant recharge process of groundwater source	**GW_RECH_DS**	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data		1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	
	Hydrogeological capture zone#	**HCZONE_DS**				
e of groundwater dependency	**Relative requirement of groundwater vs. other source (overall)**	**GW_REL_DS**	1) Dominant groundwater	NSW: Admin_HighPriority_GDEpoints_Jan2011 (All features) SA: Gazeteer_AquaticEcosystems (SPRG features) QLD: HYD_springsV3 (All features) VIC: springs (All features) VIC: Wetlands_1994 (PWS field; 'Groundwater' attribute)	1) Dominant groundwater 2) Both unsaturated zone water and groundwater 3) Dominant unsaturated zone water 4) No data 5) Unknown	
			2) Both surface water and groundwater			
			3) Dominant surface water	VIC: Wetlands_1994 (PWS field; 'Rainfall fed', 'River fed', 'Coastal' attributes)		
			4) No data 5) Unknown			
	Critical groundwater service	**GW_REQ_DS**	Water source (when surface flows cease)		Water availability (water capacity above wilting)	
			Habitat	SA: Baseflow MLR; baseflow attribute;' DRY SEASON FLOW attribute field SA: Gazeteer_aquaticecosystems: DIST_ADM_2 attribute SA: Baseflow_Willochra: BASEFLOW attribute SA: Pool_or_dam_15m: intersect SA: Pools_baseflows: intersect SA: Pools_Willochra: intersect SA: Mambpools: intersect SA: Riparian_baseflow_light: Permanent baseflow attribute SA: Riparian_baseflow_broughton: Permanent baseflow attribute NSW: adminGDE_highpriority_point: GDETYPE attribute	Water capacity provides reduced salt concentrations to below osmotic limit	

Natur			Artesian pressure	NSW: Admin_HighPriority_GDEpoints_Jan2011 (SPRING features) SA: Gazeteer_AquaticEcosystems (SPRG features) QLD: HYD_springsV3 (All features)	Dry period water supply	
			Thermal water supply	NSW: Admin_HighPriority_GDEpoints_Jan2011 (GEOTHERMAL SPRING features)	Other (Physical integrity)	
			Other (Physical integrity)		Water quality	
			Water quality		No data	
			No data			
	Example Indicative species	**END_SPEC_DS**	Free text No data		Free text No data	
	Environmental Groundwater Requirement	**ENV_WAT_DS**	Free text No data		Free text No data	
	Additional information on dependency/ resilience/ sensitivity	**DETAILS_DS**	Free text No data		Free text No data	

F.4 Attributes populated from existing spatial datasets – WP4

			Surface ecosystems dependent on SURFACE expression of groundwater		Surface ecosystems dependent on SUBSURFACE presence of groundwater	
GENERAL ECOSYSTEM SETTING		**Database Reference**	**Categories**	**Dataset used to fulfill attribute**	**Categories**	**Dataset used to fulfill attribute**
Ecosystem Attributes	**Ecosystem type**	**ECOTYPE_DS**	NA	From standard list of ecosystem types	NA	From standard list of ecosystem types
	Ecosystem type	**S_ETYPE_DS**	NA	NSW: ADMIN_HighPriority_GDEPoint; GDETYPE attribute NSW: ADMIN_HighPriority_GDEPoly; intersect NSW: BM_Swamps_5B_region; SUBCOMMNAME attribute QLD: HYD_springs; HAB_ attribute NSW: Murray-darling_M305_VISmap_917; GENUS1/SPECIES1 attribute	NA	QLD: QLD_RE06b: DBVG2M attribute NSW: murray_darling_M305_VISmap_917: GENUS1/SPECIES1 attributes (concatenated)
	Name	**NAME**	NA	From feature datasets	NA	From feature datasets
	Occurrence on other ecosystem inventories	**ECO_OCC_DS**	NA	QLD: Qld_Directory of important wetlands: intersect QLD: Ramsar sites: intersect	NA	NA
	Ecosystem salinity	**SALINE_DS**	< 1500 mg/L TDS	QLD: HYD_springs; SALINMOD attribute field: 'fresh' QLD: QLD_WETLANDS SYSTEM_100K: SALINMOD attribute field: 'fresh'	NA	
			1500 - 3000 mg/L TDS	not attributed	NA	
			3000 - 35000 mg/L TDS	QLD: QLD_WETLANDS SYSTEM_100K: SALINMOD attribute field: 'hyposaline'	NA	
			> 35000 mg/L TDS	QLD: QLD_WETLANDS SYSTEM_100K: SALINMOD attribute field: 'saline'	NA	
			Fluctuating Stratified Unknown No data * include measurement date	not attributed	NA	NA
	Water Regime	**WREGIME_DS**	1) Ephemeral (unpredictable, short term)	QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR1 (Rarely (20% of images))	NA	
			2) Intermittent (irregular, persists for medium term)	not attributed	NA	
			3) Seasonal (annual, regular)	QLD: HYD_springs; WTRREGIME_ attribute field; WR2 attribute QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR2 (Intermediately (40 - 60% of images))	NA	
			4) Permanent, near permanent (flowing)	QLD/NSW: National Watercourses; PERENNIAL attribute	NA	
			5) Permanent, near permanent (static)	QLD: HYD_springs; WTRREGIME_ attribute field; WR3 attribute QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR3 (Commonly (80 - 100% of images))	NA	
			6) Unknown	QLD: HYD_springs; WTRREGIME_ attribute field; WR0 attribute QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute: WR0 (Uncertain)	NA	
			7) No data	not attributed	NA	NA
	Soil/Substrate	**SOILSUB_DS**	1) Organic 2) Mineral 3) Rock 4) Unknown 5) No data	not attributed	NA	NA

INFLOW DEPENDENT ECOSYSTEMS (IDEs)		**Database Reference**				
	IDE	**IDE_N**	Class combo	[illegible]	Class combo	[illegible]

DESCRIPTION OF GW INTERACTION		**Database Reference**	**Categories**	**Dataset used to fulfill attribute**	**Categories**	**Dataset used to fulfill attribute**

	GDE class	**ECOCLS_DS**	**Surface ecosystems dependent on surface expression of groundwater**	NSW: ADMIN_HighPriority_GDEPoint; all features assumed to be surface GDEs NSW: ADMIN_HighPriority_GDEPoly; all features assumed to be surface GDEs NSW: BM_Swamps_5B_region; SUBCOMMNAME attribute; all 'hanging swamps' assumed to be surface GDEs QLD/NSW: CSIRO GW/SW Connectivity mapping; CLASS attribute field; GAINING & VARIABLE attribute fields NSW: GDE_Alstonville_stream40mBuffer; all features assumed to be GDEs NSW: nsw_gw_management_area: GMATYPE coastal sands attributes	**Surface ecosystems dependent on subsurface presence of groundwater**	Derived from feature datasets (includes vegetation)
	Confidence of ecosystem being a GDE	**GWDEP_DS**	**5) Known/Established (by field validation)**	From literature	**5) Known/Established (by field validation)**	
			4) Derived - identified by third party	NSW: ADMIN_HighPriority_GDEPoint; all features NSW: BM_Swamps_5B_region; SUBCOMMNAME attribute; all 'hanging swamps' QLD/NSW: CSIRO GW/SW Connectivity mapping; CLASS attribute field; GAINING & VARIABLE attribute fields NSW: GDE_Alstonville_stream40mBuffer; all features assumed to be GDEs QLD: HYD_SPRING_V3: WETRE attributes	**4) Derived - identified by third party**	NSW: Alstonville_veg_200m buffer QLD: RE06B: LANDZONE = 4 attribute QLD: RE06B: Spring RE attributes
			3) Derived – high confidence	From GIS analysis	**3) Derived – high confidence**	From GIS analysis
			2) Derived - low confidence	From GIS analysis	**2) Derived - low confidence**	From GIS analysis
			1) IDE	From GIS analysis	**1) IDE**	From GIS analysis
Connectivity	**Spatial connectivity between GDE and groundwater**	**SP_CONN_DS**	1) Connected, gaining (includes springs, terminal wetlands)	NSW: ADMIN_HighPriority_GDEPoint; all features assumed to be gaining NSW: BM_Swamps_5B_region; SUBCOMMNAME attribute; all 'hanging swamps' QLD: HYD_springs; all features assumed to be gaining QLD/NSW: CSIRO GW/SW Connectivity mapping; CLASS attribute field; GAINING attribute field QLD: Depth to WatertableCALLIDE; depth to water 1m assumed gaining	1) Watertable <2m	NSW: gwslices6
			2) Connected, losing	QLD/NSW: CSIRO GW/SW Connectivity mapping; CLASS attribute field; LOOSING attribute field	2) Watertable 2m - 20m	NSW: gwslices6
			3) Connected, variable gaining / losing (includes flow through wetlands)	Not attributed	3) Watertable >20m	NSW: gwslices6
			4) Disconnected, losing 5) Unknown 6) No data	Not attributed	4) Unknown 5) No data	Not attributed
	Temporal nature of groundwater connectivity/use	**PERMCON_DS**	1) Ephemeral (unpredictable, short term)	Not attributed	1) Ephemeral (unpredictable, short term)	Not attributed
			2) Intermittent (irregular, persists for medium term)	Not attributed	2) Intermittent (irregular, persists for medium term)	Not attributed
			3) Seasonal (annual, regular)	QLD/NSW: CSIRO GW/SW Connectivity mapping; CLASS attribute field; VARIABLE attribute field	3) Seasonal (annual, regular)	Not attributed
			4) Permanent, near permanent	Not attributed	4) Permanent, near permanent	Not attributed
			5) Unknown 6) No data	Not attributed	5) Unknown 6) No data	Not attributed
	Residence time	**RTIME_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Saturation regime	**SAT_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Source Aquifer Confinement	**AQ_SRCT_DS**	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered
	Source Aquifer name	**AQ_NAME_DS**	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered
	Broad geology type of source aquifer	**AQ_GEOL_DS**	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	No attributes entered	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	No attributes entered

Groundwater Source	**Porosity of source aquifer**	**AQ_POR_DS**	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	No attributes entered	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	No attributes entered
	Groundwater Flow System of source aquifer	**AQ_GWFL_DS**	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered
	Salinity of Groundwater Source	**GW_SAL_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered
	Ph of Groundwater Source	**GW_PH_DS**	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered
	Dominant recharge process of groundwater source	**GW_RECH_DS**	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered
	Hydrogeological capture zone#	**HCZONE_DS**		No attributes entered		No attributes entered
Nature of groundwater dependency	**Relative requirement of groundwater vs. other source (overall)**	**GW_REL_DS**	1) Dominant groundwater	NSW: ADMIN_HighPriority_GDEPoint; all features assumed to be dominant GW NSW: BM_Swamps_5B_region; SUBCOMMNAME attribute; all 'hanging swamps' QLD: HYD_springs; all features assumed to be dominant GW	1) Dominant groundwater 2) Both unsaturated zone water and groundwater 3) Dominant unsaturated zone water 4) No data 5) Unknown	No attributes entered
			2) Both surface water and groundwater			
			3) Dominant surface water			
			4) No data			
			5) Unknown			
	Critical groundwater service	**GW_REQ_DS**	Water source (when surface flows cease)	QLD/NSW: CSIRO GW/SW Connectivity mapping; CLASS attribute field; GAINING attribute fields	Water availability (water capacity above wilting) Water capacity provides reduced salt concentrations to below osmotic limit Dry period water supply No data Other (Physical integrity) Water quality No data	No attributes entered
			Habitat			
			Artesian pressure	NSW: ADMIN_HighPriority_GDEPoint; all spring features QLD: HYD_springs; all features		
			Thermal water supply	NSW: ADMIN_HighPriority_GDEPoint; all geothermal features		
			No data Other (Physical integrity) Water quality No data			

2						
	Example Indicative species	**END_SPEC_DS**	Free text No data	No attributes entered	Free text No data	NA
	Environmental Groundwater Requirement	**ENV_WAT_DS**	Free text No data	No attributes entered	Free text No data	No attributes entered
	Additional information on dependency/ resilience/ sensitivity	**DETAILS_DS**	Free text No data	NA	Free text No data	NA

F.5 Attributes populated from existing spatial datasets – WP5

			Surface ecosystems dependent on SURFACE expression of groundwater		Surface ecosystems dependent on SUBSURFACE presence of groundwater	
GENERAL ECOSYSTEM SETTING		**Database Reference**	**Categories**	**Dataset used to fulfill attribute**	**Categories**	**Dataset used to fulfill attribute**
Ecosystem Attributes	**Ecosystem type**	**ECOTYPE_DS**	NA	From standard list of ecosystem types	NA	From standard list of ecosystem types
	Ecosystem type	**S_ETYPE_DS**	NA	Geomorphic Wetlands Swan Coastal Plain (Classification): CLASSIFCTN attribute Geomorphic Wetlands Augusta to Walpole: CLASS attribute Geomorphic_wetlands_Cervantes_Eneabba: CLASSIFCTN attribute Geomorphic_wetlands_Cervantes_South: Classifica attribute Geomorphic_Wetlands_Darkin(AreaD): CLASSIFCTN attribute South Eastern Coast Wetlands: TYPE attribute Important wetlands: WET_TYPE attribute MW_Potential_GDEs_Associated_Values_Points: NAME	NA	Pre-european: SOURCE_DES attribute
	Name	**NAME**	NA	From feature datasets	NA	From feature datasets
	Occurrence on other ecosystem inventories	**ECO_OCC_DS**	NA	Ramsar wetlands: intersect; Directory of Important Wetlands in Australia: intersect	NA	NA
	Ecosystem salinity	**SALINE_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered	NA	NA
	Water Regime	**WREGIME_DS**	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent (flowing) 5) Permanent, near permanent (static) 6) Unknown 7) No data	Geomorphic Wetlands Swan Coastal Plain (Classification): CLASSIFCTN attribute Geomorphic Wetlands Augusta to Walpole: CLASS attribute Geomorphic_wetlands_Cervantes_Eneabba: CLASSIFCTN attribute Geomorphic_wetlands_Cervantes_South: Classifica attribute Geomorphic_Wetlands_Darkin(AreaD): CLASSIFCTN attribute South Eastern Coast Wetlands: TYPE attribute	NA	NA
	Soil/Substrate	**SOILSUB_DS**	1) Organic 2) Mineral 3) Rock 4) Unknown 5) No data	NA	NA	NA
INFLOW DEPENDENT ECOSYSTEMS (		**Database Reference**				
	IDE	**IDE_N**	Class combo	ID Likelihood (1 to 10)	Class combo	ID Likelihood (6 to 10)
DESCRIPTION OF GW INTERACTION		**Database Reference**	**Categories**	**Dataset used to fulfill attribute**	**Categories**	**Dataset used to fulfill attribute**
	GDE class	**ECOCLS_DS**	**Surface ecosystems dependent on surface expression of groundwater**	Derived from feature datasets	**Surface ecosystems dependent on subsurface presence of groundwater**	
	Confidence of ecosystem being a GDE	**GW_DEP_DS**	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM; 3 - 1) GDEs derived during the project	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM; 3 - 1) GDEs derived during the project	
Connectivity	**Spatial connectivity between GDE and groundwater**	**SP_CONN_DS**	1) Connected, gaining (includes springs, terminal wetlands) 2) Connected, losing 3) Connected, variable gaining / losing (includes flow through wetlands) 4) Disconnected, losing	MW_Potential_GDEs_Associated_Values_Points: NAME attribute - applied to springs only 1) Connected, gaining (includes springs, terminal wetlands)	5) Watertable < 2m 6) Watertable 2m - 20m 7) Watertable > 20m 8) Unknown 9) No data	Depth to watertable layer derived from Groundwater Contours, Historical Maximum: VALUE attribute
	Temporal nature of groundwater connectivity/use	**PERMCON_DS**	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	No attributes entered	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	No attributes entered
	Residence time	**RTIME_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Saturation regime	**SAT_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Source Aquifer Confinement	**AQ_SRCT_DS**	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered
	Source Aquifer name	**AQ_NAME_DS**	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered

DESCRIPTION OF GW INTERACTION		Database Reference	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute
Groundwater Source	**Broad geology type of source aquifer**	**AQ_GEOL_DS**	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	No attributes entered	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	No attributes entered
	Porosity of source aquifer	**AQ_POR_DS**	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	No attributes entered	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	No attributes entered
	Groundwater Flow System of source aquifer	**AQ_GWFL_DS**	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered
	Salinity of Groundwater Source	**GW_SAL_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered
	Ph of Groundwater Source	**GW_PH_DS**	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered
	Dominant recharge process of groundwater source	**GW_RECH_DS**	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered
	Hydrogeological capture zone#	**HCZONE_DS**		No attributes entered		No attributes entered
Nature of groundwater dependency	**Relative requirement of groundwater vs. other source (overall)**	**GW_REL_DS**	1) Dominant groundwater 2) Both surface water and groundwater 3) Dominant surface water 4) No data 5) Unknown	MW_Potential_GDEs_Associated_Values_Points: NAME attribute - applied to springs only 1) Dominant groundwater	1) Dominant groundwater 2) Both unsaturated zone water and groundwater 3) Dominant unsaturated zone water 4) No data 5) Unknown	No attributes entered
	Critical groundwater service	**GW_REQ_DS**	Water source (when surface flows cease) Habitat Artesian pressure Thermal water supply No data Other (Physical integrity) Water quality No data	Important wetlands: CRITERIA attribute MW_Potential_GDEs_Associated_Values_Points:	Water availability (water capacity above wilting) Water capacity provides reduced salt concentrations to below osmotic limit Dry period water supply No data Other (Physical integrity) Water quality No data	
	Example Indicative species	**END_SPEC_DS**	Free text No data	No attributes entered	Free text No data	No attributes entered
	Environmental Groundwater Requirement	**ENV_WAT_DS**	Free text No data	EWR_EWP_Groundwater and SurfaceWater: TITLE attribute	Free text No data	EWR_EWP_Groundwater and SurfaceWater: TITLE attribute
	Additional information on dependency/ resilience/ sensitivity	**DETAILS_DS**	Free text No data	No attributes entered	Free text No data	No attributes entered

F.6 Attributes populated from existing spatial datasets – WP6

			Surface ecosystems dependent on SURFACE expression of groundwater		Surface ecosystems dependent on SUBSURFACE presence of groundwater	
GENERAL ECOSYSTEM SETTING		**Database Reference**	**Categories**	**Dataset used to fulfill attribute**	**Categories**	**Dataset used to fulfill attribute**
Ecosystem Attributes	**Ecosystem type**	**ECOTYPE_DS**	NA	From standard list of ecosystem types	NA	From standard list of ecosystem types
	Ecosystem type	**S_ETYPE_DS**	NA	QLD: HYD_SPRINGS: HAB attribute QLD: QLD_WETLAND_SYSTEM_100K: HAB_ attribute WA: Hydrography_Linear_Hierarchy: HYD_TYPE attribute WA: important_wetlands: WET_TYPE attribute NT: Potential springs: FEATTYPE_g NT: Geodata flats & swamps: FEATTYPE NT: Geodata lakes: FEATTYPE	NA	QLD: QLD_RE06b: DBVG2M attribute WA: pre-european: SOURCE_DES attribute NT: greater_darwin_lc_52m: COMM attribute NT: NVIS2005_Combo_part_1\2\3: NVIS_L4 attribute
	Name	**NAME**	NA	From feature datasets	NA	From feature datasets
	Occurrence on other ecosystem inventories	**ECO_OCC_DS**	NA	QLD: Qld_Directory of important wetlands: intersect WA: Ramsar wetlands: intersect	NA	NA
	Ecosystem salinity	**SALINE_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	QLD: HYD_SPRING: SALINMOD attribute QLD: QLD_WETLANDS SYSTEM_100K: SALINMOD attribute NT: Springs_21_04_2009: ECSPRING attribute	NA	NA
	Water Regime	**WREGIME_DS**	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent (flowing) 5) Permanent, near permanent (static) 6) Unknown 7) No data	QLD: HYD_SPRINGS - WTRREGIME attribute NT: NT Lakes - PERENNIAL attribute NT: Endofdryflows - intersect NT: Potential spring - PERENNIAL attribute NT: spring_21_04_2009: TYPE attribute NT: NT_Riv_Cks_250p - PERENNIAL attribute QLD: National watercourses - PERENNIAL attribute QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute QLD: GAB Watercourse Springs: intersect	NA	NA
	Soil/Substrate	**SOILSUB_DS**	1) Organic 2) Mineral 3) Rock 4) Unknown 5) No data	NA	NA	NA
INFLOW DEPENDENT ECOSYSTEMS (IDEs)		**Database Reference**				
	IDE	**IDE_N**	Class combo	ID Likelihood (1 to 10)	Class combo	ID Likelihood (6 to 10)
DESCRIPTION OF GW INTERACTION		**Database Reference**	**Categories**	**Dataset used to fulfill attribute**	**Categories**	**Dataset used to fulfill attribute**
	GDE class	**ECOCLS_DS**	**Surface ecosystems dependent on surface expression of groundwater**	Derived from feature datasets	**Surface ecosystems dependent on subsurface presence of groundwater**	
	Confidence of ecosystem being a GDE	**GWDEP_DS**	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM; 3 - 1) GDEs derived during the project	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	
Connectivity	**Spatial connectivity between GDE and groundwater**	**SP_CONN_DS**	1) Connected, gaining (includes springs, terminal wetlands) 2) Connected, losing 3) Connected, variable gaining / losing (includes flow through wetlands) 4) Disconnected, losing 5) Unknown 6) No data	QLD: HYD_SPRINGS with a WTRREGIME attribute - all assumed to be connected gaining NT: Potential springs.xls with a PERENNIAL attribute - all assumed to be connected gaining NT: Springs_21_04_2009: all assumed to be gaining	1) Connected, gaining (includes springs, terminal wetlands) 2) Connected, losing 3) Connected, variable gaining / losing (includes flow through wetlands) 4) Disconnected, losing 5) Unknown 6) No data	No attributes entered
	Temporal nature of groundwater connectivity/use	**PERMCON_DS**	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	QLD: HYD_SPRINGS - WTRREGIME attribute NT: NT Lakes - PERENNIAL attribute NT: Endofdryflows - intersect NT: Potential spring - PERENNIAL attribute NT: NT_Riv_Cks_250p - PERENNIAL attribute QLD: National watercourses - PERENNIAL attribute QLD: QLD_WETLANDS SYSTEM_100K = WTRREGIME attribute QLD: GAB springs - all assumed to be permanent	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	No attributes entered
	Residence time	**RTIME_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Saturation regime	**SAT_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA

Groundwater Source	**Source Aquifer Confinement**	**AQ_SRCT_DS**	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered
	Source Aquifer name	**AQ_NAME_DS**	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	NT: Springs_21_04_2009: AQUIFERNAME attribute	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered
	Broad geology type of source aquifer	**AQ_GEOL_DS**	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous	NT: Springs_21_04_2009: AQUIFERTYP attribute	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous	No attributes entered
	Porosity of source aquifer	**AQ_POR_DS**	1) Primary 2) Secondary	No attributes entered	1) Primary 2) Secondary	No attributes entered
	Groundwater Flow System of source aquifer	**AQ_GWFL_DS**	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered
	Salinity of Groundwater Source	**GW_SAL_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered
	Ph of Groundwater Source	**GW_PH_DS**	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered
	Dominant recharge process of groundwater source	**GW_RECH_DS**	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered
	Hydrogeological capture zone#	**HCZONE_DS**		No attributes entered		No attributes entered
Nature of groundwater dependency	**Relative requirement of groundwater vs. other source (overall)**	**GW_REL_DS**	1) Dominant groundwater 2) Both surface water and groundwater 3) Dominant surface water 4) No data 5) Unknown	QLD: HYD_SPRING - WTRREGIME attribute NT: endofdryflows - intersect NT: Potential springs - PERENNIAL attribute NT: NT_Riv_Crk_250p - PERENNIAL attribute NT: springs_21_4_2009 - TYPE attribute	1) Dominant groundwater 2) Both unsaturated zone water and groundwater 3) Dominant unsaturated zone water 4) No data 5) Unknown	No attributes entered
	Critical groundwater service		Water source (when surface flows cease) Habitat Artesian pressure Thermal water supply No data Other (Physical integrity) Water quality No data	QLD: HYD_SPRING - WTRREGIME attribute NT: endofdryflows - intersect NT: Potential springs - PERENNIAL attribute QLD: National Watercourse - PERENNIAL attribute NT: springs_21_4_2009 - TYPE attribute	Water availability (water capacity above wilting) Water capacity provides reduced salt concentrations to below osmotic limit Dry period water supply No data Other (Physical integrity) Water quality No data	No attributes entered
	Example Indicative species	**END_SPEC_DS**	Free text No data	NT: Landform Class - SPECIES_1 attribute	Free text No data	NA
	Environmental Groundwater Requirement	**ENV_WAT_DS**	Free text No data	WA: EWR_EWP_Groundwater and SurfaceWater: TITLE attribute	Free text No data	WA: EWR_EWP_Groundwater and SurfaceWater: TITLE attribute
	Additional information on dependency/ resilience/ sensitivity	**DETAILS_DS**	Free text No data	NA	Free text No data	NA

F.7 Attributes populated from existing spatial datasets – WP7

			Surface ecosystems dependent on SURFACE expression of groundwater		Surface ecosystems dependent on SUBSURFACE presence of groundwater	
GENERAL ECOSYSTEM SETTING		Database Referenc	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute
Ecosystem Attributes	**Ecosystem type**	**ECOTYPE_DS**	NA	From standard list of ecosystem types	NA	From standard list of ecosystem types
	Ecosystem type	**S_ETYPE_DS**	NA	NT Riv Cks 250p: FEATTYPE attribute; revised arid NT data to SKM 5Mar2012: GDE_Type_p attribute; QLD_WETLAND_SYSTEM_100K_A: HAB_L atribute; Hydrography_linear_hierachy: HYD_TYPE attribute; Important wetlands: WET_TYPE attribute; Gazetteer_AquaticEcosystems: DIST_ADM_2 attribute; GD3_Stirling_Swamp: FEATTYPE	NA	SA VEG DATA: SA_VEGDESC attribute; Pre-european: SOURCE_DES attribute Rangeland land systems mapping: MU_SUM_DESC attribute; Subsystems north: Descriptio attribute; re06b_NW_Qld, re06b_SW_Qld, IQ_QLD_REGECOPRECL_DCDB_A: DBVG2M attribute
	Name	**NAME**	NA	From feature datasets	NA	From feature datasets
	Occurrence on other ecosystem inventories	**ECO_OCC_DS**	NA	Ramsar wetlands: intersect; Directory of important wetlands: intersect	NA	NA
	Ecosystem salinity	**SALINE_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	QLD_WETLAND_SYSTEM_100K_A: SALINMOD_L atribute	NA	NA
	Water Regime	**WREGIME_DS**	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent (flowing) 5) Permanent, near permanent (static) 6) Unknown 7) No data	NT Riv Cks 250p: PERENNIAL attribute; revised arid NT data to SKM 5Mar2012: Long_term attribute; Topo_Geodata250k_Waterholes: PERENNIALITY attribute QLD_WETLAND_SYSTEM_100K_A: WTRREGIME_ atribute; Wetlands_GDE_Classification_v1: WATERREGIM attribute; Watercourse250K_GDE_Classification_v1: PERENNIALITY attribute; Important wetlands: WET_TYPE attribute;	NA	NA
	Soil/Substrate	**SOILSUB_DS**	1) Organic 2) Mineral 3) Rock 4) Unknown 5) No data	NA	NA	NA
INFLOW DEPENDENT ECOSYSTEMS (IDEs)		Database Reference				
	IDE	**IDE_N**	Class combo	ID Likelihood (1 to 10)	Class combo	ID Likelihood (6 to 10)
DESCRIPTION OF GW INTERACTION		Database Referenc	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute
	GDE class	**ECOCLS_DS**	**Surface ecosystems dependent on surface expression of groundwater**	Derived from feature datasets	**Surface ecosystems dependent on subsurface presence of groundwater**	
	Confidence of ecosystem being a GDE	**GW_DEP_DS**	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM; 3 - 1) GDEs derived during the project	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM; 3 - 1) GDEs derived during the project

DESCRIPTION OF GW INTERACTION		Database Referenc	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute
Connectivity	**Spatial connectivity between GDE and groundwater**	**SP_CONN_DS**	1) Connected, gaining (includes springs, terminal wetlands) 2) Connected, losing 3) Connected, variable gaining / losing (includes flow through wetlands) 4) Disconnected, losing	revised arid NT data to SKM 5Mar2012: GDE_Type_p attribute; Gazetteer_AquaticEcosystems: Include only "SPRG" from "DIST_ADM_2" field; QLD_WETLAND_SYSTEM_100K_A: Selected spring RE codes	5) Watertable < 2m 6) Watertable 2m - 20m 7) Watertable > 20m 8) Unknown 9) No data	GWater_Shallow_SWL: SWL_MIN attribute
	Temporal nature of groundwater connectivity/use	**PERMCON_DS**	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	revised arid NT data to SKM 5Mar2012: GDE_Type_p attribute	1) Ephemeral (unpredictable, short term) 2) Intermittent (irregular, persists for medium term) 3) Seasonal (annual, regular) 4) Permanent, near permanent 5) Unknown 6) No data	No attributes entered
	Residence time	**RTIME_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Saturation regime	**SAT_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
Groundwater Source	**Source Aquifer Confinement**	**AQ_SRCT_DS**	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	No attributes entered
	Source Aquifer name	**AQ_NAME_DS**	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	revised arid NT data to SKM 5Mar2012: Aquifer Name attribute	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered
	Broad geology type of source aquifer	**AQ_GEOL_DS**	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	revised arid NT data to SKM 5Mar2012: Aquifer type attribute, Rock_Type attribute	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown	No attributes entered
	Porosity of source aquifer	**AQ_POR_DS**	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	revised arid NT data to SKM 5Mar2012: Aquifer type attribute, Rock_Type attribute	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	No attributes entered
	Groundwater Flow System of source aquifer	**AQ_GWFL_DS**	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered

DESCRIPTION OF GW INTERACTION		Database Referenc	Categories	Dataset used to fulfill attribute	Categories	Dataset used to fulfill attribute
	Salinity of Groundwater Source	**GW_SAL_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered
	Ph of Groundwater Source	**GW_PH_DS**	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered
	Dominant recharge process of groundwater source	**GW_RECH_DS**	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered
	Hydrogeological capture zone#	**HCZONE_DS**		No attributes entered		No attributes entered
Nature of groundwater dependency	**Relative requirement of groundwater vs. other source (overall)**	**GW_REL_DS**	1) Dominant groundwater 2) Both surface water and groundwater 3) Dominant surface water 4) No data 5) Unknown	Gazetteer_AquaticEcosystems: Include only "SPRG" from "DIST_ADM_2" field; QLD_WETLAND_SYSTEM_100K_A: Selected spring RE codes	1) Dominant groundwater 2) Both unsaturated zone water and groundwater 3) Dominant unsaturated zone water 4) No data 5) Unknown	No attributes entered
	Critical groundwater service	**GW_REQ_DS**	Water source (when surface flows cease) Habitat Artesian pressure Thermal water supply No data Other (Physical integrity) Water quality No data	Important wetlands: CRITERIA attribute; revised arid NT data to SKM 5Mar2012: Discharg_1 attribute;	Water availability (water capacity above wilting) Water capacity provides reduced salt concentrations to below osmotic limit Dry period water supply No data Other (Physical integrity) Water quality	
	Example Indicative species	**END_SPEC_DS**	Free text No data	No attributes entered	Free text No data	No attributes entered
	Environmental Groundwater Requirement	**ENV_WAT_DS**	Free text No data	EWR_EWP_Groundwater and SurfaceWater: TITLE attribute	Free text No data	EWR_EWP_Groundwater and SurfaceWater: TITLE attribute
	Additional information on dependency/ resilience/ sensitivity	**DETAILS_DS**	Free text No data	No attributes entered	Free text No data	No attributes entered

F.8 Attributes populated from existing spatial datasets – WP8

			Surface ecosystems dependent on SURFACE expression of groundwater		Surface ecosystems dependent on SUBSURFACE presence of groundwater	
GENERAL ECOSYSTEM SETTING		**Database Reference**	**Categories**	**Dataset used to fulfill attribute**	**Categories**	**Dataset used to fulfill attribute**
Ecosystem Attributes	**Ecosystem type**	**ECOTYPE_DS**	NA	From standard list of ecosystem types	NA	From standard list of ecosystem types
	Ecosystem type	**S_ETYPE_DS**	NA	World Heritage Area: WHA layer: Vegetation type attribute Remainder of Tasmania: Tasveg layer: Vegetation type attribute	NA	World Heritage Area: WHA layer: Vegetation type attribute Remainder of Tasmania: Tasveg layer: Vegetation type attribute
	Name	**NAME**	NA	From feature datasets	NA	From feature datasets
	Occurrence on other ecosystem inventories	**ECO_OCC_DS**	NA	NA	NA	NA
	Ecosystem salinity	**SALINE_DS**	< 1500 mg/L TDS	NA	NA	NA
			1500 - 3000 mg/L TDS	NA	NA	NA
			3000 - 35000 mg/L TDS	NA	NA	NA
			> 35000 mg/L TDS	NA	NA	NA
			Fluctuating Stratified Unknown No data * include measurement date	NA	NA	NA
	Water Regime	**WREGIME_DS**	1) Ephemeral (unpredictable, short term)	not attributed	NA	NA
			2) Intermittent (irregular, persists for medium term)	Tasdemstreamsv293.shp: metagroup attribute = D	NA	NA
			3) Seasonal (annual, regular)	Tasdemstreamsv293.shp: metagroup attribute = G	NA	NA
			4) Permanent, near permanent (flowing)	Tasdemstreamsv293.shp: metagroup attribute = H, I or J	NA	NA
			5) Permanent, near permanent (static)	not attributed	NA	NA
			6) Unknown	not attributed	NA	NA
			7) No data	not attributed	NA	NA
	Soil/Substrate	**SOILSUB_DS**	1) Organic 2) Mineral 3) Rock 4) Unknown 5) No data	not attributed	NA	NA
INFLOW DEPENDENT ECOSYSTEMS (IDEs)		**Database Reference**				
	IDE	**IDE_N**	Class combo	ID Likelihood (1 to 10)	Class combo	ID Likelihood (6 to 10)
DESCRIPTION OF GW INTERACTION		**Database Reference**	**Categories**	**Dataset used to fulfill attribute**	**Categories**	**Dataset used to fulfill attribute**
	GDE class	**ECOCLS_DS**	**Surface ecosystems dependent on surface expression of groundwater**	Derived from feature datasets (includes wetlands, rivers, springs, vegetation)	**Surface ecosystems dependent on subsurface presence of groundwater**	Derived from feature datasets (includes vegetation)
	Confidence of ecosystem being a GDE	**GWDEP_DS**	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM 3 - 1) GDEs derived during the project	5) Known/Established (by field validation) 4) Derived - identified by third party 3) Derived – high confidence 2) Derived - low confidence 1) IDE	5) GDEs from literature, field validated spatial datasets; 4) GDEs from spatial datasets given to SKM 3 - 1) GDEs derived during the project
Connectivity	**Spatial connectivity between GDE and groundwater**	**SP_CONN_DS**	1) Connected, gaining (includes springs, terminal wetlands)	CSIRO Tas SY GW_SW_Code.shp: class = gaining attribute OR tas_demstreamsv293.shp: metagroup attribute = J, I or H AND slope = steep, moderate, gentle	1) Watertable <2m	Not attributed
			2) Connected, losing	CSIRO Tas SY GW_SW_Code.shp: class = losing attribute OR tas_demstreamsv293.shp: metagroup attribute = H, G or D AND slope = flat AND geology = Qh or Qps	2) Watertable 2m - 20m	Not attributed
			3) Connected, variable gaining / losing (includes flow through wetlands)	Remaining streams	3) Watertable >20m	Not attributed
			4) Disconnected, losing 5) Unknown 6) No data	Not attributed	4) Unknown 5) No data	Not attributed
	Temporal nature of groundwater connectivity/use	**PERMCON_DS**	1) Ephemeral (unpredictable, short term)	Not attributed	1) Ephemeral (unpredictable, short term)	Not attributed
			2) Intermittent (irregular, persists for medium term)	Tasdemstreamsv293.shp: metagroup attribute = D	2) Intermittent (irregular, persists for medium term)	Not attributed
			3) Seasonal (annual, regular)	Tasdemstreamsv293.shp: metagroup attribute = G	3) Seasonal (annual, regular)	Not attributed
			4) Permanent, near permanent	Tasdemstreamsv293.shp: metagroup attribute = H, I or J	4) Permanent, near permanent	Not attributed
			5) Unknown 6) No data	Not attributed	5) Unknown 6) No data	Not attributed
	Residence time	**RTIME_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA
	Saturation regime	**SAT_DS**	For Cave & aquifer ecosystems only	NA	For Cave & aquifer ecosystems only	NA

Groundwater Source	**Source Aquifer Confinement**	**AQ_SRCT_DS**	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	1) Unconfined (water table aquifer)	1) Unconfined (watertable aquifer) 2) Confined & semi-confined aquifers 3) Unknown 4) No data	1) Unconfined (water table aquifer)
	Source Aquifer name	**AQ_NAME_DS**	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered	Attributes from BOM watertable mapping or literature. Can be multiple aquifers	No attributes entered
	Broad geology type of source aquifer	**AQ_GEOL_DS**	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	1) Proscode.shp: proscode attribute = 7, 8 or 9 2) Proscode.shp: proscode attribute = 6 AND geology = Ol, Ola 3) Proscode.shp: proscode attribute = 1, 2, 3 or 4 4) Proscode.shp: proscode attribute = 5 6) Proscode.shp: proscode attribute = 6 AND geology = OD, ODp, ODq 7) Proscode.shp: proscode attribute = 6 AND geology = Ls, Lsd, Lst, Lss, Lwc	1) Fractured rock 2) Cavernous (includes karstic) 3) Unconsolidated sedimentary 4) Consolidated sedimentary 5) Fractured & cavernous 6) Fractured & consolidated sedimentary 7) Cavernous & consolidated sedimentary 8) Unknown 9) No data	1) Proscode.shp: proscode attribute = 7, 8 or 9 2) Proscode.shp: proscode attribute = 6 AND geology = Ol, Ola 3) Proscode.shp: proscode attribute = 1, 2, 3 or 4 4) Proscode.shp: proscode attribute = 5 6) Proscode.shp: proscode attribute = 6 AND geology = OD, ODp, ODq 7) Proscode.shp: proscode attribute = 6 AND geology = Ls, Lsd, Lst, Lss, Lwc
	Porosity of source aquifer	**AQ_POR_DS**	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	1) Proscode.shp: proscode attribute = 1, 2, 3 or 4 2) Proscode.shp: proscode attribute = 8 or 9 3) Proscode.shp: proscode attribute = 6 AND geology = Ol, Ola 4) Proscode.shp: proscode attribute = 5, 7 or 6 AND geology = OD, ODp, Odq 7) Proscode.shp: proscode attribute = 6 AND geology = Ls, Lsd, Lst, Lss, Lwc	1) Primary 2) Secondary 3) Tertiary 4) Primary & Secondary 5) Primary & Tertiary 6) Secondary & Tertiary 7) All 8) Unknown 9) No data	1) Proscode.shp: proscode attribute = 1, 2, 3 or 4 2) Proscode.shp: proscode attribute = 8 or 9 3) Proscode.shp: proscode attribute = 6 AND geology = Ol, Ola 4) Proscode.shp: proscode attribute = 5, 7 or 6 AND geology = OD, ODp, Odq 7) Proscode.shp: proscode attribute = 6 AND geology = Ls, Lsd, Lst, Lss, Lwc
	Groundwater Flow System of source aquifer	**AQ_GWFL_DS**	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered	1) Shallow alluvial, Local 2) Shallow alluvial, Intermediate 3) Shallow alluvial, Regional 4) Basin, Local 5) Basin, Intermediate 6) Basin, Regional 7) Bedrock, Local 8) Bedrock, Intermediate 9) Bedrock, Regional 10) Perched 11) Nested	No attributes entered
	Salinity of Groundwater Source	**GW_SAL_DS**	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered	< 1500 mg/L TDS 1500 - 3000 mg/L TDS 3000 - 35000 mg/L TDS > 35000 mg/L TDS Fluctuating Stratified Unknown No data * include measurement date	No attributes entered
	Ph of Groundwater Source	**GW_PH_DS**	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered	<6 6 - 8 >8 Fluctuating Unknown No data * include measurement date	No attributes entered
	Dominant recharge process of groundwater source	**GW_RECH_DS**	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered	1) Infiltration (local) 2) Infiltration (distant) 3) Inundation (local) 4) Inundation (distant) 5) Marine throughflow 6) Combination 7) Palaeo (i.e. not recharged) 8) Unknown 9) No data	No attributes entered
	Hydrogeological capture zone#	**HCZONE_DS**		No attributes entered		No attributes entered
Nature of groundwater dependency	**Relative requirement of groundwater vs. other source (overall)**	**GW_REL_DS**	1) Dominant groundwater 2) Both surface water and groundwater 3) Dominant surface water 4) No data 5) Unknown	No attributes entered	1) Dominant groundwater 2) Both unsaturated zone water and groundwater 3) Dominant unsaturated zone water 4) No data 5) Unknown	No attributes entered
	Critical groundwater service	**GW_REQ_DS**	Water source (when surface flows cease) Habitat Artesian pressure Thermal water supply No data Other (Physical integrity) Water quality No data	No attributes entered	Water availability (water capacity above wilting) Water capacity provides reduced salt concentrations to below osmotic limit Dry period water supply No data Other (Physical integrity) Water quality No data	No attributes entered
	Example Indicative species	**END_SPEC_DS**	Free text No data	No attributes entered	Free text No data	NA
	Environmental Groundwater Requirement	**ENV_WAT_DS**	Free text No data	No attributes entered	Free text No data	No attributes entered
	Additional information on dependency/ resilience/ sensitivity	**DETAILS_DS**	Free text No data	NA	Free text No data	NA